FOUNDRY CORE PRACTICE

By
HARRY W. DIETERT



THIRD EDITION
1966

PUBLISHED BY
AMERICAN FOUNDRYMEN'S SOCIETY
DES PLAINES, ILL.

040661

COPYRIGHT 1942, 1950, 1966
by the
AMERICAN FOUNDRYMEN'S SOCIETY
(INCORPORATED)

TS213
.A53
1966

All rights reserved. This book or parts thereof may not be reproduced without permission of the publishers.

Printed in the United States of America

The American Foundrymen's Society as a body is not responsible for the statements and opinions advanced in this publication. Nothing contained in any publication of the American Foundrymen's Society is to be construed as granting any right, by implication or otherwise, for manufacture, sale or use in connection with any method, apparatus or product covered by Letters Patent, nor as insuring anyone against liability for infringement of Letters Patent.

PREFACE

The improvement in the art and science of foundry coremaking has necessitated a third edition of FOUNDRY CORE PRACTICE. The book has been completely reorganized to accommodate present day thinking on the subject, and six chapters have been added to cover the new processes now being widely used by the industry. In any book it is impossible to include all information. Therefore a completely updated Bibliography is included as Chapter 27 and covers more than 45 years of the literature pertinent to coremaking.

The first edition of Foundry Core Practice was published in 1942 and was the result of lecture courses prepared by the author for presentation at the 1941 and 1942 conventions of the American Foundrymen's Society. It was found necessary to publish a second edition in 1950 because of new developments in the field.

The author has been fortunate in having the assistance of many who have cooperated unselfishly in helping prepare the material for all three editions of this book. Especially do we wish to acknowledge the assistance and aid of Frank S. Brewster who correlated the new material and photographs for this edition, and who wrote the Shell Core and Silicate Bonded chapters as well as doing the testing procedure sections for the last four chapters. We are also most indebted to Edw. W. Koglin, who, at the last minute, took over the task of writing the chapters on the Oil Oxygen Process, the Oil No Bake Process, The Furan No Bake Process, and the Hot Box Process of coremaking. We would also like to offer our appreciation to the many others who have given generously of their time and knowledge in the preparation of these three editions of Foundry Core Practice.

HARRY W. DIETERT

CONTENTS

Chapter	Page
1 — Introduction	1
2 — Core Sands	2
3 — Core Binding Materials	31
4 — Core Mixtures	46
5 — Storage and Conditioning of Core Materials	55
6 — Handling of Core Sand	60
7 — Coremaking (Methods and Equipment)	67
8 — Core Baking	94
9 — Core Ovens and Their Control	103
10 — Core Finishing Operations	124
11 — Core Coatings	130
12 — Core Handling	136
13 — Procedures for Determining the Properties of Cores and Core Mixtures	142
14 — Controlling Core Properties	164
15 — Core Setting	175
16 — Core Knockout	186
17 — Core Sand Reclamation	189
18 — Casting Surface as Affected by Core-Sand Mixtures	193
19 — Economics of Core Production	195
20 — Defects Caused by Faulty Cores	202
21 — Shell Cores	207
22 — Silicate Bonded Cores	233
23 — Oil Oxygen Process of Coremaking	241
24 — Furan No Bake Process of Coremaking	247
25 — Oil No Bake Process of Coremaking	252
26 — Hot Box Process of Coremaking	257
27 — Bibliography	265
Index	275

Chapter 1

INTRODUCTION

FACTORS INVOLVED IN COREMAKING

The material presented in this book covers ingredients used in the making of cores for foundry purposes; methods of mixing the ingredients; methods of forming, baking, preparing the cores for the molds; setting and holding the cores in place in the molds. Casting imperfections originating from cores are described with suggested remedies detailed for each particular defect. It is hoped that this information will prove of benefit to both the practical and technical men of the foundry industry.

Coremaking practice in this country has improved rapidly in recent years in response to the demands on the foundry industry for increasingly rigid tolerance on quality and conformance to dimensions of castings. Progress has been made possible as much by improvement in coremaking materials and equipment as by the development of better techniques of coremaking and testing. To this progress, therefore, supplier and manufacturer, technician and practical foundrymen, alike have contributed.

The specific properties and usefulness of a core are the result, not only of the materials used in its making, but also of the means used to mix the materials, the equipment used to make and bake it, and the conditions of baking and storing. Likewise, the selection of the raw materials and their proportion must take into account all of these factors and also envision the behavior and functioning of the core in the mold. Superimposed on these considerations are the economic factors of ultimate casting costs. No discussion of modern coremaking is complete without consideration of these factors.

WHAT IS A CORE?

A core is an aggregate of inert material, possessing a degree of porosity, and a controlled mechanical strength sufficient to allow the aggregate to be assembled without breakage, for the purpose of making internal or external portions of a mold. The core may be either baked in its entirety, made of green or dry sand, or a combination of green and baked core material, and made strong enough to support itself or be supported on an internal arbor.

The function of the core may be to form internal cavities surrounded by metal, or to make it possible to draw some portion of the external surface of a casting from the sand which naturally would not permit this; or it may be used to strengthen or improve a particular inner or outer surface because of its special properties. A core must be vented to the outside of the mold or through the mold itself, but occasionally, as in certain radiator practice, the core vented to the outside, also vents the mold.

A core must be strong enough in the process of preparation to retain its form without deformation. After baking or drying, it must be sufficiently strong to resist erosion and deformation by metal during the filling of the mold. To make a true form for the casting, it must have a minimum of contraction and expansion. The core must have sufficiently low residual gas forming materials to prevent excess gas from entering the metal, and the metal must remain quiet in contact with the core during pouring and solidification. On the other hand, the core must disintegrate, following initial solidification, to minimize strains on the casting and to make its removal from the casting easy during shaking out.

Chapter 2

CORE SANDS

TYPES AND LOCATIONS

Silicon is the most abundant solid material found in nature, and is exceeded only by oxygen as the most abundant of all elements. Silicon combines with oxygen to form an oxide, SiO_2 (silicon dioxide), which occurs in a variety of forms. Silica sand, a form of quartz, is most common.

Siliceous sand is by far the most widely used base material for cores. In foundry practice, a wide range of sands is used which vary in purity, structure, grain size, grain distribution, and refractoriness. These sands occur in natural deposits in many parts of the country, either on the surface, such as dunes and beaches; under water, such as river, lake and seashore bottoms; or as subsurface deposits of various geologic formations. In all cases, sands are the residue of rock structures, broken up by natural agencies, such as erosion, ice, frost, wind, and water.

In general, the degree of purity of these materials is the result of their geologic history and preparation. Sands deposited along lake beaches, or in the form of dunes near the shore, frequently are of higher purity than river sands. The grain structure of the former is likely to be subangular and the grain distribution, as naturally found, irregular and ungraded.*

Sands found at the edge of advancing glaciers, river and lake beds may be graded quite accurately. Inland sands — such as some bank sands — usually are small in grain size, accurately graded, but quite impure, except in sand dunes of original beach surface deposits.

The Middle West, especially the Great Lakes region, is fortunate in possessing a large variety of core sands of glacial origin. The most unusual deposit of silica sand occurs in Illinois, in the Ottawa district, and is known as St. Peter sandstone. When washed of its slight clay content, this material contains 99.5 per cent silica. The grains are rounded in shape and solid in structure. Somewhat similar deposits occur in the upper Mississippi Valley dating to the same geologic age as the St. Peter sandstone.

The Eastern seaboard is distinguished for many deposits of high grade silica sand, particularly those occurring in the southern New Jersey and Providence districts. Sands from these sections are rounded to subangular in form. The New Jersey sands occur in subsurface deposits with small quantities of clay, which makes it necessary that these materials be washed and graded before use as core sands. The Providence River deposits are free from clay as found, and of a finer grade than the New Jersey sands.

A number of districts in Pennsylvania have silica rock, which is crushed to make sands of extreme purity, well graded as to size. The structure of these sands is sharply angular. Silica rock deposits also occur in Ohio, Virginia, California, Tennessee, and Nevada.

Great progress has been made in the past few years in the grading, cleaning and preparing of sands, so that today a specific sand for any definite purpose is readily available, quite uniform as to cleanliness, grading and distribution.

PROPERTIES OF SANDS

Based on their origin, as previously outlined, sands vary in grain shape, grain composition, relative surface, grain size, and distribution. These properties, in addition to chemical analysis, sintering point, expansion, etc., vitally affect the usefulness and ultimate properties of the core.

Chemical Analysis

For some years emphasis was placed on chemical analysis, but it is now known that, while chemical analysis is desirable, it is not sufficient to judge all the qualities of a sand. A screen analysis, an examination to determine grain shape, and in many cases a refractory test, are necessary to apply a sand intelligently. Chemical analysis tells only the constituent elements but nothing definite about their mineralogical composition. Many minerals have cleavage planes and are brittle, while others are tough and hard. Pure silica, or quartz, is tough and does not fracture readily, but many silicates are brittle and weak. This condition is not shown by a chemical analysis alone. Calcium and magnesium also might be present as silicates rather than carbonates, as is often deduced from the analysis. These properties of a sand can be determined only by mineralogical examinations, along with observations of behavior in actual use.

*In this book, the term "graded" should be interpreted to mean that, in the fineness test, the majority of sand grains is retained, properly proportioned, on a relatively few or a number of desired sieves either as the sand is found or as processed by the producer. The term "ungraded" naturally means that the grains may be distributed over a larger number of sieves or not properly proportioned on the sieves on which the grains are retained.

Screen Analysis

Screen analysis is as important as chemical analysis. Each type of work may require a slightly different fineness of sand to secure the best results. In general, core sands are coarser than molding sands. However, there is a trend toward the use of finer sands for core purposes. Sands which show from 80 to 90 per cent of the grains between 50 and 100 mesh screens are being used more each year.

Grain Shape

Sand grains may be either rounded, subangular, angular or compound, depending on their origin and geologic history. In general, rounded (see Fig. 2.9) grains give the greatest permeability when rammed and have the least contact area between grains. As a result, they have a low green strength, bake easily, and frequently require the least bonding material.

On the other hand, sharply angular grains give lower permeability, often a higher green strength, frequently require greater amounts of bonding material.

The other shape grains are intermediate, except the compound grains which may break down when heat is applied, may absorb more core oil, and therefore are not desirable.

The grains in any of these forms may be homogeneous in structure, or show cracks or fissures. In general, the more rounded the grain, the stronger its structure and the less likely it is to have minute fractures. The highly angular grains are most subject to fractures.

The surface of the grain increases rapidly with a decrease in fineness, as shown in Table 2.1. The importance of this astounding increase in surface with increase in fineness is apparent in the amount of bonding material necessary to develop required strength properties, as the amount of binder necessary is directly proportional to the surface area of the grains.

Grain Size

While Table 2.1 shows that the surface area varies inversely to diameter, the number of grains in a given volume varies inversely to the cube of the diameter; in other words, there would be eight times as many 270 mesh grains as 140 mesh grains in a given volume.

The effect of fines on permeability is very important. For example, 40 mesh grains alone have a permeability of 550. If the percentages of 140 and 270 mesh grains indicated in Table 2.2 are added to 40 mesh grains, the permeabilities would be affected as indicated.

TABLE 2.1* — PROGRESSIVE SUBDIVISION OF A CUBE
(1 unit mass = 1 cm. cube)

Length Side	No. of Cubes	Total Surface Sq In.	Total Surface Sq Ft
1 cm. = 0.3937-in.	1	0.93	—
1 mm. = 0.0394-in.	1,000	9.3	—
0.1 mm.	1,000,000	93.	—
0.01 mm.	1,000,000,000	930.	6.46
0.001 mm. = 1 micron	1,000,000,000,000	9,300.	64.58
0.1 micron	1,000,000,000,000,000	93,000.	645.8
0.01 micron	1,000,000,000,000,000,000	930,000.	6,459.0

*Aptekar, R. E., "Core Making," presented at Regional meeting, Michigan State College, East Lansing, Mich., April 10, 1937.

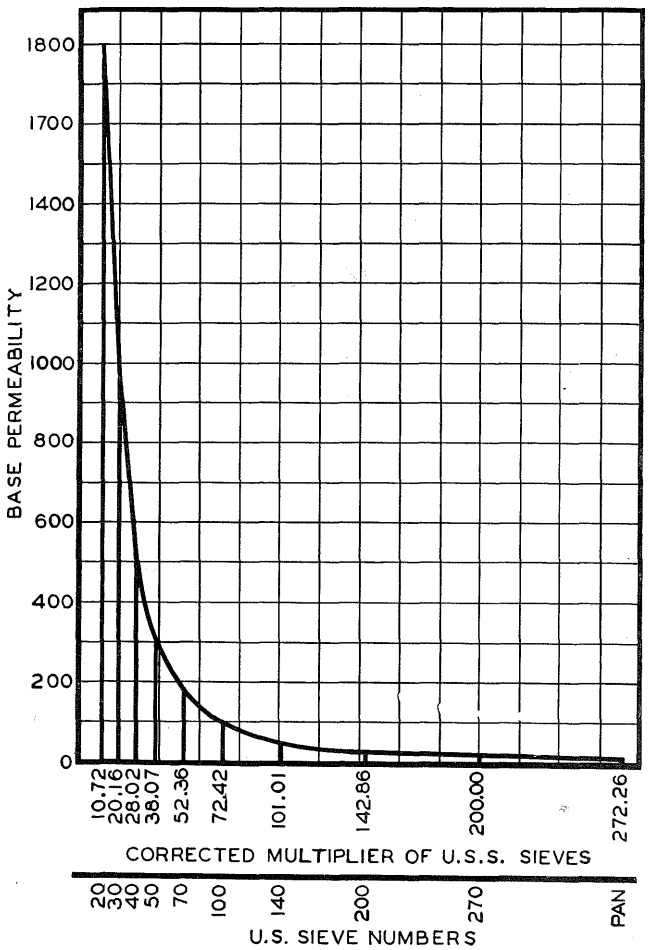


Fig. 2.1 — Base permeability curve of sand grains according to mesh size.

The drop in permeability, noted in Table 2.2, with only a small percentage of 140 or 270 mesh grains illustrates clearly how a small amount of a fine material from a poorly graded sand can greatly reduce the permeability of a normally open sand which is washed and graded uniformly. Conversely, it would require a large quantity of coarse material to increase the permeability of very fine sand.

TABLE 2.2 — EFFECT ON PERMEABILITY OF ADDING FINE TO COARSE GRAINS

Mesh Grains Added	Percentage	Permeability
40 (Base)	—	550
140	10	250
140	20	130
270	10	110
270	20	35

The author has made a detailed study of the effect of grain size and distribution on permeability, using base permeability results as the basis for his conclusions. Figure 2.1 shows the relation between the sand grain size and base permeability, ranging from grains retained on the 20 mesh sieve to very fine material.

The 20 mesh material has a base permeability of 1796 and the pan material, a permeability of 6.9. While the diameter of the coarse sand is 15.5 times greater than the pan material, the base permeability is 238 times as great. Figure 2.1 definitely shows that the

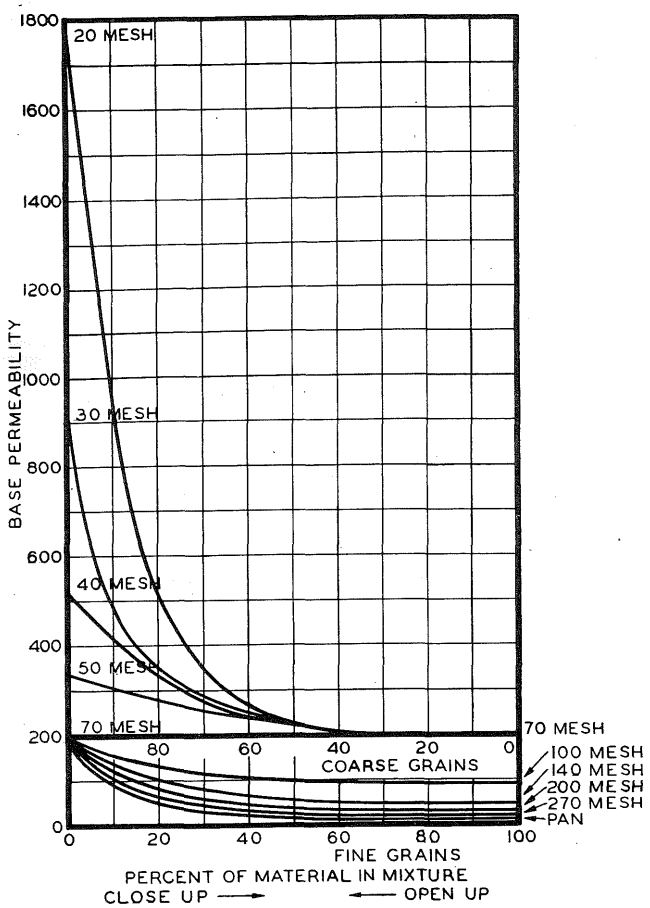


Fig. 2.2 — Base permeability of sand grains consisting of standard 70 mesh sand to which various percentages of sands of all other grain sizes have been added.

base permeability increases very slowly from the pan material size to the 140 mesh size, but a very rapid increase in permeability occurs as the size of the grains increases above 140 mesh.

Figure 2.2 shows the difference in permeability due to the addition of various percentages of coarse and fine sands to a standard 70 mesh sand. When the coarse sand is added to the 70 mesh sand, the permeability does not increase until the coarse grains are in excess of 30 per cent. Also, the addition of 270 mesh grains to the standard 70 mesh sand will cause the permeability to drop rapidly. Only 10 per cent of pan material is required to reduce the permeability of the standard 70 mesh sand from 200 to 100. It will also be noted that fine grains, when in excess of 70 per cent, will control the permeability of the sand. The reason for this is obvious. The fine material fills the space between the larger grains, reducing the gas passageways, and the influence of the coarse sand is recognized only after 30 per cent has been added. Figure 2.2 shows that fine sand grains have a much greater influence on permeability than do the coarser grains.

Figure 2.3 shows the base permeability of sands retained on four adjacent sieves. The resultant permeability of a four adjacent sieve mixture is not the average calculated permeability of that mixture, but is only 50 to 55 per cent of this average. This shows that as the distribution or spread of grain size increases, the base permeability is greatly reduced.

Core Sand Selection

Core sand selection is of the utmost importance in any foundry. The proper selection of core sand is just as important to the foundry in maintaining satisfactory sand heaps as it is to the core room in maintaining satisfactory core sand mixtures. Foundry sand heaps, or systems, may be partially or wholly maintained by the addition of new sand through the disintegration of the cores at the time of shaking out.

The essential properties to be considered in the purchase of a core sand are grain size, shape, distribution, base permeability, sintering point, clay content, and mineralogical composition. Once a suitable source of supply has been located and the above properties determined, periodic tests on the fineness and grain distribution usually are sufficient to maintain a check on the future purchases of sand from the same source, in accordance with the AFS procedure as outlined in the AFS FOUNDRY SAND HANDBOOK.

The ultimate chemical analysis of a sand seems to have very little value, since sands used for the same purpose may bear no chemical relation to each other. It is generally very difficult, if not impossible, to predict even the refractoriness from a chemical analysis, since texture or degree of fineness plays such an important part.

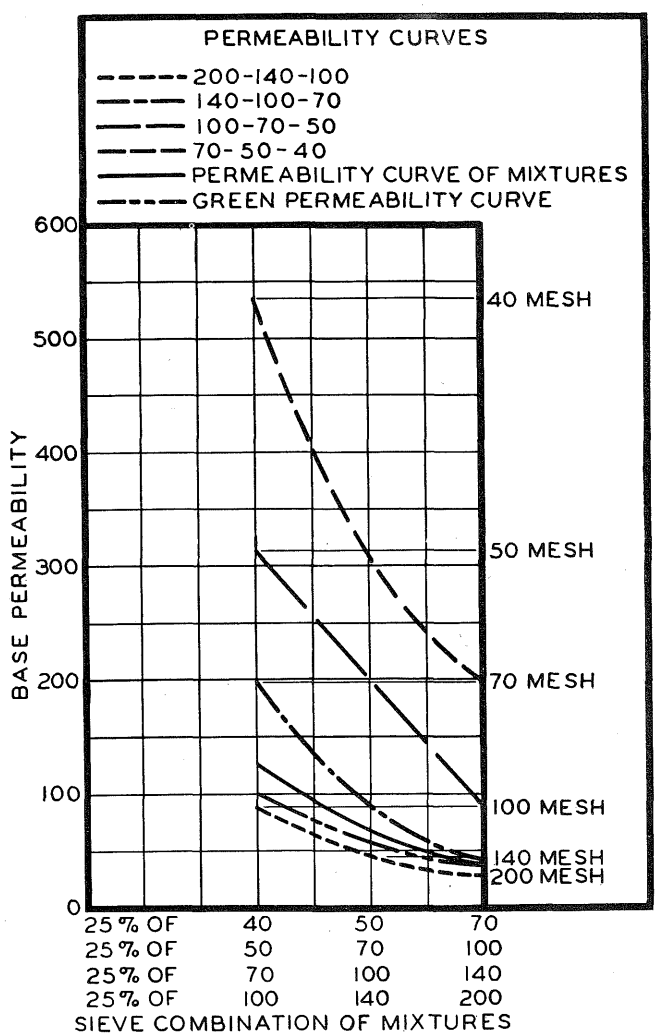


Fig. 2.3 — Base permeability of sand grains retained on four adjacent sieves.

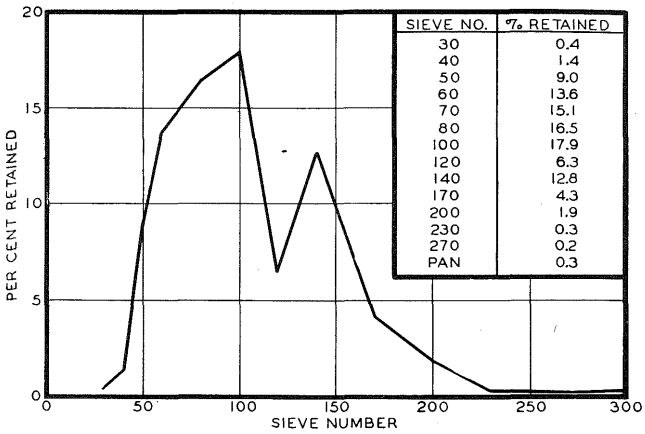


Fig. 2.4 — Effect of adding additional sieves in the AFS standard series on the grain distribution curve.

A coarse grained sand is much more refractory than a fine grained one of the same composition. The amount of quartz in a sand is regarded as a measure of the shrinkage resisting and refractory properties. Since quartz confers refractoriness, the amount of it present should be as high as possible.

Necessity of Records

Records should be kept on each type of sand purchased so that any variation in the sands will be found immediately. One method is to make a periodic record of the grain distribution curves. In one foundry, once a characteristic curve has been established for a certain sand pit, screens are inserted in the AFS standard series where the majority of the grains are retained. As shown in Fig. 2.4, sieves No. 6, 12 and 20 have been removed and sieves No. 60, 80 and 120 have been inserted. This, it is claimed, gives a more complete analysis where the maximum grains are concentrated. Some shaking equipment permits the use of additional sieves. In Fig. 2.4, it will be noted sieves No. 170 and 230 have been added to determine more accurately the fines and their distribution. Although the above method has functioned satisfactorily in some plants, other methods of checking core sand supply are used.

ADVANTAGES OF PRODUCER PLANT CONTROL TO THE FOUNDRYMAN

The question often is asked, "What are the advantages of buying sand on analysis when the foundry has no testing equipment?" Terms and control methods promulgated by the American Foundrymen's Society are the common ground on which producer and foundryman meet understandingly. Few foundrymen today are not familiar with standard AFS test methods and their direct relation to castings. Foundrymen continually discuss their difficulties and exchange ideas on one phase or another of their problems and, in many instances, are following AFS recommendations.

To secure uniform results in sand control in the foundry, the shipments of sand from the producer must be uniform. To secure uniformity, the producer must adopt the same control methods of testing sands as the foundries. AFS standard methods of testing have brought about a better understanding between the foundries and producers, and tolerances have been worked out cooperatively that have resulted in the same type purchasing conditions for sand as apply to iron, coke, etc.

Sand testing alone means no more to the sand producer than does sand testing alone in the foundry. When control is based on test findings, then it means a great deal. Most sand producers make shipments from stock piles of various grades of sand. This is done for more than one reason. The sand is loaded with less moisture and, at the same time, it is possible to double check the tests before the sand is loaded. In addition to tests on stock piles, some of the producers take a representative test from the car, as recommended by AFS, and these test findings are retained as the final record. Customers' specifications can be met with the allowable tolerances which have been agreed upon between producer and consumer. If the test findings come within the specifications, the car is released for shipment. Some producers keep actual samples of the shipments for a period that will vary according to consumption by the user.

Practically all sand deposits will vary somewhat and these variations must be taken into consideration in selection and preparation to meet shipping requirements. Standardized testing equipment has helped to make testing more rapid, which gives the producer an opportunity to prepare for bank variations before preparation and loading.

Many producers find that drilling ahead, in the working direction of the bank, means much in keeping their shipments more uniform. Should there be some variation in the bank, the necessary changes can be made in the preparation plant to take care of this variation. It is these varying conditions that made constant testing necessary. Should the producer neglect this most important work, fail to overcome bank irregularities, or be careless in his testing operations, the consumer pays for the negligence with mounting shop costs.

Visual inspection of core sands is unreliable, as appearance often is deceiving. A sand judged by appearance alone may contain just the right amount of moisture to make it seem very open and well graded, whereas the opposite may be true, due to a high percentage of pan material. Another sand may seem entirely too fine, when, as a matter of fact, it is open, due to its grain distribution and low percentage of fines.

Another good reason why sand purchasers should buy from producers using sand control methods in shipping their various grades is that usually these producers are reliable and have developed deposits by careful and conscientious methods of production. Their sands are well known to all foundrymen. The district and the producer may make a name for sands that may be a criterion in the minds of foundry sand buyers.

It is not uncommon, however, for sand to be offered to foundries as being produced near a well-known district or producer and the claim that such a sand is just as good as that produced from the well-known district. It often is true that the general appearance of the sand resembles closely what it is supposed to duplicate, but the methods used in the production often are not the best. Consumers should buy sand from producers who control their product by proper testing meth-

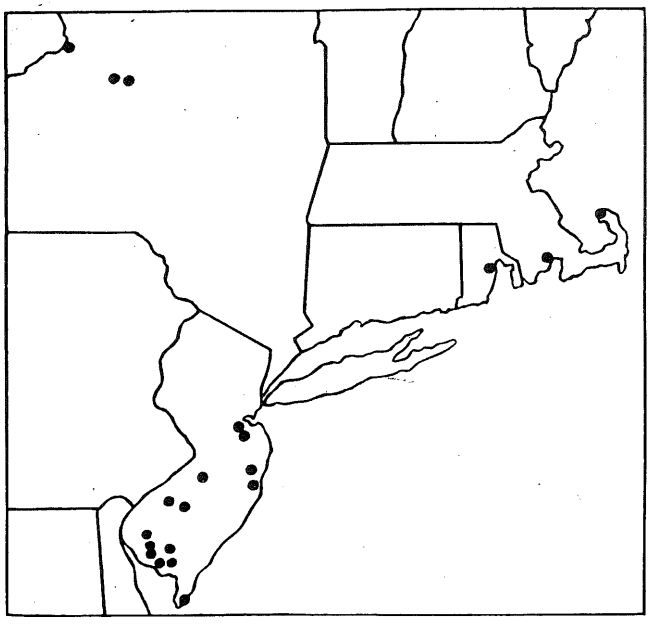


Fig. 2.5 — Principal areas of core sand production in the Eastern states.

ods and on specifications and tolerances agreed on jointly between consumer and producer.

A great deal of harm may result from sand test data secured from carelessly made tests. The test procedure is simple and may lead some to believe that the human equation is not important. Sand is sensitive to handling while making the test. Great care should be exercised in each step during the test to make the data worthwhile.

Core sand segregates very easily in stock piles, bins, silos and in transportation. Thus great care must be exercised to sample correctly to obtain a representative sample, and not to charge a change in grain fineness to the sand producer when it is due to segregation in the foundry.

OCCURRENCE OF CORE SANDS IN THE UNITED STATES

New England and New York Core Sands

Introduction

The principal areas of core sand production in the East are, as shown in Fig. 2.5, New Jersey, New England and New York. It is obviously impossible to mention and describe every operation which produces or has produced core sand. Many plants, some large and some small, send a portion of their product to the foundry trade. It should not be inferred that because an operation is not mentioned, its product is not worthy of consideration. However, the sands described are loaded primarily for the foundry. Many companies producing them are familiar with the requirements of that industry. Moreover, the sands discussed occur in quantities sufficient to guarantee their availability for many years to come.

Many bonded molding sands often are used in cores. The most outstanding example of an Eastern sand is the use of Millville gravel in large cores, usually with dry binders, and the addition of Albany sand to batches for medium or light cores to increase the green strength, to produce a smoother cored surface, and to retard core collapsibility.

McConnellsville Sand

This sand is used for cores in medium and light weight iron and nonferrous castings. Mined near McConnellsville, Oneida County, New York, the silica content varies somewhat over the wide range of grain sizes. The grains are classed as subangular, with the coarsest grades containing a few compound grains. The coarser grades of McConnellsville sand, down to about AFS Fineness No. 113, are low in pan material. In the finer grades, the pan material increases more rapidly. One deposit has a distinct pinkish cast, others are various shades of gray, some approaching a white. As these various deposits often are blended to produce



Fig. 2.6 — McConnellsville core sand deposit in Oneida County, New York State.



Fig. 2.7 — Deposit of Providence core sand near Providence, R.I. Note heavy overburden.

the desired grade, there is a variation in color shades in shipments from this district.

Grades—Many grades of this sand are available, from medium to extremely fine. The coarsest grade is of about AFS Fineness No. 55 while the finest is about AFS Fineness No. 225. All grades are available in the screened condition and either damp or dried. Representative fineness tests of McConnellsville sands are given in Table 2.3, columns 1, 2, 3, 4 and 5.

General—At McConnellsville, there is a heavy overburden which is removed by power shovel or drag line. Occasionally, the sand is recovered the same way, but most of it is loaded by hand shovel for more accurate grading. Figure 2.6 shows an operation in this field. Nature has laid down in the immediate vicinity of McConnellsville large deposits of five or more distinct grain sizes, shown in Table 2.3. Through careful blending from these various banks, many grades between the extremes are available. Grades with fineness numbers above 100 develop considerable green strength.

Geology—During the time that the continental glacier was melting off northern New York, the northward stream drainage was dammed by the ice front, thus causing the formation of lakes. Into these lakes, the streams brought large quantities of gravel, sand, and clay. In the McConnellsville area, production is from one of these stratified sand plains formed by the

TABLE 2.3 — REPRESENTATIVE FINENESS TESTS OF EASTERN CORE SANDS

	McConnellsville					Providence		Wareham		Province-town Silica	Mexico Bay
Column No.	1	2	3	4	5	6	7	8	9	10	11
Sieve No.	Percentage Retained										
6	None	None	None	None	None	None	None	None	None	None	None
12	None	0.02	None	None	None	None	None	None	None	None	None
20	0.02	0.04	0.02	None	0.03	None	None	1.0	1.2	4.0	None
30	0.08	0.10	0.02	0.02	0.03	None	0.2	1.4	6.2	33.6	0.02
40	1.38	0.76	0.02	0.02	0.03	None	0.2	3.8	10.6	53.0	0.50
50	15.58	6.60	0.04	0.04	0.06	0.6	0.4	9.2	14.8	7.6	9.46
70	44.20	26.48	1.56	0.06	0.12	3.0	1.6	16.8	21.2	0.8	51.88
100	32.46	40.50	23.80	0.88	0.18	15.4	7.8	32.0	24.4	0.6	32.56
140	4.42	20.86	33.82	19.42	5.30	26.8	19.2	22.0	11.8	0.2	5.22
200	0.88	3.24	33.82	41.80	23.77	29.6	31.0	9.6	5.0	0.2	0.18
270	0.18	0.44	4.08	13.34	15.40	13.4	19.6	2.6	1.8	None	0.02
Pan	0.80	0.96	2.82	24.42	55.08	11.2	20.0	1.6	3.0	None	0.16
AFS Fineness No.	58	73	113	177	133	141	168	81	70	27	58
AFS Grain Class	5	4	3	2	1	2	2	4	4	8	5

deltas and beaches of the former Lake Iroquois, which became extinct some twenty or thirty thousand years ago.

Providence Core Sand

This sand is used for cores in light castings of iron and nonferrous metals. Mined near Providence, R.I., this core sand is used extensively in New England in the production of light weight castings, where high green sand strength is needed.

Providence core sand is very fine. The grains are commonly angular but many subangular grains often may be present. The subangular grains are well distributed over the finer sieves. This sand is characterized by a smooth, velvety feel.

Grades—Two grades are available. Both are very fine. The coarser grade is of about AFS Fineness No. 140, while the finer is of about AFS Fineness No. 170. Representative fineness tests of these two grades are shown in Table 2.3, columns 6 and 7.

Typical Uses—Typical applications are in cores for food choppers, impellers and light hardware.

General—Present operations are in the outskirts of Providence, although deposits have been worked within the city. The sand layers total from 30 to 50 ft deep, covered with a heavy overburden that frequently is thicker than the sand deposit itself, as shown in Fig. 2.7. Prospecting is difficult because of this great depth, but the banks now in operation insure a supply for many years to come.

In loading this sand, the overburden is removed by drag line. However, the sand itself ordinarily is dug by hand shovel to insure freedom from contamination.

Providence core sand has been used for many years in making light castings in New England foundries. It is noted principally for its high green strength.

Geology—At the maximum extent of the great ice sheet that at one time covered northeastern North America, the southern border of the ice was approximately along the southern New England coast. As this glacier melted, vast quantities of gravel, sand, and clay were deposited at the front of the ice. Where the melt waters issued from the glacier, the streams were charged heavily with these materials. As the waters spread out and lost velocity, the sediments were deposited. Only those materials washed, sorted, and laid down in beds of relatively uniform size grain are of importance as core sands. Those deposited directly from the ice have little or no commercial value.

Wareham Sand

This sand is used for cores in medium and light medium iron or nonferrous castings. Mined near Wareham, Plymouth County, Mass., at the base of Cape Cod, the silica content is about 94 per cent. Most grains are subangular in shape but a few round grains are included. In the fineness test, there is not a high peak on any one sieve. In most cases, a considerable proportion is retained on each of four or five sieves.

Grades—This sand is mined in two grades. The coarser, washed grade is about AFS Fineness No. 60 to 70 in the screened condition, while the finer unwashed grade is of about AFS Fineness No. 70 to 85 as screened. Representative fineness tests of these two grades are shown in Table 2.3, columns 8 and 9.



Fig. 2.8—Wareham core sand being dumped into a basin prior to the screening operation.

Typical Uses—Typical applications of Wareham sand are in cores for valves, power transmission machinery, and boiler castings.

General—The coarser grade is dredged from below the water line. It is elevated to a vibrating screen and washed through by fine water sprays. The finer grade is dug above the water line and is trucked directly to the screen. An illustration of the mining operation in Wareham district is shown in Fig. 2.8.

In New England there is no extensive core sand production of a grade between 45 and 60 AFS Fineness No. When such a grade is required, it often is obtained by mixing (in the foundry) the Wareham and Provincetown silica sands. They blend well together and, by using them in various ratios, a variety of grades may be obtained.

Geology—The geology of this sand is the same as that of the Providence core sand previously discussed.

Provincetown Silica Sand

This sand is used for cores in heavy and medium weight iron castings. It is mined near Provincetown, Mass., at the tip of Cape Cod and has a silica content of 95 to 96 per cent. The quartz content is 97 to 98 per cent, which is high. The grains are classed as subangular but they tend towards the rounded with many of the round type present. About 86 per cent of the grains are retained on the 30 and 40 mesh sieves, classing it as an extremely uniform grained sand. Its most distinguishing characteristic is uniformity in grain size and freedom from both fine and oversize materials.

Grades—Only one grade is available, which has an AFS Fineness No. of 27. Table 2.3, column 10, shows a representative fineness of this sand.

Typical Uses—A typical application is in cores for heavy machine tool bases.

General—This sand is loaded with a power shovel from dunes on a short stretch of beach near the tip of Cape Cod. Its coarse, uniform grade is due to the sorting it received by the strong currents before being deposited on the beach and to the high winds prevail-

ing on the tip of Cape Cod. These winds completed the sorting action and piled the sand up into tremendous dunes extending as much as three miles back from the beach. Due to its high quartz content and freedom from fines, this sand is used for abrasive blasting as well as for cores.

High permeability and refractoriness, with a minimum of oversize grains, may be obtained by a judicious use of this sand.

Geology—Ocean currents are in a large measure responsible for the accumulation of the sand deposits at Provincetown. Through a period of thousands of years, the outer end of Cape Cod has been slowly extended toward the northwest. Currents sweeping along the cape have picked up the sands and deposited them further on. This process has resulted in the development of a succession of beaches, each formed to the seaward from the preceding. As the deposits have built up and emerged above the level of high tide, they have been attacked by the winds, which have continued the work of cleaning and sorting, previously done by the water, and piled the sediments as sand dunes.

Mexico Bay Sand

This sand is used as a general purpose core sand for a wide variety of medium sized iron and nonferrous castings. It is mined at Selkirk Beach, on Lake Ontario, near Pulaski, Oswego County, N.Y. The silica content is over 90 per cent and the grains are subangular, tending towards the rounded with some round grains included. The peak in the fineness test is on the 70 mesh sieve with about 95 per cent retained cumulatively on the 50, 70, and 100 sieves. In chemical and physical characteristics, as well as in working properties in the foundry, Mexico Bay sand is similar to the dune sand on the southern shore of Lake Michigan near Michigan City, Ind. It is known for its uniformity of grain size and freedom from fine or coarse particles.

Grades—One grade only, in the screened condition, is available. It has an AFS Fineness No. of about 58. The base permeability is well over 100. Representative fineness test of Mexico Bay sand is shown in Table 2.3, column 11.

Typical Uses—The grain size, grain distribution, and cleanliness of this sand make it desirable for broad and general use in gray iron, malleable, and nonferrous foundries. A good example of a suitable application is motor cylinder cores.

General—This sand occurs in large sand dunes on the shore of Mexico Bay, Lake Ontario. Although the area is very restricted, the dunes are large and tonnage is available for many years. Notwithstanding the unusual quality, this sand was not mined until recently. Many years of sorting by water and wind is responsible for the uniformity of grain size.

There are many sand dunes along the shores of Lake Erie and Lake Ontario. Most of them, however, contain lime carbonate and the characteristics, both chemical and physical, are somewhat different. Mexico Bay appears to be the only dune sand on Lake Erie or Lake Ontario which is now being operated primarily for core sand. This sand contains no lime carbonate.

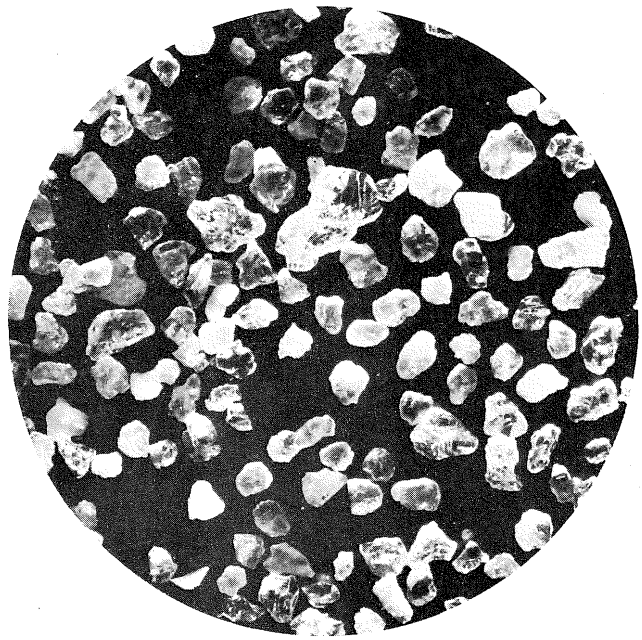


Fig. 2.9 — Round-grained New Jersey core sand.

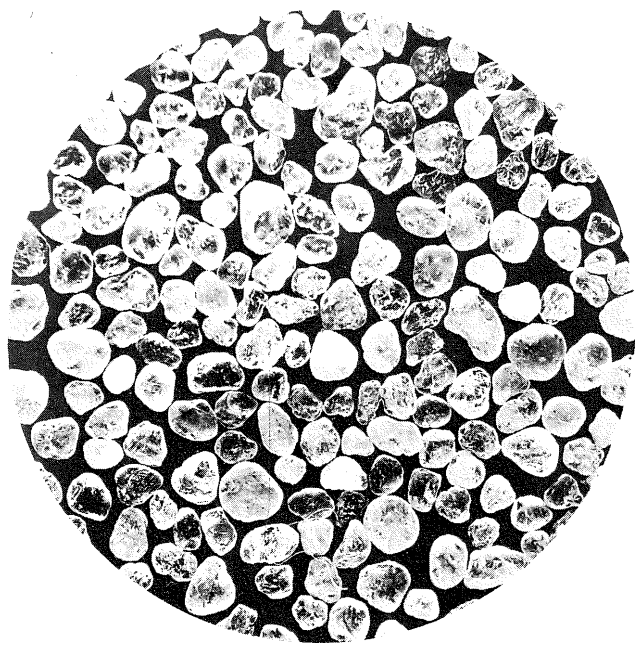


Fig. 2.10 — Subangular grains of core sands from the New Jersey area.

Geology—The commercial sands of the Mexico Bay area have been washed, sorted, and deposited on the broad beaches by the waves and currents of Lake Ontario. Continued deposition, through thousands of years, has filled in some of the shallow indentations of the coast and has widened the belt of beach sands. As the deposits have built up above the water level high enough to dry out, they have been attacked by the winds, with the result that they have been further cleaned, sorted, and piled as dunes.

New Jersey Core Sands

The core sands of New Jersey are used in all types of foundries. The grains of these sands are solid, and are not cemented together. Figures 2.9 and 2.10 show the shape of the sand grains found in the New Jersey



Fig. 2.11 — Typical core sand deposit in southern New Jersey. Sand is pumped to the preparation plant.

area. Location of core sand mining operations is shown in Fig. 2.5.

Grades—A large number of grades of core sand are produced in the New Jersey area, including approximately 40 grades of washed silica sands. These range from an AFS Fineness No. of about 36 to higher than 100. Table 2.4 shows some of the grades used in the eastern section of the country.

Typical Uses—Typical applications of New Jersey core sand cover steel, gray iron, malleable and nonferrous foundries. For example, the sand illustrated in column 1, Table 2.4, is used extensively for large steel casting cores and molds. Extremely fine silica sand with an AFS Fineness No. of over 100 is used as a facing in foundries where it is standard practice to use a fine facing sand. Where such a sand is used, the center of the core must be of the proper materials.

TABLE 2.4 — FINENESS TESTS OF SOME REPRESENTATIVE NEW JERSEY CORE SANDS

Sieve No.	1	2	3	4	5	6
	Percentage Retained					
6	None	None	None	None	None	None
12	None	None	None	None	None	None
20	1.7	0.2	0.6	None	None	None
30	15.4	1.4	4.3	0.2	None	None
40	30.1	5.7	13.3	1.3	None	None
50	33.5	22.1	28.9	11.3	0.7	None
70	18.8	45.3	35.1	35.9	8.8	0.3
100	1.5	23.1	15.9	38.8	43.1	15.3
140	None	2.0	1.6	11.3	35.3	41.6
200	None	0.2	0.2	1.7	10.6	31.6
270	None	None	None	0.1	0.9	7.8
Pan	None	None	None	0.1	0.6	3.4
AFS Fineness No.	36.4	52.6	47.6	65.5	87.1	124
AFS Grain Class	7	5	6	5	4	3
Type Grain	Rounded	Sub-angular	Sub-angular	Rounded	Sub-angular	Sub-angular
Base Permeability	300	148	189	96	80	58

The sand, shown in column 2, Table 2.4, is used extensively in steel foundry cores. It is said to be an all around sand for jobbing foundries which use a wide range of core sizes. It also is a popular grade for radiator cores, while the sand in column 3 has been used in boiler cores.

Many eastern steel foundries, particularly those specializing in alloy steel castings, use the sand shown in column 4, Table 2.4, for both green and dry sand cores, while the coarser sand, shown in column 5, is used for oil burner core work and for light cores. This same sand can be used as a facing for large cores, provided such cores have a center of cinders or some other material that is open.

Column 6, Table 2.4, shows a sand that has been used by airplane manufacturers with success. It has been used for small cores made on blowing machines. Sands having a fineness of over 100 often may be used to good advantage and sometimes a sand with a fineness number of over 130 is used. Such sands are especially good where cores must stand up in the green state.

General—Core sand deposits in the New Jersey area are covered with an overburden, consisting of sandy soil with small oak trees, underbrush and some pine trees. The average overburden depth is about 4 ft. The working bank is from 25 to 35 ft deep. The sand grains vary from 1½-in. diameter pebbles to very fine sand. Test drillings usually are made to determine the depth of the bank as well as the amount of overburden that will have to be removed.

Many grades of unwashed sand in this section are used for making cores. This unwashed sand usually is found on slight hills that appear near other silica deposits in the South Jersey area. Most of the area is comparatively level. The upper spring level is only a

few feet below the surface, near enough to form lakes in places from which the sand has been removed. This permits the use of dredges, which house pumps for pumping raw sand to the preparation plants.

The shape of the grains will vary from those that are decidedly rounded to the more angular ones found in the northern part of the state. Figure 2.11 shows a sand bank typical of the South Jersey area.

The method of mining, shown in Fig. 2.11, typifies the washing of sand from bank or lake deposits. The sand is delivered from a dredge by pipeline, which may include booster pump equipment, when the distance to the preparation plant becomes too great for the dredge to force the sand the full distance of the line, either to a distributing tank, which takes care of the fluctuations in the flow, or directly to the first screens. Plants are constructed high enough to permit gravity feed to the screens and classifiers. The water pumped with the sand, as well as additional fresh water, is used in the washing process and carries off the slight percentage of clay that is found in some of the banks.

Sand classifiers assure a closer gradation as well as the removal of fines that are so detrimental in most core mixes. There are many types of classifiers, most of which work on a settling basis plus hydraulic action that is brought about by the use of float controls. Drag classifiers and screw washers also are used. The washed sand is delivered to drainage piles, as shown in Fig. 2.12.

Many grades of unwashed or run of bank sands suitable for cores are produced in the New Jersey area. Such sands are loaded on cars without preparation. However, some producers pass the material through a large, revolving screen to remove a small percentage of oversize grains.

Behavior Under Heat—Due to a demand by steel foundries for information on the behavior of New Jersey silica sands under heat, producers became interested and numerous tests were made to obtain data on this problem. One test used to indicate the behavior of washed New Jersey sands under heat is described.

The sand was photographed to show the grain structure and shape. A screen test was made on the sample and then the sand was placed in an open crucible and heated for 10 min over a Bunsen burner. There was no clay or binder on the sand grains to protect them. The sample then was immersed in cold water, instead of allowing it to cool gradually to room temperature. If it was possible to crack, split or break down the grains, this procedure would do it.

After such a test, the sample was photographed again, another screen test made, and the same procedure followed as before. This was done again for a third time. At the end of the test, the sand grains showed no sign of breakage and the screen analysis was identical with the original. The sand analyzed 99 per cent plus silica and had a fusion temperature of 3218 F (1770 C).

Geology*—Southern New Jersey lies in what is called the Coastal Plain. The plain's highest point in New Jersey is less than 400 ft in altitude and descends to sea level at about the borders of the state. The larger part of this coastal plain, as it occurs in southern New Jersey, may be regarded as a plain highest toward its middle and lowest at its margins, the surface of which has been trenched by streams which flow over it. The formations are chiefly sands, gravels, clays and marls.

Part of southern New Jersey is located in that portion of the coastal plain which is less than 50 ft in altitude. This portion extends along the Delaware River and Bay from Camden to Cape May, and along the Atlantic Coast from Cape May to Raritan Bay. Within this belt, there is but one place where land 50 ft in height reaches the shore. This is in the Navesink highlands.

While the ice that covered the northern half of the state was at its maximum, the streams flowing from it were flooded and brought southward heavy burdens of sand and gravel. These materials were deposited along the Delaware, Musconetcony, Greenbrook and in the vicinity of Plainfield.

Before the close of the glacial epoch, the southern part of the state appears to have sunk so as to convert the lower course of the Delaware into a sort of estuary.

*Abstracted from *"The Physical Geography of New Jersey,"* by Rollin D. Salisbury, Geological Survey of New Jersey, Final Report, State Geologist, vol. IV (1898).

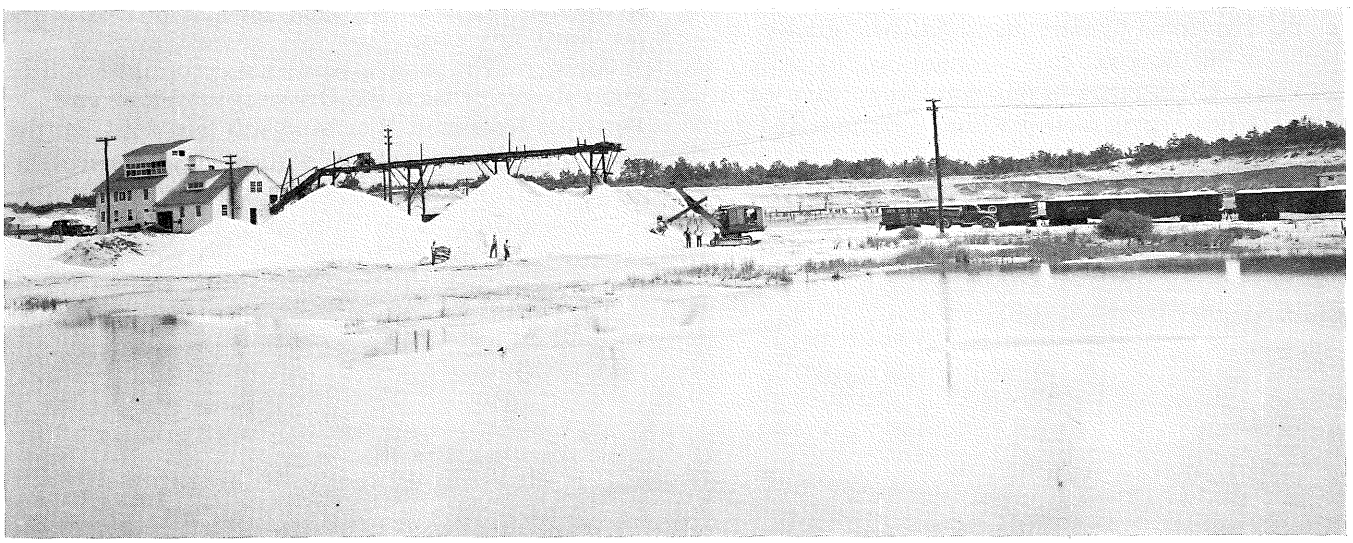


Fig. 2.12 — A southern New Jersey core sand preparation plant, showing stock piles and loading facilities

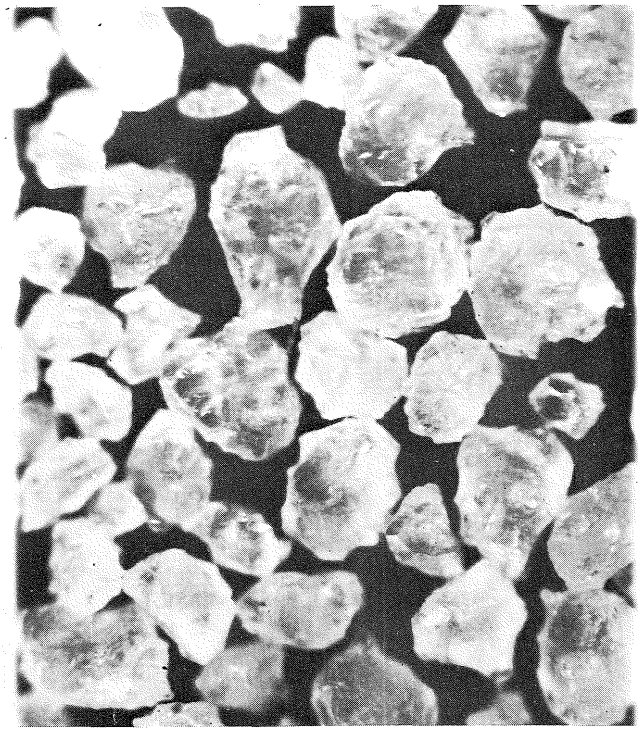


Fig. 2.13 — Subangular grains of Pennsylvania core sand.

Into this, the Delaware emptied in the vicinity of Trenton and there spread out a great plain of gravel and sand, washed down from the moraine at Belvidere.

Coincident with the submergence of the lower course of the Delaware, the lower courses of its tributaries were also submerged. Along them, flats of sand, gravel and loam were deposited.

Pennsylvania Core Sands

Silica sand for cores is found in the south central section of Pennsylvania, for example, in Huntingdon and Mifflin Counties, and also in the western end of the state.

Pennsylvania core sands are subangular in shape, as shown in Fig. 2.13. The crude sand contains a small percentage of clay which is washed from the sand in the processing.

Grades—While several grades of sand are available in Pennsylvania, fineness data on two grades are shown in Table 2.5.

Typical Uses—Pennsylvania core sands are used in cores for heavy gray iron machinery castings and for steel castings.

TABLE 2.5 — TYPICAL FINENESS TESTS OF TWO GRADES OF PENNSYLVANIA SILICA SAND

Sieve No.	Coarse Grade Percentage Retained	Fine Grade Percentage Retained
6	None	None
12	None	None
20	0.35	None
30	4.55	None
40	8.10	None
50	38.85	None
70	37.15	11.50
100	7.75	12.30
140	1.25	26.30
200	1.00	27.30
270	1.00	3.80
Pan	None	18.80
AFS Fineness No.	47.57	142.88
AFS Grain Class	6	2

General—The Pennsylvania silica sandstone deposits are soft enough in certain places to be mined with a steam shovel with no blasting. Figure 2.14 is an excellent illustration of the Oriskany sandstone formation.

The firmer sandstone is shot down with explosives. An illustration of this type of mining is shown in Fig. 2.15. A steam shovel is used to load trucks that deliver the broken rock to a grizzly or inclined screen made of steel rails. The over rigid pieces, larger than 2 in. diameter, go to a crusher, while the material that has passed the grizzly is delivered to grinding pans. The grinding pans consist of two large steel rolls revolving in a large steel pan. Water is fed to this unit and the ground materials escape through a screen. This material is then screened to size in electric vibrating or revolving screens.

The sand is then washed in a series of inclined, auger washers. In this type of washer, the sand elevates through a series of flights against a stream of water. This washing removes the clay material and reduces the ferric oxide content. A belt conveyor delivers the clean sand direct to railroad cars if it is to be shipped wet, and to a draining shed if the sand is to be dried.

If to be shipped dry, the sand is allowed to drain for at least half a day and then is dried in steamheated rooms or hoppers. The dried sand falls through the bottom of the hoppers and is classified further by screening. The dried, screened sand is shipped in paper lined box cars.

Geology—The sand in the south central section of Pennsylvania is from the Oriskany sandstone and the Pottsville formation. The sand was laid down on the bottom of a prehistoric sea with other sediments and

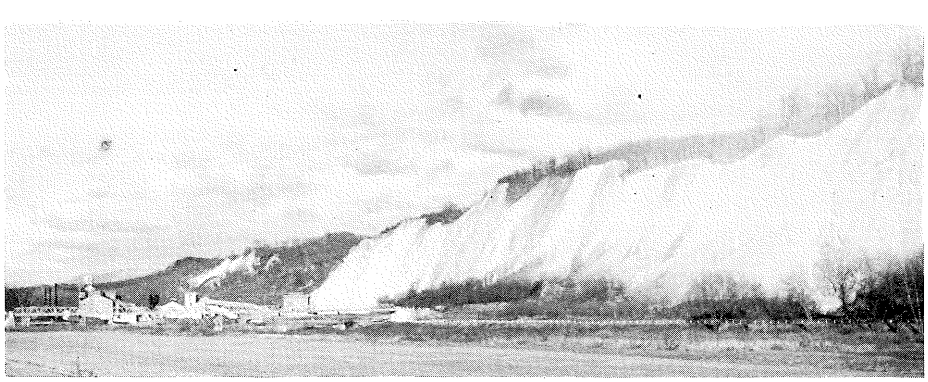


Fig. 2.14 — Pennsylvania core sand deposit near Mapletown, Pa. This deposit consists of white friable sandstone.



Fig. 2.15 — Oriskany sandstone formation near Huntingdon, Pa. These deposits require some blasting before the sand can be prepared for use.

became cemented into a sandstone. Due to intense folding of the formations, the beds now stand up at a 65 degree angle and the outcrops may be 200 ft high. In the western part of the state, for example, the Homewood formation occurs as flat lying beds.

Michigan and Indiana Core Sands

An abundant supply of excellent core sands for all types of gray iron, malleable and nonferrous castings is found in the states of Michigan and Indiana. These sands may be divided into two distinct types. The most abundant, and the type which is most used, is dune or lake sand which finds application for a wide variety of cores for malleable and gray iron castings. The other type of core sand, known commercially as "bank" sand, is used for cores for nonferrous castings. In smaller quantities it is used for increasing the



Fig. 2.16 — Bank sand mining in Michigan.

green bond strength of core mixtures for ferrous castings. Fineness and other properties of several dune and bank sands are shown in Tables 2.6 and 2.7.

The dune sand deposits are located along the southern shores of Lake Michigan in Indiana and on the eastern shores of the same lake in Michigan. The largest deposit of bank sand in Michigan is located in Tuscola County near the city of Vassar (Fig. 2.16) and a good deposit is found about 70 miles west of Logansport, Ind., at Lake Cicott.

An extensive deposit of core sand also is located at Port Crescent, Mich., on the northern portion of the "thumb" of the state. This sand has an AFS Fineness No. of about 50.

A considerable quantity of core sand lies under water, particularly in the Saginaw Bay region. Some years ago, a considerable amount of this sand was pumped by sand boats and sold to foundries in that area. This sand has a good range of grain fineness, however, it contains about 0.60 per cent lime, which some foundrymen feel is detrimental.

The dune sands are subangular and graded, within each deposit, to an extremely uniform size by the sorting action of the wind. The northernmost deposit of this sand, at Manistee, Mich., is the coarsest and has an AFS Fineness No. of 43. Sand in the dune deposits becomes finer progressively, the farther south the deposit. For example, at Gary, Ind., the sand has an AFS Fineness No. of 69.

Bank sands found in the northern part of Indiana have a grain structure very similar to the dune sands found in southern Michigan.

TABLE 2.6 — REPRESENTATIVE FINENESS TESTS OF MICHIGAN AND INDIANA DUNE SANDS

Sieve No.	Sand 1	Sand 2	Sand 3	Sand 4	Sand 5	Sand 6	Sand 7	Sand 8
	Percentage Retained							
6	None	None	None	None	None	None	None	None
12	None	None	None	None	None	None	None	0.1
20	None	None	None	None	None	None	0.2	0.3
30	0.3	0.4	0.1	0.1	0.1	1.0	5.8	8.5
40	1.3	2.5	1.5	2.3	1.7	5.8	41.6	54.7
50	2.0	7.0	17.5	26.5	24.5	34.2	48.2	33.7
70	17.7	28.1	54.3	50.5	60.8	49.1	4.0	2.7
100	66.7	55.2	24.9	18.7	12.7	7.7	None	None
140	11.3	6.4	1.1	1.3	0.1	1.5	None	None
200	0.1	None	0.1	0.1	None	0.5	None	None
270	0.1	None	0.1	0.1	None	None	None	None
Pan	None	None	0.2	0.1	None	None	None	None
AFS Clay, per cent	0.1	0.4	0.3	0.3	0.2	0.3	0.2	0.2
AFS Clay Class	A	A	A	A	A	A	A	A
AFS Fineness No.	69	62	54	52	50	48	45	43
AFS Grain Class	5	5	5	5	6	6	6	6
Base Permeability	110	115	150	155	195	215	260	270

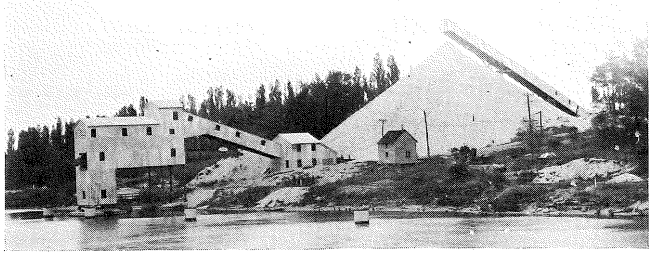


Fig. 2.17 — Sand storage piles and boat landing dock at Manistee, Mich.

Grades—A useful range of grades of core sand are available in the dune and bank sands of Michigan and Indiana. Table 2.6 shows representative fineness tests of several grades of dune sands, together with the AFS grain classification, AFS clay content, AFS Fineness No. and base permeability. Table 2.7 shows the same properties for bank sands. Table 2.8 shows the chemical analyses of two bank sands.

Typical Usès—Dune sands are used for a wide variety of cores in gray iron, malleable and nonferrous castings, while bank sand is used for cores for nonferrous castings. The latter core sand is also blended with coarser grade dune sands for the purpose of increasing the green bond strength of core mixtures.

General—Dune sand generally is mined by power shovel. The sand may be loaded directly into freight cars or on a belt conveyor which takes the sand to the storage piles. Figure 2.17 shows the sand being conveyed to a storage pile and also the layout for loading the sand either into cars or large lake boats for transport. Bank sands are mined and loaded either by hand or power shovel.

Geology—Deposits of dune sand, as the name indicates, are in the form of large dunes covered with little or no vegetation. The sand contained in the dunes of Michigan and Indiana occurred originally in glacier deposits. Later, it was loosened by wave action and was picked up by the wind and piled in large hills. The force of the wind is still moving these hills.

Bank sand deposits are undoubtedly also deposits of the glacial age and occur on the shores of glacial lakes. The thickness of bank sand deposits is only a few feet and often the overburden, which must be removed

TABLE 2.7 — REPRESENTATIVE FINENESS TESTS OF MICHIGAN BANK SAND

Sand No.	1	2	3	4	5
Sieve No.	Percentage Retained				
6	None	None	None	None	None
12	None	None	None	None	None
20	0.1	None	0.2	None	0.15
30	0.3	0.05	0.25	0.2	0.6
40	1.1	0.1	0.5	0.8	4.25
50	8.7	0.2	0.6	5.0	21.15
70	27.2	1.05	2.1	14.0	37.2
100	31.2	10.0	17.2	29.0	21.75
140	21.6	36.2	45.05	36.0	9.6
200	5.1	25.05	21.45	10.0	2.75
270	2.3	16.95	10.4	4.3	1.15
Pan	0.3	8.25	1.0	0.3	0.6
AFS Clay, per cent ..	2.1	2.15	1.25	0.7	0.8
AFS Clay Class	C	B	B	B	B
AFS Fineness No. ...	75	141	114	90	62
AFS Grain Class	4	2	3	4	5
Base Permeability ...	70	22	37	45	105

TABLE 2.8 — TYPICAL CHEMICAL ANALYSES OF TWO BANK SANDS

Sand No. (Table 2.6)	1	4
Silica (SiO_2), per cent	89.2	92.09
Alumina (Al_2O_3), per cent	5.31	6.09
Iron Oxide (Fe_2O_3), per cent	0.99	
Calcium Oxide (CaO), per cent	0.66	0.58
Magnesium Oxide (MgO), per cent	0.27	0.22
Alkalies, per cent	2.65	....
Ignition Loss, per cent	0.74	1.02
Fusion Point, F	2993	3100



Fig. 2.18 — Rockwood silica pit, Rockwood, Mich.

before the sand can be mined, equals the thickness of the sand deposits. Bank sands usually contain from 0.25 to 1.0 per cent clay.

Since the structure of northern Indiana bank sands is similar to dune sands found in the same location, it is assumed that these bank sands originated from the dune sands.

Lake and bank sands of Michigan do not possess sufficient refractoriness for extensive use in the steel foundry. A high quality silica sand is mined and processed at Rockwood, Michigan. This deposit of sand is covered with 15 to 20 ft of overburden which is stripped, uncovering a strata of some 20 ft of silica. A view of the pit is shown in Fig. 2.18.

This sand is thoroughly washed with water to remove a calcium coating yielding a pure sand having an analysis shown in Table 2.9.

TABLE 2.9 — TYPICAL CHEMICAL ANALYSIS OF MICHIGAN SILICA SANDS

	Per Cent
Silica (SiO_2)	98.63
Iron Oxide (Fe_2O_3)	0.02
Aluminum Oxide (Al_2O_3)	0.32
Titanium Oxide (TiO_2)	0.02
Calcium Oxide (CaO)	0.61
Magnesium Oxide (MgO)	0.40

The sand is dried and graded and, at present, core sands for the steel foundry are furnished in three grades having fineness shown in Table 2.10.

TABLE 2.10 — REPRESENTATIVE FINENESS TESTS OF MICHIGAN SILICA SANDS

No. 1 Sand		No. 2 Sand		No. 75 Sand	
Sieve No.	Per Cent Retained	Sieve No.	Per Cent Retained	Sieve No.	Per Cent Retained
40	2	40	3	50	2
50	24	50	43	75	16
70	28	70	32	100	55
100	28	100	17	140	24
140	16	140	4.5	200	2.5
200	2	200	0.5	270	0.5
270	0	270	0		

St. Peter Sandstone Formation

St. Peter sandstone, an extensive deposit of silica sand found in the central portion of the United States, is of the Ordovician Age. The extent of this deposit is best illustrated by the map shown in Fig. 2.19, as compiled by Dr. G. A. Thiel.* The average thickness of deposit is about 100 ft. The sandstone in Minnesota yields a sand of the finest grain, with Arkansas and Missouri next in fineness. The sand in Illinois is coarser. The sands mined in Wisconsin, Illinois, and Minnesota will be discussed separately. This sandstone formation is mined commercially only in a few localities, due to the great depths beneath the surface, except at Ottawa, Ill.

Core sands mined from the St. Peter sandstone formation are used widely by the foundry industry. In some instances, they are shipped great distances because of their excellent properties.

*"*Sedimentary and Petrographic Analysis of the St. Peter Sandstone*," Bulletin. Geological Society of America, Vol. 46, pp. 559-614 (1935).

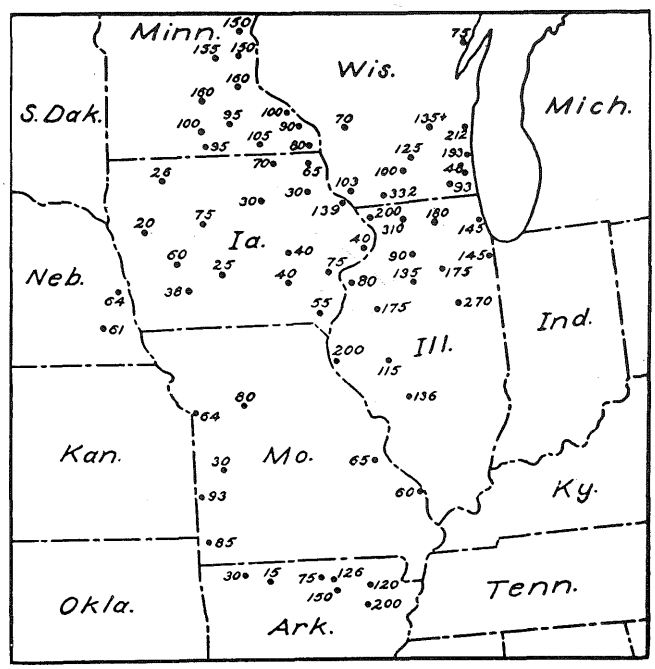


Fig. 2.19 — The St. Peter sandstone formation covers Illinois, Wisconsin, Minnesota, Iowa, Missouri and Arkansas. This illustration indicates the thickness in feet of the deposits in these areas.

Illinois Core Sands

Silica sand from Illinois is used widely as a core sand in both nonferrous and ferrous foundries. The largest deposits of core sand in Illinois are found in La Salle County, in the vicinity of Ottawa. Here the St. Peter sandstone formation occurs only a few feet beneath the surface.

This sand contains a high percentage of silica, as shown in Table 2.13, and the grains are rounded, as is illustrated in Fig. 2.20, except for the smaller grains which are subangular. As mined, the crude sand con-

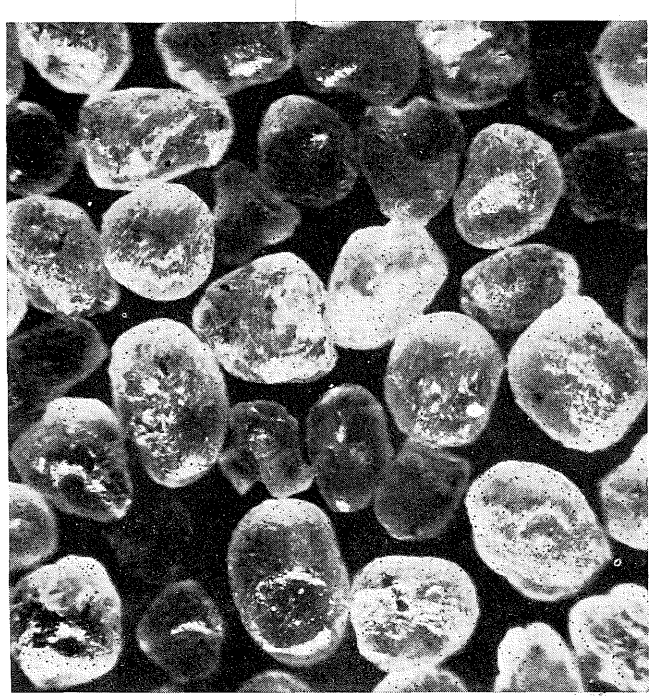


Fig. 2.20 — Round-grained Ottawa silica sand, 40 to 80 mesh, used extensively for cores.

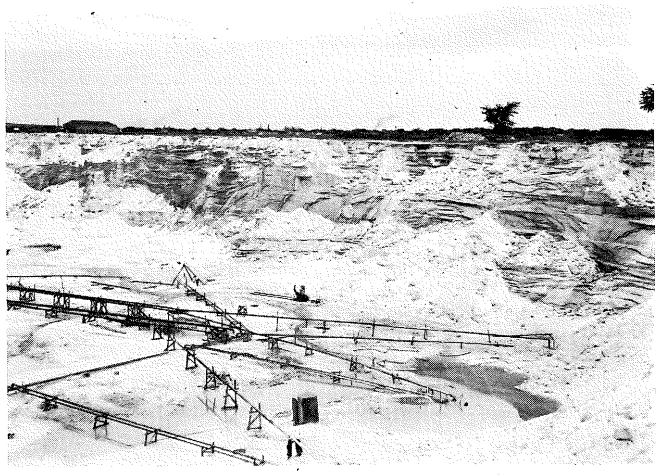


Fig. 2.21 — Pit of Ottawa Silica Co., Ottawa, Ill.

tains from 2 to 3 per cent clay substance, but this is removed, when necessary, by processing operations.

Grades—Ottawa silica sand is supplied in the crude, washed and dried grades. The crude sand, which contains the original clay bond, may be secured in a number of grades. Table 2.11 shows the fineness of coarse, medium and fine grades of Ottawa crude silica sand. The washed and dried sand may be obtained in a wide variety of grain finenesses of carefully graded distribution and of high purity. Representative examples of different grades of washed and dried Ottawa silica sand are shown in Table 2.12. Chemical analyses are shown in Table 2.13.

TABLE 2.11 — REPRESENTATIVE SIEVE TESTS OF FINE, MEDIUM AND COARSE GRADES OF CRUDE OTTAWA SILICA SAND*

Grade Sieve No.	Fine	Medium	Coarse
	Percentage Retained		
6	None	None	None
12	None	None	None
20	0.1	0.05	0.1
30	1.5	1.9	4.45
40	18.65	26.55	40.70
50	26.15	32.65	30.55
70	15.2	14.3	10.55
100	12.05	8.5	5.60
140	15.45	9.15	2.65
200	4.5	2.65	1.10
270	1.95	1.7	0.55
Pan	0.95	0.6	0.30
AFS Clay	3.1	2.0	3.15
AFS Clay Class	C	C	C
AFS Fineness No.	63	54	42
AFS Fineness Class	5	3	1
Base Permeability	37	118	253

*At least 10 different grades are available.

TABLE 2.12 — REPRESENTATIVE SIEVE TESTS OF WASHED AND DRIED OTTAWA SILICA SAND IN THE FINE, MEDIUM AND COARSE GRADES

Grade Sieve No.	Fine	Medium	Coarse
	Percentage Retained		
6	None	None	None
12	None	None	None
20	None	None	None
30	None	None	11
40	None	8	74
50	Trace	48	14
70	21	33	1
100	45	9	None
140	23	2	None
200	7	None	None
270	4	None	None
Pan	None	None	None
AFS Clay	0	None	None
AFS Clay Class	A	A	A
AFS Fineness No.	83	46.5	30.5
AFS Fineness Class	6	1	1
Base Permeability	42	230	650

TABLE 2.13 — TYPICAL CHEMICAL ANALYSES OF CRUDE AND WASHED AND DRIED OTTAWA SILICA SAND

	Crude	Washed and Dried
Silica (SiO_2), per cent	98.364	99.89
Alumina (Al_2O_3), per cent	0.376	0.04
Iron Oxide (Fe_2O_3), per cent	0.073	0.01
Calcium Oxide (CaO), per cent	0.264	0.02
Magnesium Oxide (MgO), per cent	0.297	0.04
Loss on Ignition, per cent	0.626	....
Fusion Point, F	3100	3100

Typical Uses—While used in many foundries, the greatest use for Ottawa silica sand is in cores for steel castings.

General—In mining, the overburden of dirt first is removed by power shovels and the exposed face is drilled and blasted. The loosened sand then is quarried hydraulically by high pressure water jets directed against the quarry face. This operation is illustrated in Fig. 2.21. In this same view may be seen the end of the pipeline which pumps the loosened sand and water into collecting pipelines which convey it to the washing and screening building. The sand, on entering the washing building, is further washed and

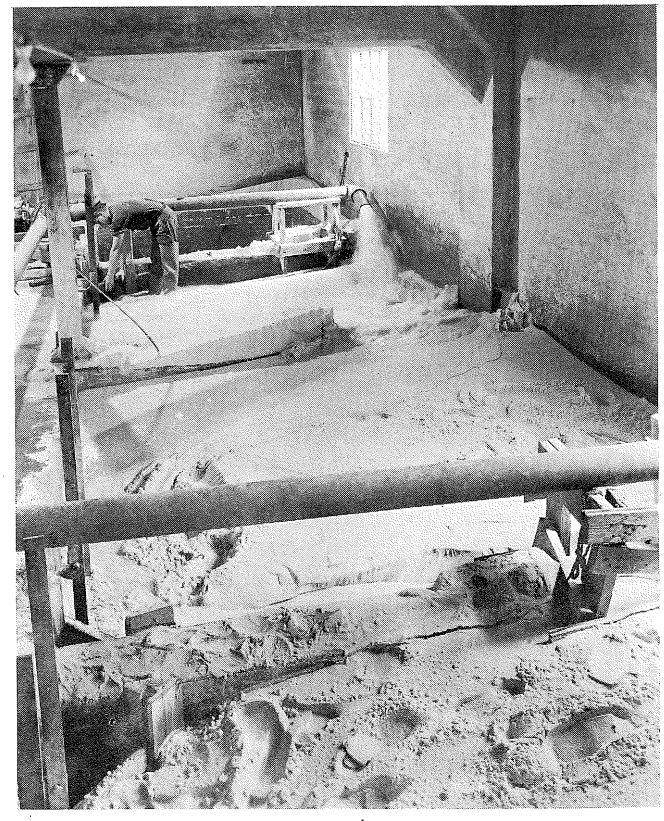


Fig. 2.22 — Ottawa sand being pumped into large bins for storage and draining.

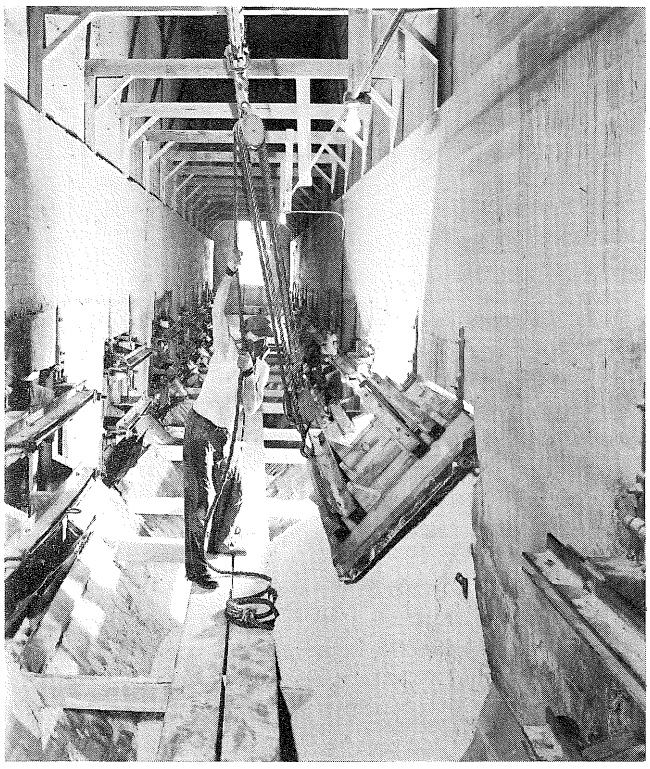


Fig. 2.23 — Dried core sand being released from storage bins for shipment.

pumped into large storage bins to drain (Fig. 2.22). The sand, being open in structure, allows the water and clay bond to drain through the bottom of the storage bins leaving clean silica sand. The sand then is conveyed to driers where it is dried over steam coils. Next operation is screening, where it is graded carefully. The screened sand is stored in bins, as illustrated in Fig. 2.23, from where it may be loaded into paper lined freight cars or trucks, or bagged for shipment.

Minnesota Core Sands

Core sand in Minnesota is obtained from a bed of St. Peter sandstone of nearly pure silica and uniform composition. The grain shape and appearance of the sand available in Minneapolis is shown in Fig. 2.24.

The construction of a series of sewer tunnels under Minneapolis and St. Paul resulted in approximately 600,000 cubic yards of this sand being piled as waste material for a period of five years prior to World War II. This sand was pumped hydraulically from the tunnels and is free from bond. Fineness data of this sand is shown in Table 2.14. This waste material was used for some time by Minnesota foundries for core sand.

Several local sand companies are quarrying this material from outcroppings of the deposits and selling it as a high grade core sand. It contains one-half to one per cent clay. The supply of both washed and unwashed core sand in this area is unlimited.

TABLE 2.14 — SCREEN ANALYSIS OF CORE SAND MINED AT MINNEAPOLIS

Sieve No.	Percentage Retained
6	None
12	None
20	None
30	0.2
40	5.4
50	32.8
70	21.3
100	16.3
140	18.0
200	5.9
270	0.1
Pan	None
AFS Clay	None
AFS Clay Class	A
AFS Fineness No.	63.30
AFS Fineness Class	5

Iowa Core Sands

The core sand deposits in Iowa are not as extensive as those found in its neighboring states, such as Wisconsin and Illinois. A deposit of silica dune sand 5 ft deep is located near Marshalltown and sand from this deposit is used by foundries of that city. This core

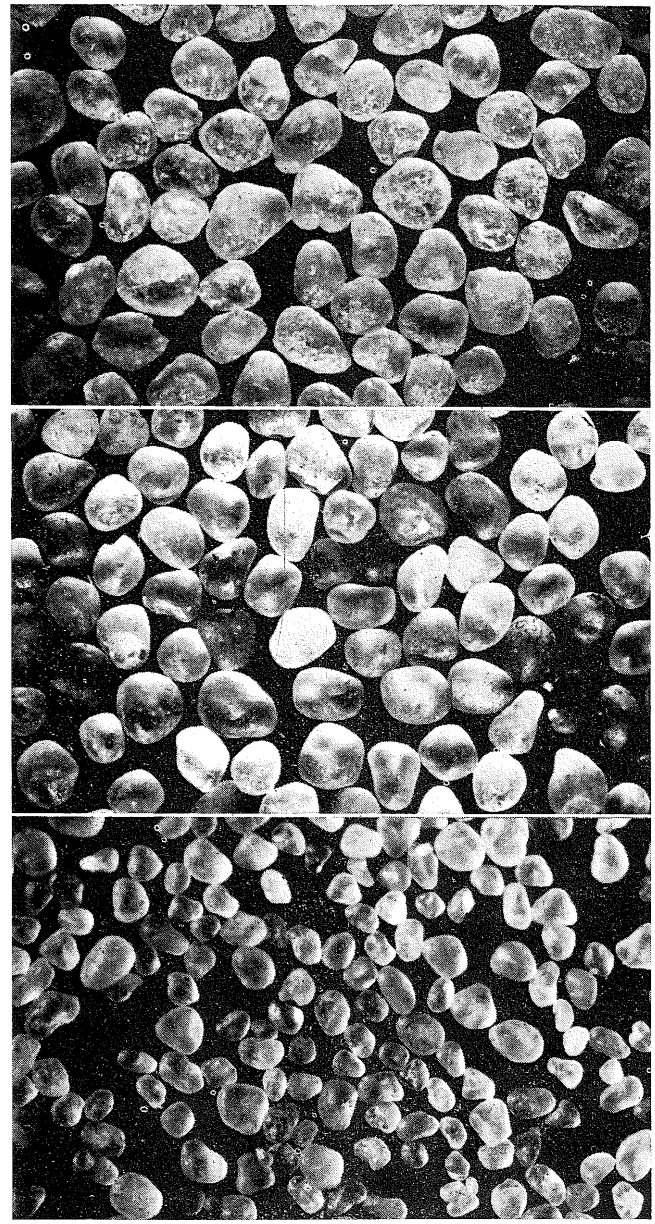


Fig. 2.24 — Shape of grains retained on the No. 40 (top), No. 70 (center), and No. 140 (bottom) screens in the fineness test of St. Peter sandstone mined at Minneapolis and St. Paul, Minn.



Fig. 2.25 — View of a core sand pit at Berlin, Wis. This pit has an 18 ft face.



Fig. 2.26 — View of Doylestown, Wis., core sand deposit showing 16 ft face of sand, stripping equipment and type of loading trucks used.



Fig. 2.27 — View of Portage, Wis., core sand deposit showing 20 ft bank with 3 ft overburden stripped off and the sand being loaded.



Fig. 2.28 — Another Portage deposit which is silica sand. The sand is taken to disintegrators from this pit and then screened for shipment.

sand contains 2.5 to 3 per cent clay with a majority of the sand grains being retained on the 70 and 100 mesh sieves.

A reddish silica sand deposit at Ottumwa supplies a coarse core sand with a fairly high clay content. This sand has a grain which is largely retained on the 70 and 100 mesh sieves. An outcropping of the St. Peter sandstone is quarried at Carlton.

Missouri Core Sands

The silica sands of Missouri are not used extensively in the foundry industry. As found in the natural state, these sands contain considerable fines. The sand, if processed by screening, washing and drying, could undoubtedly find considerable use in the foundry.

Two of the largest deposits that now are being worked for foundry consumption are located at Festus and Klondike. Some river sands from this state are also in use.

Outcrops of the St. Peter sandstone appear at Crystal City in the form of a 30 ft bluff and underground deposit which covers a large part of eastern Missouri. This light quality silica sand is mined at present largely for the glass industry both in surface and underground mines.

Wisconsin Core Sands

Wisconsin is favored with excellent core sand deposits. These deposits are of the bank sand type and are being used in nonferrous, gray iron and malleable iron foundries in a great variety of core work.

Three counties, Green Lake, Columbia and Eau Claire, produce about 90 per cent of the core sand mined in the state. Green Lake County has two main producing points, one just east of Berlin and the other near the town of Green Lake, both approximately 100 miles northwest of Milwaukee. Figure 2.25 shows a typical deposit at Berlin, Wis. Columbia County has three important producing centers, one at Doylestown and two near Portage, where both bank core sand and crude white silica sand are found. Views of these deposits are shown in Figs. 2.26, 2.27 and 2.28. Eau Claire County produces several coarse grades of core sand.

Grades—The Green Lake County Berlin area sands are of four distinct grades, ranging from 59 to 84 AFS Grain Fineness No., as shown in Table 2.15, while the deposits near the town of Green Lake run uniformly 73 to 75 AFS Grain Fineness, as indicated in the same table. Representative fineness data of both Doylestown and Portage deposits are shown in Table 2.16. Eau Claire County sands are shown in Table 2.17 in three grades.

Typical Uses—The Berlin area sands are used in both ferrous and nonferrous foundries. Sands No. 1 and 2, Table 2.15, are used for cores in brass, aluminum, gray iron and malleable foundries. Sands No. 3 and 4 are used in gray iron and malleable foundries. The Green Lake core sand shown in Table 2.15 also is used in brass, aluminum, gray iron and malleable shops. The Doylestown core sand shown in column 1, Table 2.16, is used in the same type of foundries as Berlin sands No. 1 and 2, while Portage core sand is used in the same type foundries as the Berlin sands No. 3 and 4. Portage screened silica sand, shown in

TABLE 2.15 — REPRESENTATIVE FINENESS DATA OF BERLIN AND GREEN LAKE CORE SANDS

Sieve No.	Berlin Percentage Retained 1	2	3	4	Green Lake
6	None	None	None	None	None
12	None	None	None	None	None
20	Trace	None	Trace	Trace	Trace
30	0.2	Trace	Trace	0.4	0.5
40	0.6	2.3	1.2	4.2	2.5
50	5.2	14.8	12.5	25.8	9.5
60	10.4	20.6	23.1	25.6	13.7
70	14.1	18.0	20.5	15.7	15.5
100	28.9	22.6	24.5	16.2	29.1
140	27.6	13.6	12.5	8.7	22.6
200	9.4	4.3	3.3	2.4	5.1
270	1.6	1.3	0.9	0.3	0.2
Pan	0.7	2.0	0.8	0.4	0.8
AFS Clay, per cent	1.3	0.5	0.7	0.3	0.5
AFS Clay Class	B	B	B	A	B
AFS Grain Fineness No.	83.33	72.11	68.14	59.25	74.08
AFS Fineness Class	4	4	5	5	4
Moisture, per cent	3.5	3.5	3.5	3.5	3.5
Permeability	80.0	135.0	145.0	165.0	110.0

TABLE 2.16 — REPRESENTATIVE FINENESS DATA OF DOYLESTOWN AND PORTAGE CORE AND SILICA SANDS

Sieve No.	Doylestown Percentage Retained	Portage	Screened Portage Silica
6	None	None	None
12	None	None	Trace
20	None	Trace	0.6
30	Trace	1.0	4.0
40	1.0	5.6	13.4
50	7.0	16.2	24.4
60	12.6	16.6	18.4
70	19.4	18.4	16.0
100	36.0	25.6	14.6
140	18.3	8.6	5.2
200	4.2	3.2	0.4
270	0.6	3.0	1.8
Pan	0.4	0.6	0 2
AFS Clay, per cent	0.5	1.2	1.0
AFS Clay Class	B	B	B
AFS Grain Fineness No.	72.63	66.3	54.1
AFS Fineness Class	4	5	5
Permeability ($3\frac{1}{2}$ per cent moisture)	120.0	155.0	200.0

TABLE 2.17 — REPRESENTATIVE FINENESS TESTS OF EAU CLAIRE WASHED AND SCREENED CORE SANDS

Sieve No.	Percentage Retained		
6	None	None	17.5
12	Trace	4.2	16.7
20	18.3	28.0	19.3
30	16.3	17.8	17.5
40	22.4	30.0	9.4
50	23.2	12.7	12.2
60	8.6	4.1	2.9
70	3.9	1.4	1.2
100	3.6	1.1	2.3
140	2.1	0.2	0.5
200	0.8	0.2	0.5
270	0.4	0.1	None
Pan	0.4	0.2	None
AFS Clay	None	None	None
AFS Grain Fineness No.	35.47	25.63	19.61
AFS Clay Class	A	A	A
AFS Fineness Class	7	8	9
Permeability (Dry)	290.0	380.0	460.0

Table 2.16, is used in gray iron, malleable and steel foundries for cores and in steel foundries for molding purposes. The Eau Claire sands are being used for large gray iron cores and as a filler core material.

General—Core sands produced in Green Lake County are generally mined by hand and shoveled into trucks which convey them to the drying and screening plants where the moisture, ranging from 5 to 15 per cent, is removed in oil-burning rotary driers, shown in Fig. 2.29. Following drying, the sand is screened to remove foreign matter before it is loaded into paper lined box cars or gondolas. The Berlin area sands occur in banks from 6 to 22 ft deep while the banks near the town of Green Lake vary from 15 to 20 ft deep.

The Doylestown and Portage banks are extensive, covering several hundred acres to a depth of 15 to 25 ft. At Portage, sand is loaded by crane equipment and at Doylestown the sand is trucked about one mile to the loading ramps.

The Portage silica deposit is a pure Cambrian sandstone formation with a 75 ft quarry face. The sand grains are loosely cemented together in the quarry rock and, after being blasted down, are easily crushed and screened. The Cambrian sandstone formation at Portage appears again in southern Wisconsin near Monroe and Browntown and extends into the Clayton, Iowa, district. At the above mentioned points, crude and washed silica core sands are being produced and, recently, dried silica sands have been marketed. These dried sands are screened to various grain sizes.

In the Eau Claire county deposits, the sand is brought from the mining operations to the washing plants by dragline, where it is washed in water separators and screened while wet. Plants are equipped with rotary driers and vibratory screens.

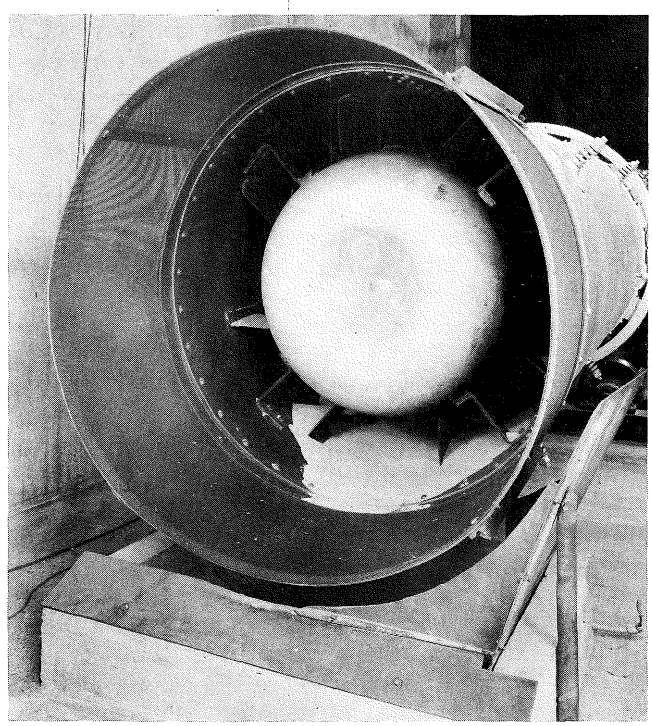


Fig. 2.29 — Core sand drier showing dried sand ready to pass through screens before being loaded into cars for shipment.

Although Wisconsin sand mining properties offer a wide selection of high grade, diversified core sands, it is possible that, with further careful prospecting, new deposits will be located and developed.

Geology—The core sands produced in the Green Lake County area occur in ridges formed from the old beach ridges of the ancient glacial Lake Oshkosh that thousands of years ago covered that entire area.

As previously noted, the Portage deposits are pure Cambrian sandstone, while the Eau Claire core sand comes from a lime free, red, quartzite deposit on high terraces above the Chippewa River near the city of Eau Claire.

The Columbia County deposits are outwash formations associated with glacial terminal morain deposits.

Ohio Core Sands

Ohio core sands are used extensively in gray iron, steel, malleable and nonferrous foundries. The main deposits for which Ohio is noted are sandstones which are mined in Portage County in northeastern Ohio and, to some extent, in Hocking, Fairfield and Muskingum counties in central Ohio. In the latter county there also exists some windblown sands with a natural bond content, and in northern Ohio, along the shores of Lake Erie, occur vast natural deposits of beach sands. In Ashtabula County, in northeastern Ohio, is located a slightly bonded sand which occupies a position somewhat between the windblown naturally-bonded sands of central Ohio and the beach sands along Lake Erie.

As discussed in the section on geology, the Ohio sandstones fall into one of six divisions. The sandstone formation which is quarried in Portage County has grains which are angular to subangular in shape, of a vitreous luster, and noticeably free from pitting and frosting. This sand is also quite free from iron oxide coloring and usually occurs as white to light buff. It contains nearly 100 per cent silica. Iron and alumina occur in minute quantities together with traces of heavy minerals. Calcium and magnesium carbonates are practically absent.

The sandstone mined in central Ohio is mined chiefly for steel molding. It has a higher iron and alumina content than the Portage County sand.

The windblown sand of central Ohio is used in gray iron and malleable foundries. These sands are fine grained and fairly uniform in texture with a high natural bond content.

The beach sands of northern Ohio, such as those found in the Sandusky district, are very fine with irregular grain and a notable amount of heavy mineral content.

The sand previously mentioned as being mined in Ashtabula County is slightly bonded and is used extensively in iron foundries. This is essentially a dune sand.

Grades—Core sands in Ohio, generally, are divided into two more or less distinct products both from the standpoint of use and production. The Conneaut and Sandusky sands are of an entirely different origin geologically. The other sources of core sand, as produced by the Ohio operators, are derived from sandstone which is disintegrated, washed and prepared.

At Geauga Lake, Ohio, core sand is obtainable

TABLE 2.18—TYPICAL FINENESS TESTS OF CORE SANDS AT GEAUGA DEPOSITS

Sieve No.	Per Cent Retained	Per Cent Retained
6	None	None
12	None	None
20	0.16	None
30	0.53	None
40	7.53	0.28
50	26.66	3.74
70	44.05	26.30
100	17.20	39.04
150	3.47	23.08
200	0.13	5.09
270	0.21	1.85
Pan	0.06	0.62
AFS Grain Fineness No.	51.36	77.82
AFS Fineness Class	5	4
Base Permeability	225	95

TABLE 2.19—TYPICAL CHEMICAL ANALYSIS OF GEAUGA DEPOSIT SANDS

Silica (SiO_2), per cent	99.47
Iron Oxide (Fe_2O_3), per cent	0.106
Aluminum Oxide (Al_2O_3), per cent	0.27
Titanium Oxide (TiO_2), per cent	0.050
Loss on ignition, per cent	0.19

ranging in AFS Grain Fineness from 45 to 80 and carrying a silica content of 99+ per cent. The shape of the grain is subangular to rounded. Typical screen analyses of the two grades being produced in this locality are shown in Table 2.18 with chemical analysis in Table 2.19.

At Phalanx, Ohio, sands ranging in AFS grain fineness from 25 to 60 are produced. Typical screen analy-

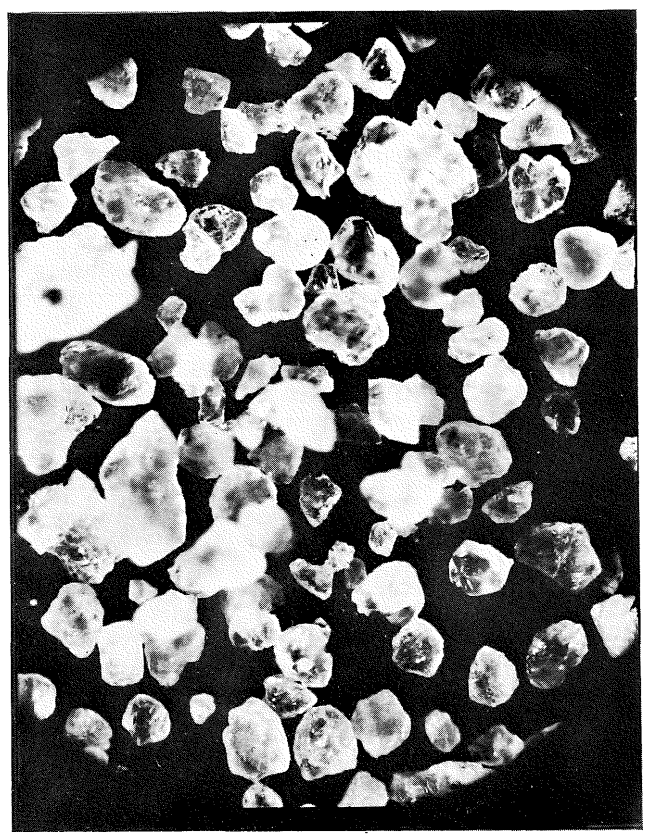


Fig. 2.30—Grains of sand produced at the Glassrock, Ohio, deposits.

ses of these sands are shown in Table 2.20 with chemical analysis in Table 2.21.

Core sand is also being produced at Glassrock, Ohio; however, this material is not classified to as high a degree as is necessary for certain types of core work. The grain structure of core sand mined in this location is shown in Fig. 2.30. This sand analyzes 99.5 per cent silica. It has an AFS Fineness No. of 53, as shown by the sieve analysis in Table 2.20.

Magnesium and armament industries have and are requiring a sand which conforms to rather strict specifications. For instance, in the case of the magnesium industry, it is necessary to add certain chemicals and inhibitors to prepare a sand which, with the addition of a very small amount of clay, will produce higher strengths and at the same time be permeable enough for their particular requirements; also, one that will produce a core that will have a very smooth surface. A series of grades of sand has been developed by one sand producer to answer the aforesaid requirements, by either blending or straight production methods.

The Conneaut (Ashtabula County) and Sandusky sands are used in gray iron and nonferrous foundries. The sands are very uniform and the production methods are efficient. Figure 2.31 shows a mining operation for naturally-bonded sand at Columbus, Ohio. Table 2.22 shows fineness data on two Sandusky and one Conneaut sand. Table 2.23 shows the chemical analysis of a Sandusky core sand.

General—Producers of Sharon conglomerate are not restricted by limitations of the various grain sizes, as are those who produce from the windblown or water washed Ohio core sands.

Before material of the latter type can be produced, about 6 in. of dirt must be stripped from the deposit. The top 2 ft of the deposit is somewhat more heavily bonded than the remainder of the sand. Usually, a complete cross-section of the pit is dug, so as to insure the uniformity of the operation. The sand is then hauled from pit to side track by truck and screened to remove the roots of any foreign material which might be in the sand. Ohio shippers of core sand equip their various plants with driers, enabling the shipping of a bone dry material, which is essential for thorough control of core sands.

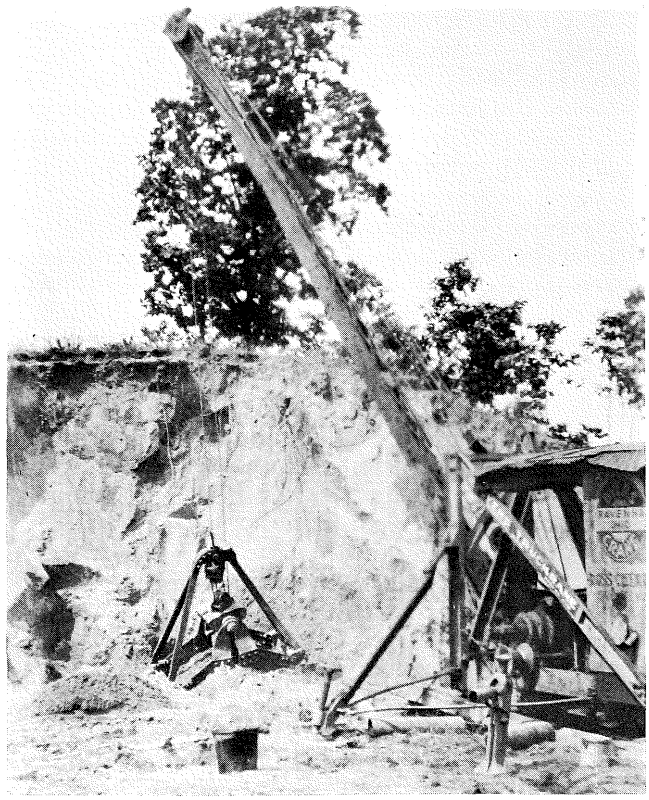


Fig. 2.31 — Mining operation for naturally-bonded sand at Columbus, Ohio.

TABLE 2.20 — TYPICAL FINENESS DATA ON CORE SANDS AT PHALANX AND GLASSROCK DEPOSITS

Sieve No.	Phalanx Per Cent Retained	Phalanx Per Cent Retained	Glassrock Per Cent Retained
6	None	None	None
12	None	None	None
20	2.75	None	None
30	21.54	0.1	0.1
40	44.51	2.2	2.5
50	22.58	11.2	10.5
70	6.51	46.5	34.3
100	1.69	29.2	24.6
150	None	9.1	16.3
200	None	1.5	8.9
270	None	0.1	2.3
Pan	0.50	0.1	0.5
AFS Fineness No.	31.87	60.55	53
AFS Fineness Class	7	3	5
Base Permeability	800	130	—

TABLE 2.21 — TYPICAL CHEMICAL ANALYSIS OF PHALANX DEPOSIT SANDS

Silica (SiO_2), per cent	98.75
Iron Oxide (Fe_2O_3), per cent	0.44
Aluminum Oxide (Al_2O_3), per cent	Trace
Calcium Oxide (CaO), per cent	0.20
Loss on ignition, per cent	0.18

TABLE 2.22 — TYPICAL FINENESS TESTS OF SANDUSKY AND CONNEAUT CORE SANDS

Sieve No.	Sandusky Per Cent Retained	Sandusky Per Cent Retained	Conneaut Per Cent Retained
6	None	None	None
12	None	None	None
20	None	None	None
30	None	0.1	None
40	0.2	0.2	0.1
50	1.0	0.6	2.0
70	6.2	4.8	5.6
100	35.2	53.0	33.7
140	43.8	20.1	45.4
200	7.8	16.4	8.5
270	1.0	1.4	1.9
Pan	1.2	1.3	1.1
AFS Clay Content, per cent	3.6	1.9	—
AFS Clay Class	C	B	
AFS Grain Fineness No.	91	90	—
AFS Fineness Class	4	4	
Permeabiliy	90	—	—
Moisture	3.0	—	—

TABLE 2.23 — TYPICAL CHEMICAL ANALYSIS OF A SANDUSKY CORE SAND

Silica (SiO_2), per cent	87.40
Iron Oxide (Fe_2O_3), per cent	2.49
Alumina (Al_2O_3), per cent	7.50
Lime (CaO), per cent	0.94
Magnesia (MgO), per cent	Trace
Loss on ignition, per cent	1.44

In the mining of sandstone deposits, the overburden usually is removed by scrapers and power shovels. The surface is finally broomed and cleaned by hand tools to avoid contamination with soil or other foreign matter. Blasting holes are drilled, hole spacing, hole size and drilling equipment varying with rock characteristics and the operator's preference. Blasting is for the purpose of breaking loose the rock and reducing it to fragments small enough to be loaded. Depending upon the hardness of the stone and size of crushing equipment, a secondary drilling and "shooting" is necessary to enable the larger blocks to be handled. Figure 2.32 shows a blasting operation at a Phalanx, Ohio, deposit.

The sand is transported by trucks or narrow gage dump cars to the processing plant where it is subjected to a series of crushing and disintegrating operations to effect the reduction to the ultimate grain size. This equipment consists of jaw and gyratory crushers, primary crushers, secondary rolls, the impact squirrel cage type of disintegrator, and wet and dry pans. Scrubbing, washing, grading, screening and classifying are accomplished by combinations of screw and drag washers, hydraulic classifiers, vibrating screens and settling tanks.

Variations in screen analysis of the quarry's raw material, and user's individual preferences with respect to grain fineness and grain distribution, necessitate constant laboratory supervision of operations during production. Grab samples are taken at frequent intervals and the screen analysis run. Variations from the desired standards are corrected by changes in size of screen openings and regulating feeds. In the case of washed silica sands, grading is accomplished by screen variations, adjustments of weirs, water velocity, pool areas, etc., in the hydraulic classifying type of equipment.

The sand is dried by means of both rotary and steam driers. Subsequent screening and scalping of coarse or fine end products permit further refinements in meeting exacting specifications. However, dried sand is subject to a greater degree of segregation in storing, loading and handling, and agitation in transit than is the case with the undried material. Care must be exercised by the user in proper mixing of the contents of a car, and unloading and handling to and from storage bins. Figure 2.33 shows the washing, drying and classification plant of a large Ohio core sand producer.

Geology—The relation of the various Ohio sandstones to one another, geologically, can be expressed by the following table:

SYSTEMIC DIVISONS	DIVISIONAL NAMES
Recent	Lake Shore sands Windblown sands
Pennsylvanian	Massillon sandstone Sharon conglomerate
Mississippian	Black hand formation
Devonian	Sylvania sandstone

The columns are given in ascending order with reference to the age and stratigraphic position, those at the bottom being older and normally overlaid by those above them. It must not be assumed that the entire sequence is present at any one locality, as this is rarely, if ever, the case.

The above columns do not attempt to set forth all recognizable sandstones to be found in the field. There are many others, some outcropping and others reached only by drilling.

Beginning with the oldest, hence the lowermost, the Sylvania is not actively quarried at present. In general, its high calcium and magnesium content makes it undesirable for use as a core sand.

Next in ascending order is the Black hand formation, known as the "Big Injun" sand to the oil drilling fraternity. It outcrops along a broad belt through Hocking, Fairfield and Muskingum counties in central Ohio, and its occurrence has been noted elsewhere. In general, this formation is not mined for core sand.

The Sharon conglomerate of Pennsylvanian Age occupies a unique stratigraphic position, occurring as it does at the very base of a vast system of strata. It is the lowermost member of the Pottsville series of formations and the first sedimentary material to be laid down on the ancient and well-worn Mississippian surface when those lands were submerged.

The Massillon sandstone, another but younger member of the Pennsylvanian series, occurs next and exhibits a great many of the physical characteristics of the Sharon conglomerate. However, as produced in central Ohio, it is not used for cores.



Fig. 2.32 — Shooting a blast at a Phalanx, Ohio, core sand deposit.

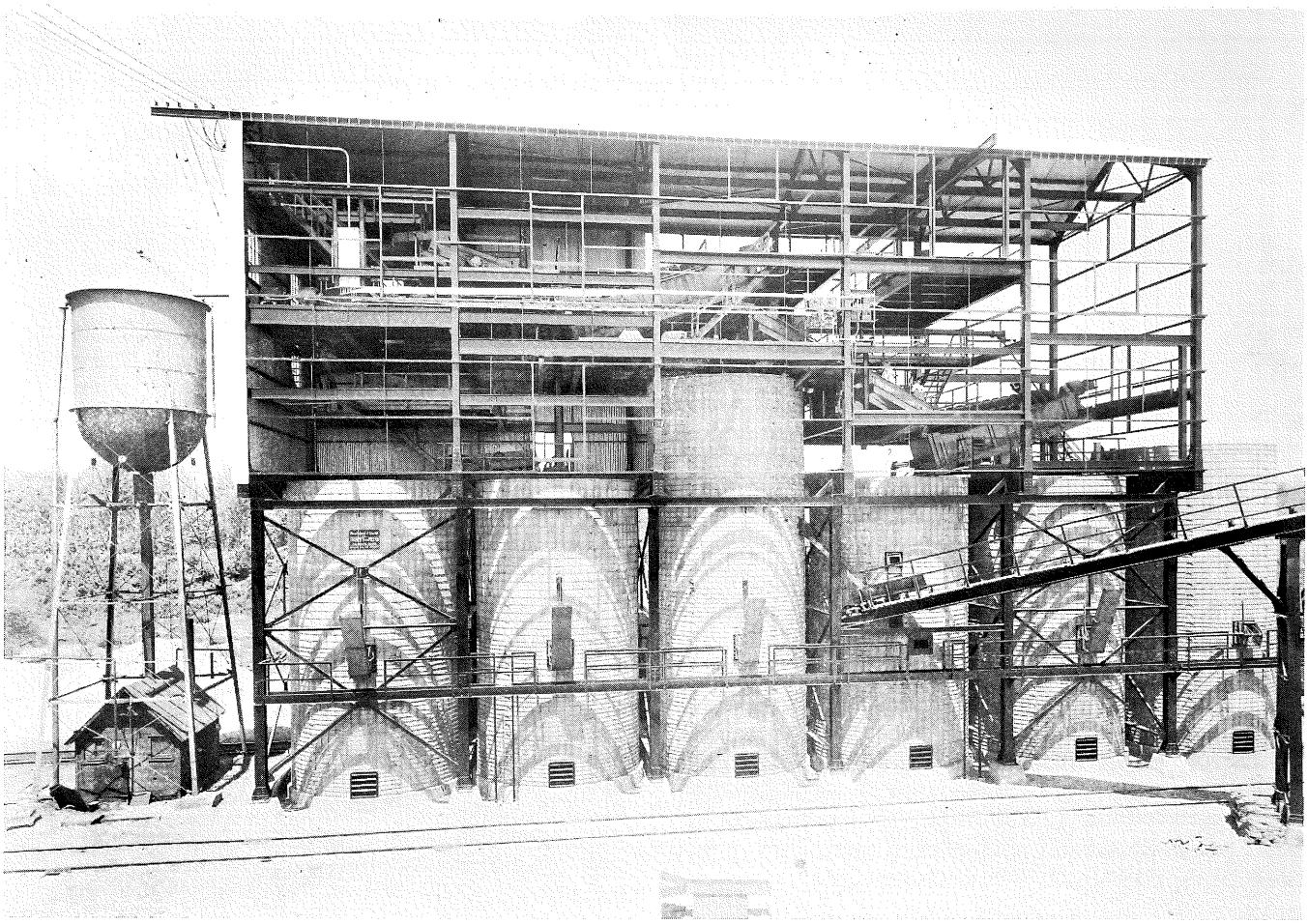


Fig. 2.33 — View of washing plant of a large Ohio core sand producer.

As previously stated, the naturally-bonded sands in central Ohio occur as deposits of loess or consolidated windblown sands.

The beach sands of northern Ohio, in general, were formed in much the same manner as the beach sands of other districts as described elsewhere in this volume.

The dune sands of Ashtabula County are partly wind deposited and partly water worked, or at least directly derived from ancient beach deposits.

Alabama, Tennessee, Georgia, Arkansas, Texas and Utah Core Sands

Core sands of the Southeastern States fall into three classes: (1) those suitable for swept cores, such as used in soil pipe shops; (2) the unwashed or bank core sands, which to a great extent are used with dry binders; and (3) those washed sands considered suitable for oil-sand cores.

Alabama

In Alabama, there are several locations from which pipe core sand may be obtained, such as Cook Springs, Round Mountain, and Gadsden. These are clay-bearing sands, similar to the molding sands produced for soil pipe molding at the same points, but carry a lower clay content, adapting them to the sweeping processes.

A typical analysis of the core sand mined at Gadsden, Ala., is shown in Table 2.24, Column 1, and the fineness of the sand mined at Round Mountain, Ala., is shown in Column 2 of the same table. The latter sand is used for pipe cores.

These sands usually are produced crude and the principal preparation consists of passing them through a pair of rollers to reduce clods. These sands are of the sedimentary type.

Tennessee

Certain sand producers of Tennessee and Georgia cater principally to the building trade. However, they furnish sand to the foundry for use as core sand. The type of sand mined at Saulsbury, Tenn., falls into this group. The fineness data on this sand are shown in Column 3, Table 2.24. The clay content of this sand is of sufficient amount to be classed as a molding sand. However, it finds use as a core sand with dry binders and for cores made by the sweeping process.

Georgia

At Albany, Ga., unwashed sand containing very low clay content is produced. The screen analysis of this sand is shown in Table 2.24, Column 4.

In the above group of sands, one may secure both unwashed and washed core sand. The sand mined at Junction City, Ga., whose average fineness is shown in Table 2.24, column 5, is shipped both unwashed and washed, suitable for cores for gray iron foundries.

Two types of core sand are produced at Howard, Ga., as shown in Column 1 and 2, Table 2.25. The sand in Column 2 is secured from the Tuscaloosa for-

TABLE 2.24—TYPICAL SIEVE ANALYSES OF SOUTHERN CORE SANDS

Sieve No*	1	2	3	4	5
	Percentage Retained				
	Alabama		Tennessee	Georgia	
6	None	None	None	None	None
12	None	None	None	None	None
20	None	None	0.6	1.8	6.0
28	None	None	3.4	8.6	12.6
35	0.2	0.4	9.4	25.0	21.0
48	2.4	4.0	15.2	35.0	23.4
65	10.6	15.0	26.4	22.4	14.0
100	20.8	23.4	20.4	6.0	18.2
150	14.8	12.2	6.2	1.0%	4.8%
200	11.0	8.0	3.0	passes	passes
270	7.0	5.4	1.0	100 mesh	100 mesh
Pan	15.6	9.2	5.8		
AFS Clay per cent	17.6	20.4	2 to 8.2	—	—
AFS Clay Class†	F	G	C to D	A	A
AFS Fineness No.†	135.4	108.7	70.5	36.8	40.5
AFS Fineness Class†	3	3	4	7	6

*Tyler Standard. †Average.

mation. These sands are produced as washed or unwashed and shipped in the damp state, principally in open cars.

Georgia is the southern source of high grade silica sands for cores. These sands are graded to specification and shipped dry in paper lined box cars. Two typical representatives of this group are the Sewanee and Ochlochnee silica sands. These sands are of high purity and are produced in a multiplicity of grain sizes so that they meet the requirements of steel, gray iron, white iron and nonferrous foundries.

Ochlochnee Silica Sand—The Ochlochnee silica sand is produced at Thomasville, Ga. Its grain is white, tending to be transparent, and of subangular shape. The size varies from gravel as large as one-half inch in diameter, to a very small amount of material as fine as 150 mesh.

Grades—Table 2.25, Columns 3 and 4, show typical fineness data on two grades of Ochlochnee core sand, a fine and a coarse grade, respectively.

General—The wide range of particle sizes in this deposit permits a variety of production seldom encountered in any single deposit. The method of mining is by dredges, equipped with Diesel engine powered centrifugal pumps operating on large diameter pipelines. Overburden is removed by draglines. Barges are floated on cuts or canals watered by natural seepage plus a connection to the Ochlochnee River, which flows through this deposit. The sand goes through the pipelines to a preliminary land plant. There it is screened to remove foreign matter, washed again, and loaded on gondolas to drain and be transported to the main plant, where it goes into stock piles. All sand is dried through steam coil driers and then screened into a number of products. It is not uncommon for the iron content in sand of this grade to run as low as 0.015 per cent.

Geology—This deposit consists of some thousand acres and belongs to a Pleistocene formation, known as Sunderland.

Sewanee Silica Sands—The extent of the Sewanee silica sand deposit is about 70 acres, but in some places approximates 180 ft in depth. The grains are subangular in shape and translucent in appearance.

Grades—The usual range of fineness of the Sewanee silica sand is shown in Table 2.25, Columns 5 and 6. Column 5 is the coarse grade and Column 6 is the fine.

Typical uses—These silica sands are used for cores in iron and steel foundries.

General—In mining, the overburden is removed with a clamshell or dragline and the sand then is dy-

TABLE 2.25—TYPICAL FINENESS TESTS OF GEORGIA SILICA SANDS

Sieve No.*	1	2	3	4	5	6
	Percentage Retained					
6	None	None	None	None	None	None
10	0.6	None	None	None	None	None
20	4.5	None	None	None	None	None
28	—	1.2	None	0.9	1.2	None
35	8.0	4.7	None	21.9	11.8	None
48	15.2	14.6	0.2	34.7	29.2	3.8
65	46.5	29.6	8.4	22.8	38.4	36.4
100	18.1	28.2	25.4	14.1	16.0	44.8
150	6.6%	14.4	26.0	5.6	3.4%	15%
200	passes	6.1	27.2	—	passes	passes
270	100	0.9	8.2	—	100	100
Pan	mesh	0.5	4.6	—	mesh	mesh
AFS Fineness No.†	50	66.05	117	44	46	63
AFS Clay Class†	5	5	3	6	6	5
AFS Fineness Class†	A	A	A	A	A	A

*Tyler Standard. †Average.

TABLE 2.26 — ANALYSIS OF REPRESENTATIVE TEXAS CORE SANDS

Fineness Mesh	Shipping Point						
	Seth		Fleming Spur		Teague		
6	—	—	—	—	—	—	—
12	—	—	—	1.0	2.4	—	—
20	—	5.4	—	5.8	14.4	—	—
30	2.6	11.6	0.2	6.2	20.6	1.0	1.6
40	9.8	23.6	1.2	12.0	18.8	13.8	10.4
50	35.2	33.8	9.8	23.4	20.0	23.8	17.4
70	33.8	20.4	28.8	27.0	14.0	32.4	26.4
100	13.6	4.6	35.0	15.0	6.6	20.0	21.6
140	3.4	0.4	18.0	5.4	2.6	6.6	12.0
200	1.2	0.2	5.8	2.2	0.6	1.8	5.8
270	0.2	—	0.8	0.6	—	—	—
Pan	0.2	—	0.4	1.4	0	0.6	4.8
Fineness No.	50	37	71	53	34	54	73
Sintering point, F	2975	2890	3000				
Base permeability	121	202	50				

namited to break up the boulder formation. By means of a clamshell, it is then dumped into a hopper from which it is fed to a coarse vibrating screen. At this screen, all material coarser than about ¼-in. in diameter is removed.

Rubber lined centrifugal pumps, water sealed, then pick up the sand and send it to the top of the plant where it is coned and wet screened into storage tanks. Different tanks contain different grain sizes. Each tank carries approximately 400 tons of sand, and is equipped with automatic feed valves operating onto an endless belt, so that any variation of any amount from one or more tanks may be fed. The belt feeds the drier, which is of the steam coil type. From the drier, the sand goes to surge tanks where it is fed into cars for shipment, but each surge hopper is equipped with vibrating screens in order that, just before going into the car, the sand may be "topped" as well as "bottomed" to further insure accuracy of specifications.

Geology—The formation, from which the Sewanee silica sand is produced, is known as the Sewanee conglomerate. The Sewanee conglomerate is a semiconsolidated formation in which the particles of sand occur in a very light clay matrix of slightly yellow color. In the banks, the sand appears to be a white sandstone, of varying grain sizes ranging from about ½-in. in diameter to a small amount passing 150 mesh.

Arkansas Core Sands

Silica sand of good quality is present in deposits of sufficient size to warrant installations for loading, grading and shipping core sands to the foundry industry of that and adjoining states. However, little activity in that direction is being taken at present.

Texas Core Sands

A good supply of clean rounded grain silica sand is available in the state of Texas. These sharp sands are well suited for all types of cores. They are relatively free of clay and do not absorb an excessive amount of core oil. The majority of the core sand deposits are located in the southeastern portion of the state. See Table 2.26.

Utah Core Sands

The state of Utah contains a number of sand deposits, the material from which is suitable for core sands and is used by foundries located in that state. The core sand at present produced in Utah all contains a small percentage of clay, from 0.6 to 4.6 per cent.

Chemical Analysis			
Loss on ignition, %	0.22	0.14	0.34
Silica, %	98.59	99.15	97.79
Iron oxide, %	0.30	0.19	0.31
Alumina, %	0.52	0.35	1.01
Titanium oxide, %	0.08	0.05	0.10
Calcium oxide, %	0.05	0.07	0.10
Magnesium oxide, %	0.02	0.03	0.08
Undetermined balance, %	0.22	0.02	0.27

TABLE 2.27 — TYPICAL FINENESS DATA OF UTAH CORE SANDS

Sieve No.	1	2	3	4	5
	Percentage Retained				
6	None	None	None	None	0.1
12	3.7	None	None	None	0.2
20	17.5	1.0	0.1	None	1.3
30	20.8	11.8	0.4	2.2	3.4
40	21.9	23.1	2.0	9.2	13.0
50	18.0	30.9	10.1	33.1	28.4
70	11.6	23.4	32.8	37.1	27.8
100	4.6	6.6	44.4	9.6	14.1
140	0.8	1.4	5.7	2.2	5.4
200	0.2	0.6	1.5	0.8	3.1
270	0.1	0.1	0.2	0.6	0.7
Pan	0.2	0.5	0.8	0.6	0.8
AFS Clay, per cent	0.6	0.6	2.0	4.6	1.7
AFS Clay Class	B	B	C	C	B
AFS Fineness No.	31	42	64	50	54
AFS Fineness Clay	7	6	5	5	5

Grades—The AFS Fineness No. of sands produced ranges from 31 to 64. Test data covering core sands of Utah, located at Sand Pit (Column 1), Vawdrey Salt Creek Canyon (Column 2), Coalville (Column 3), Thistle (Column 4), Ogden (Column 5) are shown in Table 2.27 in the order named.

Typical Uses—Utah sands are suitable for use in steel, gray iron and white iron foundries.

Nevada Core Sands

Sands suitable for use in cores are mined in Nevada in the southern section of the state. The deposits are in the general vicinity of Las Vegas near Amber, Arden, Jean and Overton. The deposits are of two types: (1) bedded sandstones of marine origin and (2) dune sands which are derived largely from sandstones that

were originally wind deposited and have since become consolidated. The dune sands of this area are not graded and their AFS Grain Fineness No. varies from 55 to 75, those in the uplands being usually coarser than those found at lower levels.

Geology of the Area—The bedded sandstones are of Permian, Jurassic and Cretaceous ages. The second is normally of a reddish color but in places the iron oxide has been removed by underground circulating waters of subterranean origin. It is these bleached patches which are worked.

After the deposition and consolidation of these beds, the sea bottom was uplifted and wearing down of the Jurassic formations gave material which was washed into the ancient sea and redeposited during the Cretaceous times. In this process, the iron oxide was removed from the sand grains so that these Cretaceous sandstones are now nearly or completely white.

Still thousands of years later when these formations were again lifted up above sea level to dry land, the weather disintegrated some of them to form loose sand which was gathered together by the wind to form sand dunes.

Dune Sand Deposits—Dune sands for cores are mined in two locations: (1) at the north end of the Valley of Fire and (2) near Overton.

Nevada Silica Sandstones—Nevada silica sands are produced from the sandstone formations which are found near Overton, Arden and Jean. A sandstone deposit suitable for core sand also exists at Dawson and is said to be of considerable extent. Sands produced from the Nevada sandstone formations have subrounded grains and may be obtained either in the washed or crude conditions.

Amber Core Sand

The sand mined in the Valley of Fire by one producer comes from dunes 10 to 50 ft in height and is red in color. It is screened to remove the coarse material but is not graded. Sands from this location are known variously as Red Gorge, Fire Valley and No. 80.

Grades—The typical sieve analysis of a dune sand from the Fire Valley deposits is shown in Table 2.28, Column 1. A typical chemical analysis of this sand is given in Table 2.29.



Fig. 2.34 — Quarry of Nevada silica sand, three miles north of Overton, Nev.

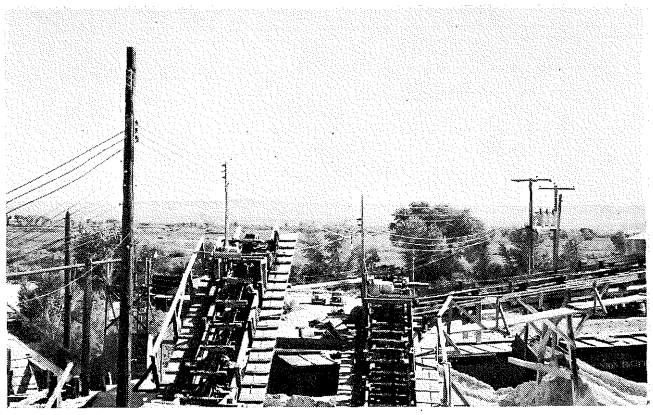


Fig. 2.35 — Washing plant at Overton, Nev.

Typical Uses—This core sand is used in gray iron, malleable and nonferrous foundries.

General—The sand is loaded by hand into trucks, hauled to the railroad siding and dumped into cars.

Geology—These dune deposits are the result of disintegration of sandstones. The wind picked up the sand grains and carried them to their present location, forming dunes.

Overton Dune Sands

The Overton dune sands are pinkish in color and somewhat finer than the Fire Valley sands. The dunes,

TABLE 2.28 — TYPICAL FINENESS TESTS OF NEVADA DUNE CORE SANDS

Sieve No.	Fire Valley Percentage	Nevada Pink Retained
6	None	None
12	None	None
20	None	None
30	None	None
40	3.2	2.0
50	12.8	26.8
70	25.2	38.6
100	23.0	19.9
140	28.6	11.1
200	6.6	1.4
270	0.3	0.1
Pan	0.3	0.1
Base Permeability	—	135
AFS Fineness No.	73	58
AFS Fineness Class	4	5

TABLE 2.29 — TYPICAL CHEMICAL ANALYSIS OF FIRE VALLEY CORE SAND

Silica (SiO_2), per cent	95.40
Iron Oxide (Fe_2O_3), per cent	0.18
Alumina (Al_2O_3), per cent	1.34
Lime (CaO), per cent	0.14
Magnesia (MgO), per cent	0.61
Alkalies, per cent	1.81
Ignition loss, per cent	0.47

TABLE 2.30 — TYPICAL CHEMICAL ANALYSIS OF OVERTON DUNE CORE SAND

Silica (SiO_2), per cent	96.50
Alumina (Al_2O_3), per cent	1.36
Iron Oxide (Fe_2O_3), per cent	0.29
Lime (CaO), per cent	0.60
Alkalies, plus ignition loss, per cent	1.25

TABLE 2.31 — TYPICAL SIEVE TESTS OF NEVADA WASHED SILICA CORE SANDS

Sieve No.	Overton		Arden				Jean	
	Percentage Retained							
6	None	None	None	None	None	None	None	None
12	None	None	None	None	None	None	None	None
20	None	None	None	None	1.78	0.36	0.3	0.81
30	None	0.2	0.3	2.3	5.57	1.30	1.5	1.75
40	None	5.3	7.6	64.8	43.77	55.91	4.0	5.86
50	1.10	15.9	19.4	14.1	34.52	34.75	25.4	56.16
70	5.70	26.9	42.0	5.4	4.32	4.93	35.5	23.37
100	24.30	26.7	18.7	4.8	3.16	1.54	15.2	5.83
140	48.80	21.9	10.2	3.0	3.55	0.69	13.4	3.36
200	13.60	2.5	1.5	2.0	1.74	0.02	2.8	1.30
270	3.20	0.3	0.3	0.6	0.53	None	0.6	0.41
Pan	2.80	0.2	Trace	0.1	1.12	0.42	1.1	0.54
AFS Fineness No.	106	66.7	58	39	43	36	62	49
AFS Fineness Class	3	5	5	7	6	7	5	6
Base Permeability	—	—	130	—			—	

from which these sands are mined, are of about the same size as the Fire Valley dunes. Mining and a view of a washing plant are illustrated in Figs. 2.34 and 2.35.

Grades—Typical sieve analysis of the dune sand mined near Overton is shown in Column 2, Table 2.28. A typical chemical analysis of Overton dune sand is given in Table 2.30.

Typical Uses—The Overton dune sand is used for gray iron, malleable iron and nonferrous foundry cores.

General—This sand is loaded into trucks by hand and hauled to the railroad siding where it is dumped into cars.

Geology—The geology of these dunes is much the same as that of the Fire Valley dunes.

Overton Silica Sand

Silica sands obtained from the Overton deposit are angular to subangular in grain shape and contain a rather high percentage of fines. The sand is mined and washed for glass manufacture and is used in foundries in the crude state, although washed sands also are available.

Grades—Table 2.31 shows two grades of washed silica sands mined in the Overton deposit. The fine sand is exemplified by that shown in Column 1. This grade contains a trace of lime. The sand shown in Column 2 is of a coarser variety and typifies the fineness of sands used in glass manufacture.

Typical Uses—The sand shown in Column 1, Table 2.31, is used for cores in magnesium, aluminum, brass, gray and white iron foundries. The sand shown in Column 2, Table 2.31, is used in cores for gray iron castings, although the quality of this sand appears to be suitable for steel castings. Table 2.32 shows a typical chemical analysis of these sands.

General—The washed sands from the Overton deposit are used by glass manufacturers while the crude sand is produced primarily for foundries. The sands are mined from open pits, some 75 ft in depth and 300 to 500 ft across. The sand is covered with an overburden of 5 to 10 ft in depth. The blasted sandstone usually is removed from the pit by trucks and hauled some 5 miles to the processing plants where it is crushed, washed, screened and hydraulically graded into the classes shown in Table 2.31.

Geology—The sandstones mined north of Overton are of the Jurassic Age and represent one of the bleached masses of sandstone to which previous reference has been made.

TABLE 2.32 — TYPICAL CHEMICAL ANALYSIS OF WASHED OVERTON SILICA SANDS

Silica (SiO_2), per cent	99.15
Alumina (Al_2O_3), per cent	0.51
Iron Oxide (Fe_2O_3), per cent	0.08

TABLE 2.33 — TYPICAL CHEMICAL ANALYSIS OF JEAN CORE SAND

Silica (SiO_2), per cent	98.72
Alumina (Al_2O_3), per cent	0.63
Iron Oxide (Fe_2O_3), per cent	0.15
Lime (CaO), per cent	0.04
Magnesia (MgO), per cent	0.09
Alkalies, per cent	0.05
Ignition loss, per cent	0.36

Arden Silica Sand

The sandstone quarried at Arden is overlaid by limestone beds and the lime carbonate has been carried downward in solution and deposited in the joint planes of the sandstone. The effect of lime in foundry and core sands is a debatable question at present but lime is looked on by foundrymen with suspicion. As a result, steps have been taken to remove any possible lime from Arden core sands.

Grades—Typical screen analyses of Arden core sands are shown in Columns 3, 4, 5 and 6, Table 2.31.

Typical Uses—Arden core sand is used in nonferrous, gray and white iron foundries.

General—These sands are mined from a location on the mountainside. Following blasting, the stone is crushed and screened. This sand is somewhat coarser than that mined in the Overton district.

Geology—The Arden core sand is mined from a Jurassic sandstone deposit whose formation has been previously described.

Jean Core Sand

Like the Arden deposit, the Jean core sands are mined from a hillside formation and are coarser than the Overton product.

Grades—Typical sieve analyses of core sands mined

at Jean are shown in Columns 7 and 8, Table 2.31. Typical chemical analysis of this core sand is given in Table 2.33.

Typical uses—This sand is used for cores in steel foundries.

General—The sandstone deposit is blasted from a hillside formation and then is crushed and screened in the dry condition to separate the coarse material from the sand. In crushing, all the cemented sand grains are not torn apart, thus leaving substantially one half of the grains retained above the 50 mesh sieve as compound grains. The sand is shipped in open cars and is dry except for rain which may fall on the open cars during transit.

Geology—This formation is a massive bedded sandstone of the Permian Age.

California Core Sands

Silica sand for cores is not too plentiful in California. While this state has extensive sandstone deposits, the sand from which might be used for core sands, the majority contain a variable and sometimes an appreciable amount of feldspar, which makes their preparation for foundry work either impossible or expensive, because the feldspar must be removed.

However, silica, beach and dune sands are mined for foundries in this state and are used for cores in steel, gray iron, malleable and nonferrous castings, although a considerable tonnage of silica sand for cores is brought into the state from other sources.

Monterey Peninsula Sands

One of the largest deposits of silica sand for cores is located on the Monterey Peninsula at Del Monte, about 125 miles from San Francisco and about 300 miles from Los Angeles. The pits are about one mile inland from the Pacific Ocean. A view of a typical deposit of this area is shown in Fig. 2.36. As can be seen, these sands are of the dune variety, although some beach sand also is mined in this locality.

Grades—Table 2.34 shows the screen analyses of two core sands mined at Del Monte. These sands contain subangular grains and have a low average silica content of 84 per cent, due to appreciable percentage of feldspar grains. A typical chemical analysis of Del Monte core sand is shown in Table 2.35.

TABLE 2.34—TYPICAL SCREEN ANALYSES OF TWO DEL MONTE CORE SANDS

Sieve No.	Percentage Retained	Percentage Retained
30	None	1.0
40	3.2	16.6
50	33.4	48.8
60	46.2	24.2
70	12.9	6.1
80	2.6	0.7
Thru 80	1.5	0.6

TABLE 2.35—TYPICAL CHEMICAL ANALYSIS OF A DEL MONTE CORE SAND

Silica (SiO_2), per cent	84.10
Iron Oxide (Fe_2O_3), per cent	0.13
Aluminum Oxide (Al_2O_3), per cent	10.21
Lime (CaO), per cent	1.65
Magnesia (MgO), per cent	0.42
Alkalies, per cent	2.99
Ignition loss, per cent	0.50

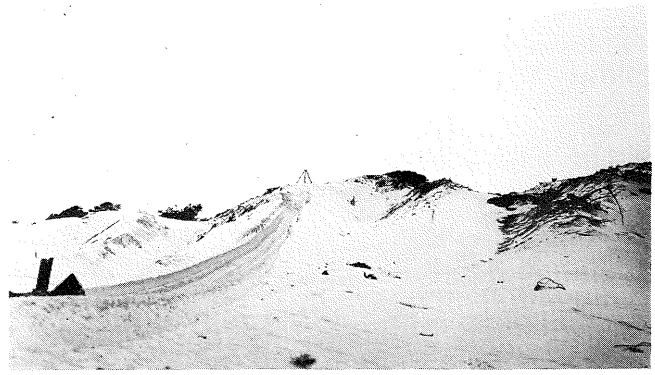


Fig. 2.36—View of core sand deposit at Del Monte, Calif.

Typical Uses—The Del Monte sands are used for cores in nonferrous foundries, particularly those making brass and aluminum castings, and in gray iron foundries for small cores.

General—At the Del Monte deposits, clamshells convey the sand from pits to hoppers, from which it is conveyed to the washing plant by endless belt. The sand is processed to remove vegetable matter, screened, dumped into drainage bins and finally loaded into gondola cars for shipment. Dry sand for cores is made available and is shipped in paper lined box cars.

The supply of sand at Del Monte is practically inexhaustible. The important features of the sand from these deposits are uniformity of grain size and freedom from silt.

Geology—As previously stated, both dune and beach sands are mined in this area. The dune sands are deposited by the Pacific Ocean and blown inland for about a mile to form dunes in a manner similar to the formation of other dune deposits.

Pittsburg Area Sands

Several producers are mining sand suitable for cores in the Pittsburg, Antioch and Sommersville, Calif., areas. This material is a soft sandstone of the Tertiary Age. These sands are washed and graded silica sands and are used for both steel molding and cores. They contain subangular grains, and have an average silica content of about 98 per cent.

Grades—Columns 1 and 2, Table 2.36, show two core sands mined in the Pittsburg area. Column 1 shows the fine grade and Column 2 the regular grade. Table 2.37 gives a typical chemical analysis of the fine variety.

Corona

A sizeable pit of sand suitable for cores is found at Corona, Calif. This is a sedimentary sand deposit with a 50 ft face and 300 ft length.

Grades—Core sand from the Corona deposit is available in several grades, as shown in Table 2.38. As can be seen, the grades vary from about AFS Fineness No. 27 to 53.

Typical Uses—These core sands are used in steel and gray iron foundries for heavy to medium-sized cores.

General—The sand in this deposit is blasted down, hauled to the preparation plant where it is crushed,

TABLE 2.36—TYPICAL SIEVE TESTS OF VARIOUS GRADES OF CALIFORNIA CORE SANDS

Sieve No.	Pittsburg		Ocean Beach		Redondo Beach	Orange County	Antioch Coarse
	Percentage Retained						
6	None	None	None	None	None	None	
12	None	None	None	None	None	None	
20	None	2.85	None	None	None	0.4	0.30
30	None	9.20	None	None	0.18	3.2	
40	0.20	21.00	None	0.2	3.26	38.5	20.20
50	2.15	34.85	1.0	1.6	31.24	43.0	19.40
70	10.60	21.00	10.9	53.5	52.08	9.5	18.80
100	27.00	7.85	75.5	27.6	12.92	3.5	21.50
140	34.85	2.90	11.5	14.6	0.44	*	13.10
200	15.50	0.60	0.6	None	None	*	4.4
270	5.30	0.20	0.3	1.6	None	*	0.70
Pan	4.50	0.25	0.2	0.4	None	1.9†	1.50
AFS Fineness No.	105	43	73	66	49	38.5	83.4
AFS Fineness Class	3	6	4	5	6	7	4
Base Permeability	*	*	165	*	*	*	*

*No figures given.
†This figure may include grains retained on 140, 200 and 270 mesh sieves.

washed, dried and classified. Before classification, the sand is passed over a magnetic separator.

Los Angeles

Within the city limits of Los Angeles is a deposit of natural quartzite, which contains 98 per cent silica and which is mined for core sand purposes. The rock is more or less shattered in its natural condition and is ground to produce a core sand whose grains are contained mostly under the 10 and over the 40 mesh sieves.

Other Beach Sands

Some of the nonferrous foundries of California use beach sand for cores. Such sand is likely to be taken from almost anywhere up and down the California coast. Beach sand also is used by gray iron foundries as filler sand for cores.

Some of the principal locations of beach sand are at San Francisco, Lapis, El Segundo and Oceana Beach. Columns 3 and 4, Table 2.36, give the finenesses of two grades of sands mined at Oceana Beach, while a sieve analysis of a Redondo Beach sand is given in Column 5 of the same table.

An ancient beach is the source of a low bonded sand whose sieve analysis is shown in Column 7, Table 2.36. It is used for dry sand cores for large gray iron castings. The sand is mined from an open pit and has subangular grains.

Other Sand Locations

A dune sand, located in Orange County, Calif., near Santa Ana, is mined from an open pit. The sand is covered by an overburden of about three feet. The sand contains some clay which causes lumps, as mined, and which are milled to break them. A typical sieve analysis of this sand is shown in Column 6, Table 2.36. While this Orange County core sand evidently is of sufficient refractoriness for steel, its main use is in cores for large gray iron castings.

TABLE 2.37—TYPICAL CHEMICAL ANALYSIS OF FINE GRADE PITTSBURG AREA CORE SAND

Silica (SiO_2), per cent	96.97
Iron Oxide (Fe_2O_3), per cent	0.12
Titanium Oxide (TiO_2), per cent	0.03
Aluminum Oxide (Al_2O_3), per cent	1.73
Lime and Magnesia (CaO and MgO), per cent	Trace
Alkalies, per cent	1.0
Ignition loss, per cent	1.1

Oregon Core Sands

The state of Oregon is not a large producer of core sands. Dune sand for cores is obtained near Florence and a sieve test of this sand is shown in Table 2.39.

It is said there is little difference between the Florence sand and other dune deposits along the coast as far north as Tillamook.

A silica sand deposit, said to be suitable for cores, has been reported near Chemult. No data regarding it are at hand, except that it is probably rather coarse grained.

TABLE 2.38—TYPICAL SIEVE TESTS OF CORONA CORE SANDS

Sieve No.	1	2	3	4	5	6	7	8	9
	Percentage Retained								
6	None	None	None	None	None	None	None	None	None
12	None	None	None	None	None	None	None	None	None
20	12.5	1.6	2.0	0.2	None	None	None	None	None
30	39.4	25.2	15.7	3.1	3.8	0.5	1.9	0.3	0.3
40	30.6	48.3	30.6	35.3	32.5	21.2	22.3	14.6	14.6
50	8.7	12.4	16.8	37.3	25.2	26.1	19.2	18.8	18.8
70	7.4	9.8	23.7	15.6	29.3	41.1	33.4	38.5	38.5
100	1.8	2.5	9.0	5.9	7.5	9.5	13.7	18.0	18.0
Pan*	0.2	0.2	2.2	2.6	1.7	1.6	9.5	9.8	9.8
AFS Fineness No.	27.5	33.9	39.7	40.7	42.2	45.7	50.5	53.6	53.6
AFS Fineness Class	8	7	7	6	6	6	6	5	5

*No information given for the 140, 200, and 270 mesh sieves.

TABLE 2.39 — SIEVE TEST OF FLORENCE, OREGON, DUNE SAND

Sieve No.	Percentage Retained
30	Trace
40	0.32
50	18.14
70	56.23
100	24.60
140	0.78

Washington Core Sands

Within the state of Washington, core sands are not abundant. A deposit is being operated at Chewelah, 75 miles north of Spokane. This sand is said to run 98 per cent silica and about 0.37 per cent iron oxide. The grains are mostly angular and various grades are shipped. The company is constructing a plant at Chewelah for washing, drying and screening.

At Wenatchee, sand deposits of Tertiary Age are being worked. The material is crushed and sized. At Sedro Wooley, the Skagit quartzite has been worked for producing core sand. North of Spokane, there is a large deposit of massive quartz which has been used in fire brick manufacture, but in the future, also may be sold for foundry use.

Sandstones occur at a number of localities in Washington which, when crushed, might serve for core sand, but the apparent objection to some of them is that they run too high in their feldspar content.

Some foundries are using ordinary plaster and beach sand for cores, but the smaller cores are said to be made almost universally from Ottawa sand.

Little information, in the way of tests, is available regarding Washington materials.

SPECIAL CORE SANDS

Sand used in foundry core rooms at present is silicon dioxide or silica. However, sands of other compositions are now used for special purposes such as improved casting surface finish and as a chill.

Zirconium silicate, zircon, is very refractory and forms a base for special core sands. Zircon sand, as sold to the foundry, contains some silica. It may be bonded and worked in the same manner as silica-base sands. These zircon sands give improved casting surface finish and due to cost they are generally used only on sections of castings where better finish is desired.

Sands composed of sillimanite from India, alumina (artificial Al_2O_3), and silicon carbide also find some special use as core sands. Sillimanite sand cores may be made of very fine grain size sand without experiencing spalling. Thus sillimanite cores may be used for precision work where dimensions are to be maintained closely.

Cores made of silicon carbide possess the property of subtracting a large quantity of heat from the metal and are of some use as moderate chills.

Chapter 3

CORE BINDING MATERIALS

INTRODUCTION

Cores are of two types: (1) dry and (2) green. They may be defined as masses of sand, in either the dried or green conditions, that are placed in the mold (or are left in the mold by the pattern) for the purpose of leaving a void in the casting, controlling its contour or the flow of metal into the mold cavity and its cleanliness. Cores may be assembled to make the mold itself.

Dry sand cores are composed of a mixture of sand and some material (termed a binder) which causes adhesion between the sand grains (termed bonding) and which becomes hard after some proper treatment. Green sand cores are those used in the green or moist condition. The material used for bonding purposes in green sand cores must give them the proper degree of rigidity.

Binders are of various types and each type is used to confer some desired property on a core for a particular use or set of conditions. Some of the properties which a binder must possess are given below. The requirements enumerated are not necessarily listed in the order of their importance.

(1) A binder must confer sufficient strength on a core for the purpose intended. The binder (or binders) used must hold the sand grains together so tenaciously that when the core is exposed to the flow of molten metal, the grains will not wash from the surface.

(2) A binder (or binders) should be such that sufficient strength is available for the core to hold its proper shape until the metal begins to contract. At that point, the strength should decrease rapidly and the core collapse so that strains, cracks or hot tears will not occur in the casting.

(3) A binder should generate a minimum of gas when the core comes in contact with the molten metal.

(4) A binder should confer sufficient green strength on the core so that it will hold its proper shape in the green state.

(5) A binder should be such that it will not cause the core to distort during baking.

(6) A binder should maintain its strength if the core is stored.

(7) A binder should absorb a minimum of moisture if the core is stored or after it has been placed in the mold.

(8) A binder should produce a core which will withstand the required handling.

(9) A binder should possess good dispersing properties so that it can be distributed evenly throughout the mixture with the minimum amount of mixing.

(10) A binder should produce a mixture which can be formed into a core without fouling the core boxes or sticking in them.

(11) A binder should be economical to use.

Core binders may be divided into four main classes: (1) binders that become firm on freezing, (2) binders that become firm at room temperature, (3) binders that become firm on baking, and (4) clays.

CLASS I BINDERS

Of the binders in Class 1, water is the only one that has been used in actual foundry practice. Other liquids could be obtained that would freeze easily and bind sand into a strong mass. Some years ago an article was published in the U.S.S.R. describing the use of frozen cores. The usual type core sand was used and substantially 12 per cent moisture was added to the sand to make a heavily tempered sand mixture. The core was formed in the usual manner and the green core then was placed in a cold room at 0 F (-18 C). After being frozen, the cores were set in the molds, which were poured within a few minutes after closing. Castings as large as six-cylinder automotive blocks were made using frozen cores. It was claimed that internal iron porosity between barrels and at bearing bosses was eliminated by the use of frozen cores.

To determine the practicability of such cores, the author made frozen open core molds and observed that molten gray iron laid quietly to the core. The next step was to try frozen cores in molds where iron surrounds the core completely, with exception of small vent ports. On this type of mold, the frozen core gave some trouble by blowing, due to the reduced size of vents. Where good sized vents may be used, frozen cores may find an application, providing molds may be poured immediately after closing. Frozen cores collapse very quickly on pouring and may find application in small special castings requiring quick core collapsibility. On humid days, the frozen cores gathered a layer of snow over their outside surface. While this can be annoying, it may be wiped off with a cloth and the core used without ill effects.

CLASS 2 BINDERS

The group of binders that become firm on setting at room temperature consist mainly of such materials as sodium silicate, silica ester, Portland cement, rubber cement, and chemical cement, such as oxychloride.

Sodium Silicate

Sodium silicate, also called water glass and often merely silicate, is used in the core room for special purposes. It is an alkaline compound of silica and is used as a water solution. While it has a considerably lower fusing point than silica itself, it does not burn out. Hence, the effect on permeability is likely to be drastic. It permits fusion of the sand onto metal too readily to allow its use as a general binder.

In contrast to organic binders, sodium silicate is a permanent bond, i.e., does not burn out at the low temperatures which destroy organic materials. Collapsibility and shakeout features are absent in cores wholly bonded with this material; therefore, for interior cores, its use is not advised. As a coating for mold protection in difficult areas, it will resist erosion. As a binder for silica and black washes, sodium silicate will provide a high degree of hardness but such coatings must be used with caution so as not to sacrifice peeling. The fusing tendency of sodium silicate confines its use more to nonferrous castings than to cores for castings of the higher melting point metals.

Sodium silicate is made by chemical manufacture in which silica is fused with soda ash. It is sold both as a solution and in dry form. As a solution, numerous grades are available varying in alkalinity, and with water contents of from 40 to 60 per cent. More concentrated solutions have the highest adhesive power.

It has been found that core sands containing some clay work better than clay-free core sands when sodium silicate bond is employed. (See Chapter 22, Silicate Bonded Cores.)

Portland Cement

Cores, made with silica sand bonded with Portland cement, are being used to some extent in molds for heavy steel, gray iron and nonferrous castings where particular attention is paid to the surface finish and accuracy of casting contour.

The silica sand and cement are mixed together in conventional mixing equipment. Substantially 12 per cent by weight of cement is used and sufficient water is added to temper to the heavy side. Cores are rammed in the usual manner and then set aside to dry in room atmosphere, preferably around 70–80 F (21–27 C) for a period of about 72 hours, after which the cement has hardened and most of the surplus water has evaporated. Customary foundry practice is employed in setting and venting the core and in pouring.

Rubber Cement

The bonding of cores with rubber cement is a patented process. Rubber latex, as it comes from the plant, is treated with a preservative. The silica sand first is tempered with water and then the rubber latex is added. The water used should be treated with a softener to reduce surface tension. The core is rammed and then allowed to harden at room temperature. When a vulcanizing ingredient is added to the rubber cement, the cores are baked. Cores made with this binder do not soften due to the presence of moisture. This binder has a quick collapsibility rate and shakes out easily.

Chemical Cements

Chemical cements, such as oxychloride, provide interesting core binders. This type binder is composed of substantially 20 per cent by weight of magnesium chloride and 80 per cent dead burned magnesite. About 8 per cent of this mixture is mixed with the silica sand and tempered with water. The core is made in the conventional manner and allowed to dry at room temperature for a period of 48 hours. Cores are set, vented, and poured in the same manner as oil-bonded cores.

CLASS 3 BINDERS

The group of core binders belonging to the baking type are numerous. Generally, this group includes such binders as oils, cereals, resins, pitch, sulfite and protein. These binders do not develop their strength by the same chemical or physical changes. In this respect, they may be subdivided into the three following types.

(1) Those that dry on heating.
(2) Those that harden on cooling after being heated.
(3) Those that adhere on heating.

Binders Which Dry on Heating

Core Oils

The drying type binders generally are composed of three classes of oils; namely, the vegetable, mineral, and marine animal. Vegetable drying oils are used most commonly, while the mineral oils, which have been processed by polymerization, are being used in increasing quantity. The use of marine animal oils, such as menhaden, is decreasing in the foundry. Table 3.1 shows the physical properties of common drying oils that have been used in core oil production.

Requirements for Core Oils

A core oil binder should fulfill the following requirements.

(1) It should possess good dispersing properties so as to coat the grains of sand evenly, with a reasonable amount of mixing.
(2) It should work clean in the core boxes.
(3) It should produce cores of proper strength.
(4) It should generate a minimum of smoke and gas.
(5) It should meet the particular foundry's requirements and baking conditions.
(6) It should produce good cores efficiently and economically.

In addition, such important core characteristics as green strength, tensile strength, hardness, permeability, smoothness of surface, heat resistance, moisture resistance and collapsibility, must be taken into consideration.

Manufacture

Before the manufactured type core oils came into

TABLE 3.1 — PHYSICAL PROPERTIES OF DRYING AND SEMIDRYING OILS

Type Oil	Specific Gravity	Flash Point, F	Flash Point, C	Saybolt Universal Viscosity at 100 F (32 C)	Saybolt Universal Viscosity at 210 F (99 C)	Iodine No.	Saponification No.
Cottonseed	0.922 -0.925	600	316	176-181	49-52	110-120	192-195
Corn	0.921 -0.927					111-130	188-193
Hempseed	0.925 -0.930			137	48.8	140-166	190-193
Linseed	0.931 -0.939	550	288	139-143	45-49	170-190	190-195
Menhaden	0.931 -0.936	530	277	135-140	45-49	139-173	189-193
Oiticica	0.976					146-152.8	190-193
Perilla	0.928 -0.935			120-123	47.6-48	200-208	189-198
Poppyseed	0.924 -0.927					133-145	190-195
Safflower	0.9251-0.928					129-150	187-193
Sardine	0.929 -0.933			127-133	48-48.6	180-195	
Sesame	0.923 -0.937	510	266	184	49	103-109	189-193
Soybean	0.924 -0.929	540	288	134-165	48-50	121-136	190-195
Sunflower	0.921 -0.930			156	50.3	129-135	188-194
Tung	0.936 -0.943			530	78.5	150-165	193
Walnut	0.925 -0.926					143-152	189-195
Whale	0.925 -0.930	455	235	139-163	45-48.9	110-146	197

use, fixed oils of the drying type (such as linseed oil) or semidrying oils (such as corn oil), or marine animal oils, were used. In some cases, fixed oils of this kind are still found in use. However, most of the commercial materials marketed as core oils are products manufactured under laboratory control and balanced to fulfill certain specific requirements.

Raw materials used in core oil manufacture usually are subjected to various tests to make sure that they are within trade tolerances. Among the tests to which these raw materials are subjected are: specific gravity, flash point, fire point, viscosity, pour test, color, acid number, saponification number, iodine number, moisture, impurities, unsaponifiable, ash, odor, break test, melting point, as well as certain other tests. Some of these tests also are used to aid in controlling uniformity in the manufacture of core oils. Finished oils, in addition to meeting various chemical standards, must conform with core testing standards. It is impossible to grade an oil on the results of any one of the chemical tests: neither is it possible to grade an oil simply on the basis of tensile strength. Good judgment in interpreting results is essential.

Many of the tests supply important and interesting data and aid in evaluating a core oil, but in addition to any laboratory tests, the oil must perform satisfactorily in actual service.

Various methods are used in the manufacture of core oils. Sometimes these methods call for simply melting resin by addition to the drying or semidrying oil, using either steam or fire heated kettles, then adding a diluent, such as kerosene. At other times, special processes are used. Some of these special processes are regarded as trade secrets and include liming of resin, esterification, partial oxidation, polymerization and the addition of dryers. Dryers (metallic salts) sometimes are added to accelerate oxidation and polymerization. Incorporating blends of drying and semidrying oils to achieve some desired result often is done. Core oils are made to fulfill many special requirements and their composition depends largely on the size and type castings that are to be produced. Several typical specifications are shown in Tables 3.2, 3.3, 3.4 and 3.5.

Specifications

At times, core oil manufacturers are confronted with a chemical specification which determines the composition of the core oil.

TABLE 3.2 — CORE OIL SPECIFICATIONS ISSUED IN 1931

Specific gravity at 60 F (16 C)	0.9360 Max.
Flash Point (Cleveland Open)	165-200 F (74-93 C)
Fire Point (Cleveland Open)	190-225 F (88-107 C)
Iodine No. (Wijs — 1 hr absorption)	160 Min.
Saponification No.	148 Min.
Acid No.	30-37
Color	Light, clear amber through 1/2-in. section
Fish Oil	Negative (according to Griffin Test)
Ash	0.10 per cent Max.

TABLE 3.3 — CORE OIL SPECIFICATIONS ISSUED IN 1932

1. This specification covers a grade of core oil suitable for use in the foundry for making dry sand cores.
2. The oil shall be a clear, homogeneous oil, free from water, dirt, sediment and objectionable odor.
3. The core oil must be capable of being used in conjunction with a cereal core binder without detrimental effects.
4. Chemical and physical properties:
   Raw Linseed Oil (ASTM Specification)

Total Blending Materials	60 per cent by volume (Max.) 40 per cent by volume (Min.)
Resin (Grade F or better)	25 per cent by volume (Max.)
Viscosity at 100 F (38 C) (Saybolt)	220 sec. (Max.)
Flash Point (Open Cup)	165 F (74 C) (Min.)
Iodine Value (Wijs — 1 hour absorption)	160 (ACCS Method) (Min.)
Saponification Value	157 (Min.)
Acid No.	53 (Max.)
Specific Gravity	Must not vary more than 0.005 above or below contract sample at 60 F (16 C)
Gallonage	Standard U.S. gallons at 60 F (16 C)
Separation	Must not separate when allowed to stand 2 weeks at 40 F (4 C)

5. Strength Tests — briquettes:
   Briquettes made with this core oil shall show a test strength within 95 per cent of that obtained with raw linseed oil under the same operating conditions.
6. Production Tests:
   In addition to laboratory tests, the core oil must satisfy all production requirements.

Somewhat limited chemical specifications are used at times in an effort to insure uniformity, but if used alone, they may not prove entirely reliable or economical. Large, up-to-date foundries, though they may require certain standards for core oils, are careful not to use specifications that might hamper or exclude improvements. Such foundries are testing and investigating these products continually on the lookout for improvements. A light colored oil is sometimes included as a part of a specification. This would exclude a darker colored oil, which often may be more economical and perform quite efficiently.

A supporter of chemical specifications might argue that such a procedure would permit the use of fish oil in the compounding of a core oil. That may be answered by stating that today it is possible not only to deodorize fish oil but to chemically treat it so that it cannot be detected by the usual tests. The processed fish oil will produce practically the same chemical test data as raw linseed oil, and, of course, defeat the specifications in this manner.

Another bad feature of most chemical specifications is that they set up chemical test values which make it impossible for the manufacturer of core binding materials to use any vegetable oils other than linseed oil, tung oil, perrilla oil, fish oil, and possibly oiticica and hempseed oils. Such vegetable oils as soybean oil, etc., are excluded because they have low iodine values; yet, they produce very good cores.

It, therefore, follows that the adoption of close chemical specifications has a tendency to prevent research and advancement in the manufacture of core binding materials because they may make it possible to use only certain ingredients in a core oil when there may be others which may be more economical and may produce as good or better results.

TABLE 3.4 — CORE OIL SPECIFICATIONS ISSUED IN 1936

Specific Gravity	0.923
Flash Point (Wijs — 1 hr absorption)	155 F (68 C) (Min.)
Fire Point (Cleveland Open Cup)	170 F (77 C) (Min.)
Saponification Value	130-140
Iodine No.	140 (Min.)
Acid No.	48-53
Saybolt Viscosity at 100 F (38 C)	140 sec. (Min.)
42½-45 per cent Pure High Grade Linseed Oil	
27½-30 per cent Gum Resin Slightly Limed	
25-27½ per cent Water White Kerosene, Acid Free, 150 F (66 C) Flash	

Adjusting Core Oils to Baking Time-Temperature Relation

Modern foundry practice demands fast baking cores of good strength. However, equipment and practice of foundries vary greatly and core oil manufacturers generally are called upon to supply an oil to fulfill a particular foundry's needs. Most core oil manufacturers carry a number of core oils, varying in price, as well as ability to fulfill certain requirements.

In some cases, it has been possible to increase core production, without increasing equipment, by furnishing faster baking oils. In other cases, the problem has been to slow the oxidation of an oil as it reached its maximum binding strength, because cores of various sizes were being placed in the oven at the same time and were passing through the same baking cycle. In such a case, the use of an oil which is not balanced properly results in the large cores being underbaked and small cores at maximum strength, or the large cores at their maximum strength and small cores overbaked. By balancing the oil, the baking strength curve can be flattened out at its maximum strength point for a greater period of time, resulting in the production of large and small cores of good strength in the same oven during the same baking cycle.

TABLE 3.5 — CORE OIL SPECIFICATIONS AS USED BY A LARGE FOUNDRY

Every tank car is weighed full and empty, tested and passed or rejected by the laboratory. The oil is purchased by the pound. New oils must be tested and approved by the laboratory before they receive a trial in the core room.

1. Direct tests on the oil:
   a. Specific Gravity — lb per gallon at 60 F (16 C)
   b. Viscosity
   c. Color
   d. Odor
2. Tests on cores made with the oil.
   a. Tensile Test
      1. Core test mixture is as follows:
         Silica sand .. 1600 grams
         Oil ..... 10 grams
         Cereal ..... 2 grams
         Water ..... 100 grams
      2. The cores are baked at a temperature of 400 F (205 C) for a period of 4 hr (comparable with our core room practice).
      3. After baking and removal from the oven, cores stand for 5 min on the drier plates, are separated from the plates and then placed in desiccators containing calcium chloride and phosphorous pentoxide.
      4. In connection with the making and baking of the cores, the amount of sand sticking to the core box and driers is always noted, and sometimes the deposits are weighed.
   b. Volume of gas evolved.
   c. Tensile strength of the cores.
      1. At 250 F (121 C), 100 F (38 C), and at room temperature in 90 per cent humid air.

No chemical specification and no restriction as to what constitutes the formula of the core oil are given. Demand is made that no change be made in an approved oil and, if a change is contemplated due to economic conditions, it is required that a sample of the revised oil be submitted for examination and approval.

Use a silica sand, screened three times; all sand retained on 30 mesh and passing 60 mesh should be rejected, and only that sand passing the 30 mesh and retained on the 60 mesh used.

Due to the constant vibration and jolting in the laboratory from molding machines in the foundry, the cereal is included for the sole purpose of air drying quickly to prevent collapse before baking has set in. The amount of cereal is in the ratio of about 400-1.

Tensile test cores are made to be tested in the Universal type strength machine, but the method of forming the cores is a combination of jolting followed by hand ramming with a special ramming device. (Ramming by different individuals gives comparable results.)

The tensile strength charts shown in Figs. 3.1, 3.2 and 3.3 illustrate how two oils of comparable strength, when tested under same time-temperature conditions (400 F–204 C), vary when compared under different temperature conditions. In actual practice, it is necessary to balance or adjust these oils to meet certain foundry conditions.

In studying a tensile strength chart of an oil, as shown in Fig. 3.4, one can see that the cores taken out just before reaching maximum strength, or in an underbaked condition, could agree in tensile strength with cores after passing maximum strength.

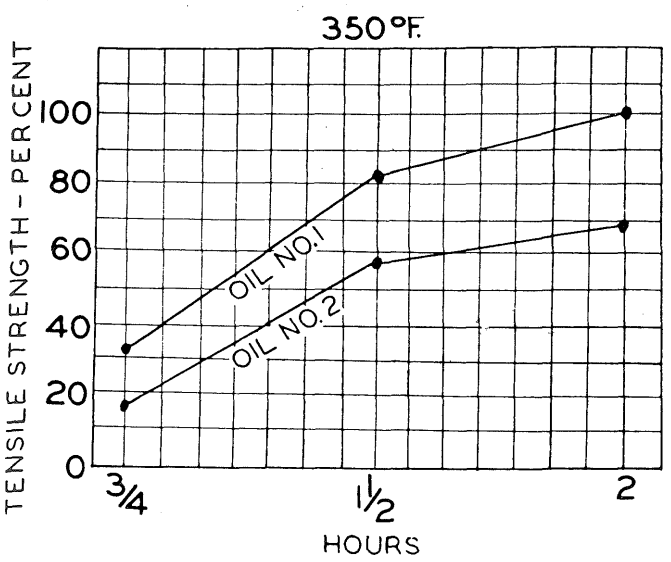


Fig. 3.1 — Tensile strength developed by two core oils after various baking times at 350 F (177 C).

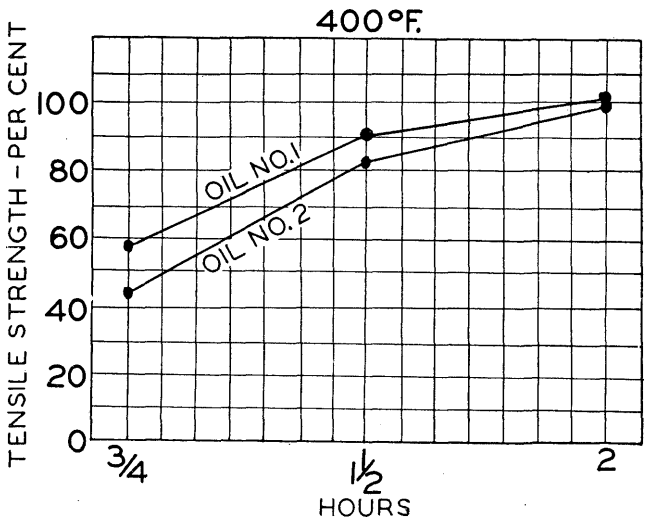


Fig. 3.2 — Tensile strengths developed by the same two core oils as in Fig. 3.1 after various baking times at 400 F (204 C).

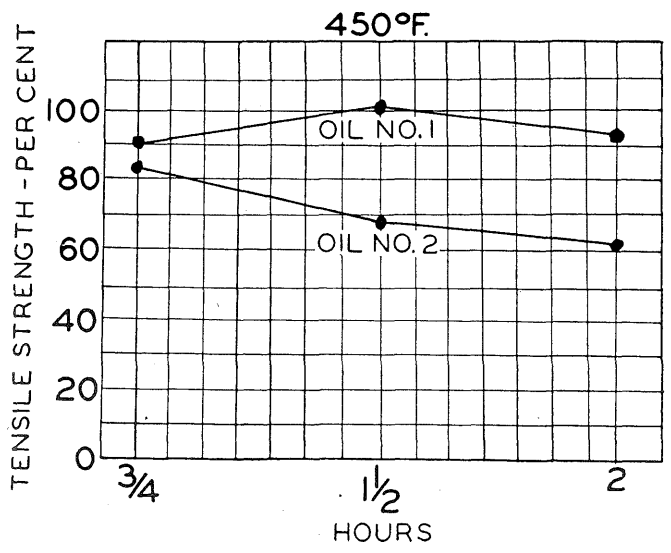


Fig. 3.3 — Tensile strengths developed by the same two core oils in Fig. 3.1 after various baking times at 450 F (232 C).

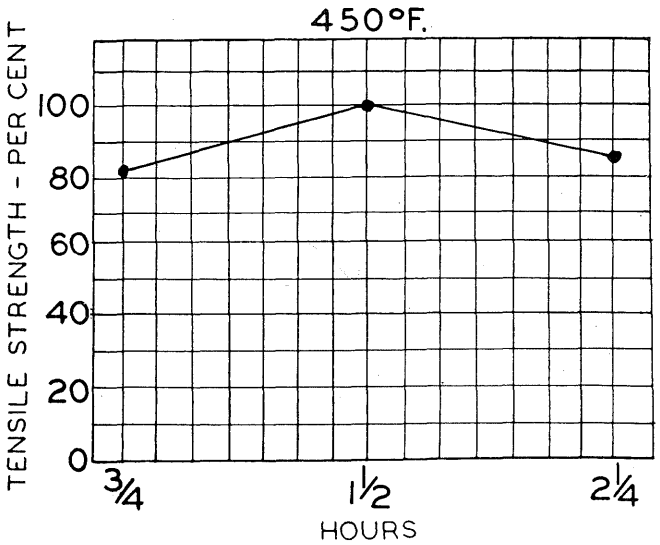


Fig. 3.4 — Illustrating how it is possible for underbaked cores to equal the strength of overbaked cores.

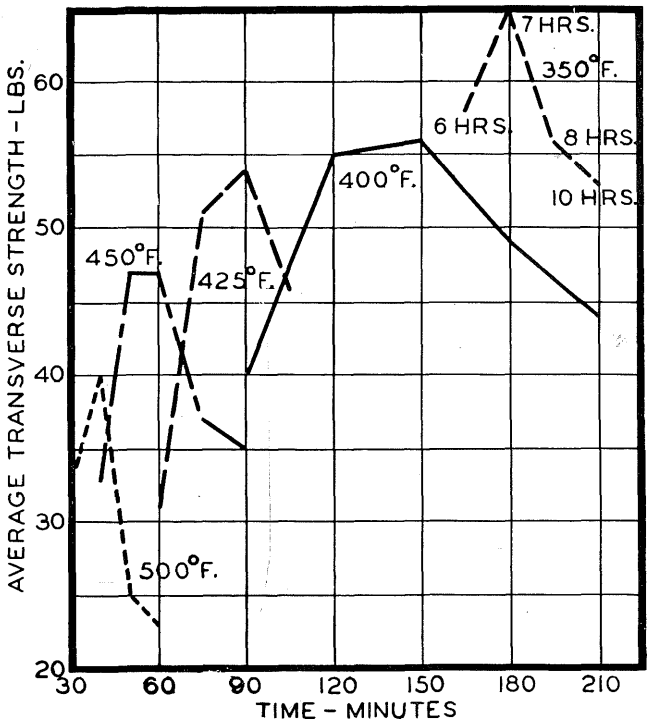


Fig. 3.5 — Strength of cores as affected by baking times and temperatures.

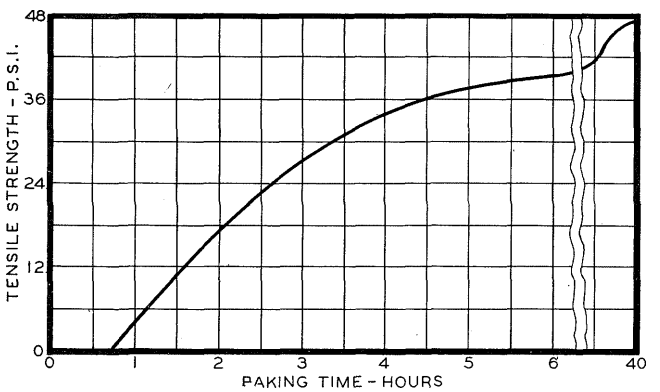


Fig. 3.6 — Strength of linseed oil — lake sand core mixture baked at 300 F (149 C) for various times. Sand to oil ratio, 60-1.

Campbell* demonstrated the importance of the time-temperature relation in the baking of cores. Using a mixture containing 60–70 mesh silica sand, 2 per cent raw linseed oil by volume and 4 per cent water by volume, he made transverse test cores 1 x 1 x 8 in. and baked them in an oven in which provision was made for the removal of a portion of the contaminated air and the admission of some fresh air. In each test, the oven was heated to a specified temperature before the test specimens were placed in it. The length of time required for the oven to reach the desired temperature, after the cores were placed in the oven, was about 30 min.

As shown in Fig. 3.5, his data demonstrate that the maximum strength of cores, which contain a given amount of oil binder, is dependent on the time-temperature relation. Figure 3.5 shows that, for the size of core tested, maximum strength is developed in 40 min at 500 F (260 C), in 60 min at 450 F (232 C), in 90 min at 425 F (218 C), in 150 min at 400 F (204 C) and in 7 hr at 350 F (177 C).

It will also be noted that as the temperature increases, the time range over which maximum strength is attained becomes less and less. This indicates that the higher the temperature used, the more critical is the point at which the cores must be withdrawn from the oven and the greater the attention that must be paid to the core baking cycle. It also would seem to indicate that production of cores of maximum strength might be increased considerably by proper attention to oven technique.

While Campbell's information was gathered on raw linseed oil as a binder, it is quite probable that a similar type of investigation on other type core oils would indicate that a similar time-temperature relation exists with probably certain differences in maximum strength and time ranges for various temperatures.

Figures 3.6, 3.7, 3.8, and 3.9 further illustrate the time-temperature relation for the development of maximum strength. Mixtures used consisted of raw linseed oil and lake sand in the ratio of 1 to 60. Figure 3.6 shows the strength developed in hours at 300 F (149 C). Even after 40 hr maximum strength has not been developed. In Fig. 3.7, showing the results obtained by baking at 350 F (177 C), the maximum strength is reached somewhere between the third and fourth hour. In Fig. 3.8, it can be noted that the maximum strength is obtained in about the second hour and that the time range for development of maximum strength is considerably decreased. Figure 3.9 shows the results of baking at 450 F (232 C). It will be noted in this illustration that maximum strength occurs approximately at the end of the first hour, but the time range for maximum strength has been reduced to minutes instead of hours. Figure 3.9 again demonstrates the necessity of close control of the baking cycle if maximum strength cores are to be obtained in the minimum of time.

Comparative baking tests frequently are run on one oil against another under certain baking time-temperature conditions. Unless sufficient work is done to cov-

*Campbell, H. L., *"Baking Practice for Oil Sand Cores,"* AFS TRANSACTIONS, vol. 37, pp. 289-294 (1929).

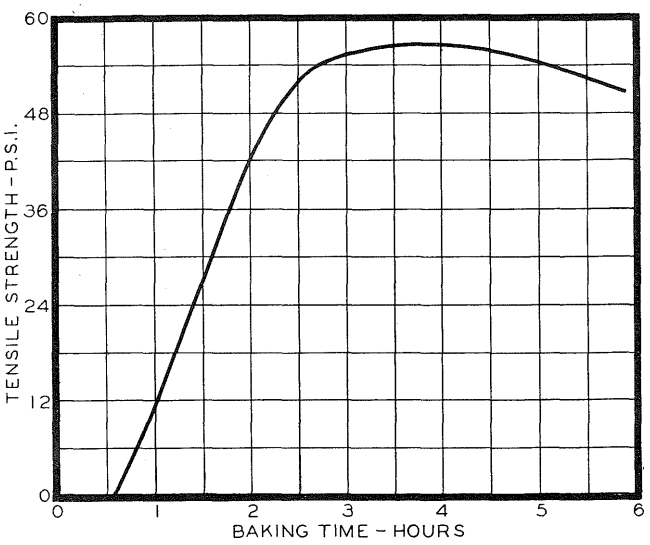


Fig. 3.7 — Same as Fig. 3.6 but baked at 350 F (177 C).

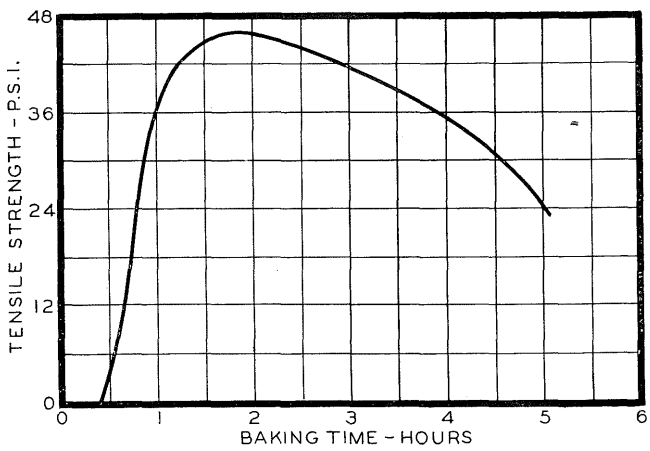


Fig. 3.8 — Same as Fig. 3.6 but baked at 400 F (204 C).

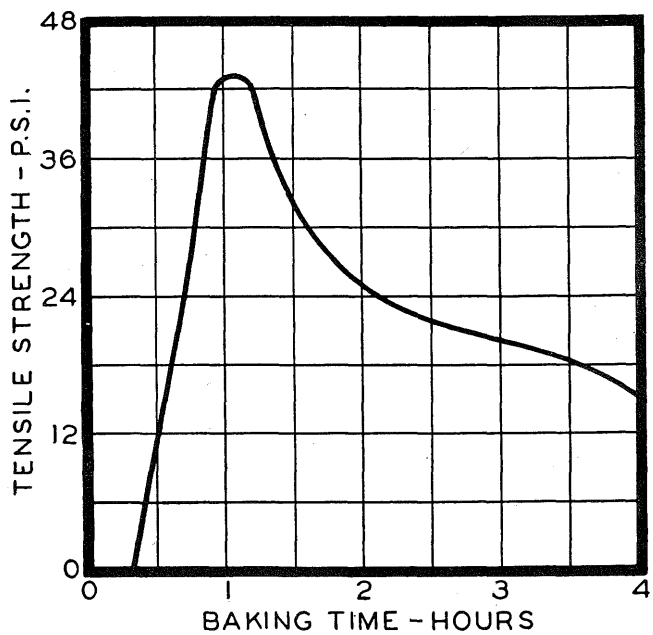


Fig. 3.9 — Same as Fig. 3.6 but baked at 450 F (232 C).

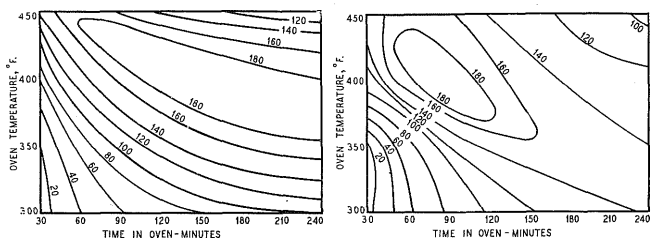


Fig. 3.10 — Graphs showing tensile strength for any given baking temperature and baking time. (Left) with raw linseed oil; (right) with commercial type of linseed-base oil.

er the baking range of an oil, it is possible to condemn one oil as being inferior in strength to another if the conditions of test are such as to have the resulting comparison fall for one oil on either the underbaked or overbaked side of its range and the other, at its maximum strength.

To prevent excessive gas formation, a core slightly on the overbaked side is better than one on the underbaked side.

Test data for a complete research of tensile strength at all baking periods and baking temperatures is well illustrated by using the method of plotting as shown in Fig. 3.10 (left). From a graph of this type one can choose various baking temperatures and baking time which will produce cores of maximum strength. For example, with a baking temperature of 425 F (218 C) the correct baking time for the test core used is from 60 to 95 min. When a baking temperature of 360 F (182 C) is used the correct baking time is from 195 to over 240 min. The binder being one per cent by weight of raw linseed oil and sand, with a maximum strength of 180 psi tensile strength.

When a commercial type of linseed base oil is used, the area of baking time and temperature is often decreased as compared to raw linseed oil. In speeding up the baking as is practiced with many commercial oils the cores are more easily oven baked. See Fig. 3.10 (right).

Types of Oils Used for Cores

As previously explained, the core binders which dry on heating are composed of drying or semidrying oils, vegetable, mineral and marine animal, treated in the proper manner. The following gives some information on the three types.

Vegetable drying oils—Drying and semidrying oils of vegetable type are the products of the fruits of plants and trees, and are extracted from the seeds or fruits, after being properly prepared, either by pressure or with solvents. These oils owe their value to their ability to combine with oxygen from the air to form solid substances.

Mineral oils—Mineral oils used as binders in the core room usually are not used in the natural state but rather are subjected to a process of polymerization. These oils, in their polymerized state, form the basis for the quick drying core oils which are being used to increasing extent by the foundry industry.

Polymerized oils or compounds made their appearance in the core room over 25 years ago. The origin of these substances may be said to be crude petroleum which is separated in certain fractions which contain unsaturated substances. These unsaturated materials may be partially polymerized by a process which involves passing them into the vapor phase over catalysts at elevated temperatures.

These materials owe their utility as core binders to the fact that, when mixed with core sand and placed in an oven, they further polymerize from a liquid stage to a hard substance. Chemically these materials are said to be composed of unsaturated hydrocarbons. In this, they differ rather markedly from the structure of vegetable drying oils.

Petroleum polymers may be compounded with other materials to form oil binders. The degree to which these materials will resist overbaking or underbaking may be controlled rather largely by the manner in which they are processed during production.

Marine Animal Oils—In this class of oils, menhaden oil, sardine oil, and whale oil, are the more commonly used. They are used mainly in conjunction with a vegetable drying oil, such as linseed oil. Their offensive odor limits the extent of use as a core binder, although it is now claimed such odor can be eliminated by processing in some cases.

Binders Which Harden on Cooling

The binders that soften on heating and harden on cooling are gum resin, wood resin, specially processed resins, petroleum resins, pitch, resin oils, synthetic resin oils, and coal tar resins. The petroleum tar and resin sometimes are used in conjunction with drying oils, such as linseed.

Resins

Resins are widely used as core binders and may be divided into two groups, natural and synthetic. Natural resins occur in nature in special cavities in plant life, while synthetic resins are those produced by chemical reaction. Natural resins, being readily available at low cost, have found wide usage.

The most abundant natural resins are those obtained from pine trees. Gum resin is obtained by tapping the living tree and distilling the gum which exudes. Wood resin is obtained by steam and solvent extraction from shredded pine stump wood.

Limed wood resin is obtained by treating wood resin with lime, which raises the melting point and renders the resin more soluble in petroleum thinners. It was widely used by foundries which ground it up for use; however, it has largely been replaced by the more efficient, higher melting resins. Carefully controlled heat treatment is often used to process wood resin.

Petroleum resins are a by-product of petroleum refining. Coal tar resins are a product of the coal tar industry.

High melting, gasoline insoluble, pine resin is obtained by extraction from pine stump wood with solvents other than gasoline. It is more suitable for use as a dry core binder because of its low ash, high melting point and higher bonding strength. It can be pulverized readily to the desired fineness to give easy mixing with core sand; when pulverized, its melting point is sufficiently high so that it can be shipped and stored in powdered form without danger of melting to a lump.

Some properties of pine resins which make them useful as core binders are listed.

(1) Moderate strength characteristics.
(2) Low in cost.
(3) Will bond reclaimed sand or sands containing clay.
(4) Bake rapidly and at low temperatures.
(5) Lose bond rapidly when metal is poured, permitting easy collapse of core, and unhindered shrinkage of the metal. This property also affects the removal of cores from large castings.
(6) Resin-bonded cores resist moisture absorption and loss of strength in storage.

A widely used resin binder meets the requirements shown in Table 3.6.

TABLE 3.6 — SPECIFICATIONS FOR RESIN BINDERS

		Max.	Min.
Melting point (Drop Method)			230 F (110 C)
Screen test — passing	30 mesh		100%
passing	80 mesh		90%
passing	200 mesh	80%	60%
Gasoline insoluble content ..			95%
Ash content		0.3	

When pulverized to this fineness, the resin will weigh 4 lb per gallon or one lb per quart. Since pine resins are thermoplastic and soften under heat, they should not be stored near heat or near core ovens, steam pipes, etc. Care should also be taken not to stack the bags too high or to place heavy objects on top of stacked bags.

The synthetic resin binder group is rapidly growing in use. The two synthetic resin binders that are finding the most favor are the urea-formaldehyde and phenolic-formaldehyde plastic binders. They are thermosetting and require no oxygen during baking to cure or harden. They are water soluble before baking so that a certain amount of the plastic binder migrates to the surface of the core and tends to give a harder skin to the core surface than the interior of the core.

The baking temperature may be as much as 100 F (55 C) lower than that used for other binders. During the baking, the moisture in the core is first driven off and then the temperature of the sand and binder is increased to a point near 300 F (149 C) where a condensation action takes place. During this chemical change the plastic binder is cured to a hard moisture resistant bond by the condensation action of the molecules combining and throwing off moisture.

The urea-formaldehyde group find their best use for molding thin walled castings where a fast collapsing core is required, while the phenolic-formaldehyde group are slow collapsing and may be used for heavier work such as found in the steel foundry.

These plastic resin core binders are obtainable in either liquid or dry powder form. They should not be stored for a long period. A greater core surface hardness is usually obtained from the liquid binder while a greater uniformity of core cross-sectional strengths is obtained with the dry powdered plastic binders.

A recent addition to the organic synthetic resin binders is one which the proprietor claims a gas content as low as 1 cc per gram of core. The binder will air set in 6 hr at room temperature and in 8 min at 400 F (204 C). A chemical reaction takes place in which the binder chemically cures itself by a change to a carbon structure and not by adding to the structure such as is experienced with drying oils. See Chapter 21, SHELL CORES, for more detailed description of synthetic resin binders.

ROSIN OILS

True rosin oils are obtained by subjecting gum or wood resin to destructive distillation and then fractionating the distillate into rosin spirit and rosin oil. The chemical composition of rosin oils, thus produced, is not fully understood; they consist mostly of hydrocarbons, and, depending on the care exercised during distillation, contain larger or smaller quantities of rosin acids. The percentage of rosin acids varies from 10 to 30 per cent. They would not be considered as strong binders for core sands. This type of rosin oil has been used by some foundries, but has not proved satisfactory in all cases.

Synthetic rosin oils are produced in large commercial quantities by heating colophony (gum resin) with a mineral oil known as paraffin oil. Generally 50 to 60 per cent of colophony and 50 to 40 per cent of paraffin oil are heated together to a temperature of 450–500 F (232–260 C). The resulting rosin oil has the same appearance as a true rosin oil.

This product is a good binder and produces cores that are collapsible under the heat of molten metal. It is used in cores and facing sand where noncollapsing might cause casting cracks.

When the cores are baked, the solvent evaporates with the water and the rosin again turns to a solid, which then liquefies and spreads on the grains of sand as the core reaches a temperature of approximately 300 F (149 C). The cores, on cooling, become hard due to the rosin solidifying.

PITCH

Pitch is a by-product from coke making, distilled off at around 350 F (177 C). Wax content is important when used as a core binder. Pitch compound, composed of pitch mixed with dextrin, is used extensively as a binder of large cores for gray iron. The use of a small percentage of seacoal often is desirable to prevent the pitch rehardening on cooling after pouring. It is an effective bond for burned or clayey core sands. Pitch is indispensable as a binder for large cores. It is the most resistant to moisture absorption of any of the known bonds. It also can be used effectively with an impure sand, old burned sand, and gangway sand. Because of its resistance to moisture absorption, it is especially adaptable to large cores and in large molds where the cores must stand a considerable time before pouring. To produce a smooth surface along with a collapsible core, medium and large cores often are faced with oil sand and backed with pitch sand.

The bond developed by pitch at high temperatures near the pouring temperature of irons is very strong. In other words, cores bonded with pitch possess a high hot strength particularly so in atmospheres which are composed largely of gases from pitch. This type of atmosphere is described in high temperature sand testing as "own atmosphere."

Binders That Adhere on Heating

Sulfite Binders

Sulfite liquor has long been the source of an important class of binders which are marketed in both the liquid and dry forms. In the preparation of pulp from wood chips, the lignin portion is separated from the cellulose by chemicals which dissolve the lignin. This lignin solution is a by-product of the pulping industry. It is processed and concentrated to yield a heavy dark liquid binder of 60–70 per cent solids or is dried to yield a light brown powder. This type of binder is, therefore, of a chemical nature entirely distinct from that of oils, resins, flours, molasses and other commonly used binders.

Grades and properties are dependent partly upon the processing applied to the liquor, but any one source of liquor provides a uniform product.

In general, the working properties of these binders are based upon the following characteristics: (1) complete solubility in water, (2) high binding power for clay materials, (3) good resistance to high temperatures, (4) rapid baking and (5) nonfermentability.

This type of binder, being water soluble, provides cores of varying nature depending upon the moisture content of the sand. High moisture promotes concentration of the binder at the surfaces of the core and gives more or less shell structure to the core. Also, the higher the moisture the harder the core. Therefore, for consistent performance, it is necessary to keep the moisture content of the sand under control. Too much moisture will cause the sand mix to become heavy on mulling.

The complete solubility of sulfite liquor binders has made them favorites for sprays and for use as binders in both black washes and silica washes. Binders of this type promote the penetration of washes into the sand and provide a high degree of hardness to the dried wash. Sprays are mixed from either the liquid or the dry product and normally are used in concentrations of from 1 to 20 up to 1 to 5 in water.

Sulfite liquor binders are perhaps unique among generally used materials in having high binding power for clay material. On the other hand, their binding power for sharp or open sands is poor. Consequently, manufacturers do not recommend their use in all sharp sand, but provide formulas for mixes containing natural molding sand, fire clay, burned sand and loam sand.

The drying process of cores involves simply the evaporation of water and there is no baking phase as in the case of core oils. Recommended temperatures are not to exceed 400 F (204 C), but in some foundries this type of binder has been found an advantageous addition to the sand to protect the cores from high oven temperatures in forced drying. There is some advantage over molasses with respect to drying time, as molasses holds the last traces of moisture tenaciously.

This type of binder has the advantage of being nonfermentable and stable in storage. Its avidity for moisture, however, makes dry storage advisable. The dry product is light in weight and packs readily. Therefore, it should be used by weight for consistent results. The liquid binders require thinning with water for ease in handling and mulling.

Through long experience, sulfite binders have been found to be an advantageous substitute for molasses for many types of work and are recommended for partial replacement of core oils to reduce costs. The contrast between the properties of these binders and oils is so great, however, that this kind of substitution must be approached by the foundryman with caution.

The outstanding weakness of the sulfite binders is their readiness to absorb moisture after the core is dried, thus limiting their usefulness under conditions where cores are stored and where dry sand cores are used in green sand molds. When used with core oils, the oil is always mixed into the sand before the sulfite binder is added.

The sulfite liquor binders are used in gray iron, malleable, nonferrous and steel shops. They also are used by manufacturers of black compound binders as an advantageous ingredient. In clay-containing sands, the sulfite binders are useful in imparting strength; used as sprays, they protect core and mold surfaces from damage in handling and in the oven; used in washes and blackings, they improve penetration resistance and impart hardness.

Protein Binders

Protein binders embrace a distinct class of materials which are organic compounds containing nitrogen, known collectively as proteins. Pure commercial proteins include gelatin, casein and glues. These materials have well-established outlets in industries other than the foundry industry. However, the raw material sources of proteins are available as dry foundry binders and are being advocated for types of core work in which their special properties are an advantage.

The special properties of protein binders include high binding power, improvement of flowability of sand, rapid drying, fair resistance to moisture and low burning out point with mild gases evolved on burning. Protein binders do not provide green bond strength in the same degree as starches but instead, are more useful in providing dry strength. They are more adaptable to the bonding of sharp or open sands than mixes containing clay material.

The low heat resistance of proteins requires that the oven temperature be held at 400 F (204 C) or lower. Core drying involves only the evaporation of water and no baking phase is involved. The cores are almost equally strong whether hot or cold. Proteins do not melt before burning but have a low burning out point and, once ignited, glow and continue burning. This contributes to rapid collapsibility of core in the casting. Hence, protein binders offer a means of making strong, hard cores which are readily collapsible.

Protein binders are made water soluble through special patented processing. After dissolving in the tempering water, they have the property of readily wetting the sand grains, the result of which is to promote the flowability of the sand. This is particularly noticeable in the finer sands. Water must be present to bring out the adhesive qualities of proteins.

The optimum moisture content varies with the type of sand but, in general, open sands require less moisture, say 4 per cent, than sands containing clay which must show at least 6 per cent moisture to obtain the required dry strength. In open sands bonded with

proteins, the moisture content has little influence on dry strength; in mixes containing clay, the higher the moisture the stronger the core. As with other water soluble binders, high moisture promotes shell structure and hardness of the core.

Protein binders have been adopted by foundries where high collapsibility of cores is essential and where a reduction in gases and smoke is desirable. Their unique properties are particularly advantageous in aluminum and other nonferrous work and in steel and malleable dry sand cores where the casting design is intricate. The high adhesive power of proteins makes them acceptable as core pastes when properly compounded with inert fillers, and as the adhesive for silica wash.

Molasses

Molasses is a by-product of sugar refining and is produced in the refining of both cane and beet sugar. Molasses from both sources is used in foundries, beet sugar molasses being encountered in foundries in the western states. Corn sugar manufacture also yields a molasses known as "hydrol," but this has not been used to any great extent in foundries.

Molasses, of course, is an established food product and the purer grades are so used. Foundry grade molasses is a cane or blackstrap molasses, unrefined and not classed as edible. Therefore, this binder is an inexpensive material. It is marketed in barrels. The solids content varies between 60 and 70 per cent.

Molasses has a venerable record as a material for the core room, though not generally used as a primary binder. Instead, molasses is used as molasses water, i.e., as a thin dilution, added as tempering water, or used as a spray. It is an adjunct to other primary binders and particularly to the starch and dextrin types. Dry sand cores bonded with starches are hardened and strengthened if the tempering water is molasses water. Molasses spray provides a superficial crust on cores not otherwise sufficiently hard.

Molasses is a mixture of water soluble materials, mostly sugars, and, therefore, responds to changes in the moisture content of the sand. High moisture promotes shell structure in cores bonded with molasses, since, in drying, the excess moisture carries the molasses to the core surfaces as the moisture is drawn to the evaporating surface from the interior of the core. Molasses shows this effect more markedly than any other binder. It is most pronounced in sharp or open sands and not as prominent in sands containing much clay material.

Molasses lacks the strength of core oils and is not used as an oil substitute. It might supplement oil to provide a core crust, but when so used, caution is required to see that the moisture resistance of the core is not too greatly reduced because molasses has great affinity for water vapor and draws moisture rapidly.

Cereal Binders

For many years wheat and rye flours were used as core binders in foundries, but did not prove satisfactory in all respects. The first improvement over wheat and rye flours was the introduction of manufactured starches, known as dextrin and British gum. These products were used first in the British Isles and were introduced to the foundries in America shortly afterward. When these products are properly used, they are very efficient. Dextrin and British gums develop great strength. Therefore, mechanical mixing is helpful in distributing a small amount of these binders over large volumes of sand. Best results are experienced when low moistures are used. Because these binders are highly soluble, they have a tendency to migrate to the surface of the cores. Under certain conditions, this is an advantage. Dextrin still is used widely for cores in aluminum and steel foundries.

Dextrins are obtainable with different degrees of water solubility, the highest water solubility percentage being in the neighborhood of 95 per cent. This type of dextrin is used to impart high hardness to the outer skin of the core and a soft center. Dextrin that is low in water solubility, for example 10 per cent, imparts an equal strength or hardness throughout the core cross-section.

Present day cereal binders are of three classes: (1) gelatinized starches, made from wet milling of corn starch; (2) dextrins, made from corn starch; and (3) gelatinized corn flour made from dry milling hominy grits or meal.

Starch milling process—From the point of view of the starch miller, the kernel of corn consists of the following parts: hull, germ, starch and gluten, together with other constituents such as solubles and hemicellulose. The first object of the starch milling industry is to separate the hull and germ from the starch and gluten. The starch and gluten together are used for the production of the gelatinized cereal binders. In the starch mill, the gluten is separated from the starch, and it is this starch that is given a dry heating or cooking to convert it to the dextrins. The by-products of the milling process are the hull, the residue left after pressing the oil from the germ, the solubles and the hemicellulose. The starch, oil from the germ, and the gluten are the primary products of the starch milling process. Starch and gluten are used together as the base of gelatinized binders because the combination of properties from the starch and the gluten gives better results than either one alone.

The starch and gluten, with the proper amount of water, are fed to rolls which cook and gelatinize the starch and roll it out into a flake. The flake is removed from the roll by a knife or scraper and is ground, screened and packed in bags.

Corn milling process—From the point of view of the corn miller or dry miller, the kernel of corn consists of the hull, germ, soft stock and hard stock, or grit. The hull and germ are removed as much as possible from the grit and soft stock. The hard part of the kernel goes into the hominy and grits, while the soft stock, with hard stock, makes up the meal. The grits or meal are moistened with water, heated, run to hot rolls which gelatinize and flake the grits. The resulting flake is ground, screened and packed in bags.

Advantages of cereal binders—At present, nearly all foundries use cereal binders. There are very definite and cogent reasons back of this widespread use. The particular advantages of cereal binders are listed.

(1) They give good green bond.

TABLE 3.7 — DATA ON CORE BINDERS

Binder	Hardness of Cores Comparative	Moisture for Machine Tempering Per Cent by Volume	Mixing Time Minutes	Bond Ratio by Volume	Removal from Castings Comparative
Linseed oil	Hard	8	5-7	1-40-120	Good
Core oil	Hard	8	5-7	1-40-100	Good
Wheat flour	Medium	10	7-10	1-12-20	Good
Corn flour*	Medium	10	6-10	1-25-50	Good
Dextrin*	Medium	8	7-10	1-10-20	Good
Clay*	Frail	8	7-10	—	Fair
Molasses*	Frail	7	5-8	—	Good
Hydrol*	Frail	7	5-8	—	Good
Sulfite solution	Hard shell	3-5	7-10	1-50-100	Good
Dry sulfite	Medium	8	7-10	1-50-100	Good
Pitch	Hard	7	5-7	1-15-25	Hard
Oilless binder	Hard	7	5-7	1-35-40	Fair
Resin	Soft	7	5-10	1-15-20	Good

*These binders seldom are used alone.

(2) They give good dry bond.
(3) They are particularly effective in sharp sand.
(4) They do not absorb core oil the way clay or naturally-bonded sand does.
(5) They are quick drying in the ovens.
(6) They burn out fast.
(7) They burn out completely.

The effective green bond of cereal binders makes it possible to use sharp sand to produce open cores. With these type binders, a minimum amount of core oil for the additional dry bond is required. The fast drying of cereal binders contributes towards increased production and oven capacity. Quick burning gives collapsible cores. Complete burning out gives easy clean out and minimum build up of fines and closing up of sand.

Cereal binders in conjunction with other binders—In many cases, the conditions in the foundry make it necessary to add other binders to get the particular combination of green and dry bond required. Cereal binders mix well and give good results in mixtures with other binders. The use of sharp sand, with enough cereal binder to give the green bond needed in conjunction with added core oil to give the dry bond required, is a combination that has worked well. In gray iron work, it is sometimes helpful to add clay or bank sand to increase the green bond. Under such conditions, cereal binders will mix well and give good results.

Storage — To prevent damage to bags while cereal binders are held in stock, the bags should be piled on skids or a subfloor which has room enough for vermin to move around beneath it. This precaution will save many torn bags. Cereal binders should never be stored directly on either clay, sand or concrete floors.

Additional Information

Typical specifications for cereal core binders—*Material:* A cereal binder for use in green and dry sand work in the steel foundry.

General requirements: A dry binder of a dextrin and cornstarch base for both green and dry sand work. It shall be of such quality that, when used in dry sand cores, it will not cause the core to swell or crack during baking or soften, deform or blow during contact with the molten metal; and shall permit the core to crush easily after the casting has cooled. The binder shall be of such quality that when used in green sand, a 24 hr, air-dried AFS standard sand shear test specimen at normal temperature of 70 F (21 C), will develop a bonding power of at least 13 lb shear.

Method of inspection and test: A 5 lb sample representative of the material proposed to be furnished shall be forwarded to the plant at the time for submitting bids, for test. A standard AFS sand specimen for shear test made up of a No. 7 grain class washed silica sand and cereal binder in the proportions of 75 to 1 by weight at 2.5 per cent moisture shall be air-dried for 24 hr at a temperature of not less than 70 F (21 C).

The specimen so prepared shall show at least 13 lb shear strength on a shear strength machine. In making the award, consideration will be given to the shear strength obtained over and above the 13 lb required.

All tests will be conducted at the plant.

Tables 3.7 and 3.8 show comparative data on various types of core binders. These tables are published only as a guide. This holds true especially for the column marked "Weight per Gal., lb." in Table 3.8. These figures may vary considerably. For example, the 9 lb per gal weight of resin will vary according to its degree of pulverization. Resin pulverized to pass 200 mesh weighs about 4 lb per gal.

CLASS 4 — FIRE CLAYS

Solids frequently are added to core mixtures to obtain additional green strength, retard the collapsibility of a core, and to prevent cutting or penetration. Such solids include fire clays, bentonites and silica flour, which are used to increase the collapsibility of a core.

Clay

Usual oil-sand core practice involves the addition of a clay-free, fine silica sand to a coarser silica sand. This addition is made partly to smooth up the core, and consequently the casting, but principally to contribute green strength to the core before baking. Because of the much greater surface area of the finer bank sand as compared to the coarser, and also because such bank sands frequently are not entirely free of clay, the addition of bank sand considerably in-

TABLE 3.8 — DATA ON CORE INGREDIENTS

Binder	Specific Gravity, (Approx.)	Weight per Gal, lb	Baking Temperature, F	Baking Temperature, (C)	Binder Destroyed F	Binder Destroyed (C)	Baking Speed, Comparative
Linseed oil	0.93	7.8	450-500	(232-260)	600-700	(316-371)	Slow
Core oil	0.90	7.5	450-500	(232-260)	600-700	(316-371)	Slow
Wheat flour	0.60	4.5-5.5	325	(163)	500-600	(260-316)	Fast
Corn flour*	0.45	2.5-4.5	325	(163)	500-600	(260-316)	Fast
Dextrin*	0.47-0.65	3.9-5.5	350	(177)	500-600	(260-316)	Fast
Clay*	1.0-2.0	8.5-17	300	(149)	2000-3000	(1093-1649)	Fast
Molasses*	1.3	10.5-11.5	250	(121)	400-500	(204-260)	Fast
Hydrol*	1.4	11.7	250	(121)	400-500	(204-260)	Fast
Sulfite solution	1.25	10.5	350	(177)	600-700	(316-371)	Fast
Dry sulfite	0.6	5	350	(177)	600-700	(316-371)	Fast
Pitch	0.46-0.59	3.9-5.0	350-400	(177-204)	500-600	(260-316)	Fast
Oilless binder	0.47	4	350	(177)	500-600	(260-316)	Fast
Resin	1.07	4-9	325	(163)	600-700	(316-371)	Fast
Silica flour	1.3	10.0	—	—	3000	(1649)	Slow
Fire clay	1.2	9.6	—	—	2700	(1482)	Medium
Wood flour	0.23	2.0	—	—	—	—	—
Iron oxide	1.3	10.8	—	—	2500	(1371)	Slow
Bentonite	0.5	7.2	—	—	2700	(1482)	Medium
Silica sand	1.3	10-13	—	—	—	—	—

*These binders seldom are used alone.

creases the amount of core oil which must be added to give a core of satisfactory strength. It decreases the permeability of the core in relation to amount added.

This reduction in permeability limits the amount of bank sand which may be added and, consequently, places a limit upon the amount of green strength which may be obtained from the use of bank sand.

It is well known that the addition of clay to oil-sand mixes increases the amount of oil which must be used. However, it has been found that the addition of a small amount of a strong clay may give as much green strength as a much larger quantity of bank sand and require no more or even less oil for equal strengths. For such equal strengths, the permeability of the clay bonded sand is usually higher.

For green strengths higher than those possible from bank sand, it is necessary to use clay, cereal binders, combinations of the two or naturally-bonded molding sand. Clay and clay-cereal combinations give lower permeability than straight cereal binder and also lower cost. As some naturally-bonded molding sands contain silt as well as clay, such sands usually require the use of more oil than is true when a specially selected bonding clay is used.

A suggested mix in which clay is used and which produces a good green strength is as follows: 600 lb lake sand; 1 gal pulverized fire clay; 1 gal cereal binder; and ¾ gal core oil.

Clay-pitch combinations sometimes are used to bond silica sand, as well as burned core sand and black sand. Any substantial percentage of clay in a core mixture will reduce the collapsibility of the core. This may be disadvantageous on light section castings, but clay-pitch mixtures are used principally on heavy castings of thick section. In such case, the delayed collapse of the core often is an advantage because it gives time for the heavy casting to set. When clay is added to oil-sand mixes, it is added in the smallest quantity which will give adequate green strength. When used in clay-pitch mixtures, it is added in greater amounts because it contributes to baked and hot strength as well as green strength. Mixtures used vary widely depending upon local conditions but a 50-50 by volume mixture of the two bonding agents is a good starting point.

Clay-cereal combinations are used in production foundries for bonding burned core sand and reclaimed sand. Because of a surface coating on the grains, such sands ordinarily require such a large amount of core oil as to make their reuse economically unsound. By eliminating core oil entirely and depending upon clay and cereal binders, hard and satisfactory cores may be, and are being produced in large tonnages. Permeability of such cores is somewhat lower than oil-bonded, new sand cores and they are used on jobs where this is not an important factor. A typical mixture contains: 175 gal burned core sand; 25 gal bank sand; 4 gal corn flour base cereal binder; 2 gal dextrin base cereal binder; and 2½ gal pulverized fire clay.

Green sand cores of a rather intricate nature now are being blown from a mixture of burned molding sand, new silica sand, bonding clay and seacoal. This sand mixture is actually the regular molding sand in the system and the same is used in molding the cope and drag. It is prepared in large quantities and no facing is used. Each time the sand in the system revolves, it is mixed in a muller with an addition of approximately 10 per cent sharp sand, 2 per cent clay bond and 1-16 seacoal by volume. Moisture is maintained at about 3.4 per cent, green compressive strength is 6.5 lb, and permeability is 90. It is necessary to use a bonding clay which gives sand of high flowability. This core replaces the usual oil-sand core. The result is a saving in initial costs, elimination of the drying operation and handling of cores into foundry.

Bentonites

In cores where green strength is required to facilitate coremaking, bentonite may be added to the mixture. Both the western and southern bentonites are used for this purpose. In oil-sand cores for nonferrous, malleable, and gray iron castings, the amount of bentonite added is very small. In cores for steel castings, the amount of bentonite added may be as high as 2

per cent. When more than 0.3 per cent bentonite is added by weight, considerable oil absorption by the bentonite is experienced and additional oil binder must be added to maintain a given baked strength. The use of bentonite in a core mix retards the rate of core collapsibility.

OTHER CORE BINDERS

There are two other groups of core binders about which little is known as to their composition or action in the core. These are the so-called blended pitch binders and the blended binders. In general, these are proprietary materials. In the former class, pitch is used together with one or more other materials. The latter class does not contain pitch. Binders of these classes are special types designed to produce a given result under a certain set of shop conditions.

OTHER CORE MATERIALS

Silica Flour

Silica flour frequently is added to a core mixture where penetration and core cutting by molten metal is encountered. The amount added varies from a fraction of a per cent to as much as 30 per cent by weight. Silica flour reduces the baked strength of an oil-sand core, but the hot strength of the core at elevated temperature, such as 2500 F (1371 C) to which the core is subjected, increases very rapidly as the percentage of silica flour is increased. The test data, as tabulated in Table 3.9, show that the hot strength at 2500 F (1371 C) is increased from 1 psi to 42 psi, when the silica flour is increased from 0 to 5 per cent by weight. An excess of silica flour may cause hot tears and crack defects.

TABLE 3.9 — EFFECT OF ADDING SILICA FLOUR ON THE HOT STRENGTH OF A CORE MIXTURE

Mix	Sand, %	Core Oil, %	Resin Binder, %	Bentonite, %	Silica Flour, %	Hot Strength at 2500 F, psi	Tensile Stgh.
A	92.7	0.9	1.1	0.3	5.0	42	123
B	97.7	0.9	1.1	0.3	0	1	103

A core may have a very low baked strength, for example, 60 psi, and yet have a very high hot strength sufficient to crack a casting.

Sawdust, Wood Flour, etc.

Sawdust, wood flour, straw, hay, etc., are among those core materials which find their usefulness in special types of work. These materials are not binders but are more correctly known as fillers. They have very little adhesive strength but serve instead to reduce the refractoriness of the core body as a whole. In core work, their usefulness lies in softening or weakening the core to render it more collapsible under shrinkage of the cooling casting.

The addition of moderate amounts of sawdust or wood flour has but little effect on the physical tests of the sand, that is on green and dry strength values, but is there to burn out from around the sand grains when subjected to hot metal temperature. In this respect, these products behave oppositely from clays, which harden and strengthen the core under molten metal temperatures.

Sawdust in the sand mix can serve as a guard against over-ramming, the particles of wood acting as a cushion and resisting the packing effect caused by ramming. It is used occasionally as a filler in hollow cores, being porous and therefore a good conductor of gases.

Typical sawdust mixes are encountered in malleable shops. Sawdust is sometimes an ingredient in resin sand, where its value probably results from a strengthening effect on the resin when in molten form and a weakening effect when cool. Sawdust mixes must contain large amounts of sawdust, say 1 to 10 by volume, for it to have any effect, since this material is so light in weight. Sawdust has an adverse effect on casting finish, preventing its general use.

Finely ground sawdust is preferred to coarse material so as not to sacrifice too much in casting finish. Classified grades of both sawdust and wood flour of standardized finenesses are available from the dealers specializing in these products. Miscellaneous sources of rough and nonuniform sawdust are not recommended.

CORE BINDER PERFORMANCE

Very few materials in industry must perform as many exacting functions over a wide range of operation and temperature as a core binder in the foundry. Whether it be in the selection or in the use of a core binder, one should definitely know how the core binder performs each duty or function.

Desirable Attributes and Characteristics

The desirable attributes and characteristics of a core binder number to a total of twenty-four distinct items. They may be outlined as listed.

(1) Core binder should be in concentrated form.
(2) There should be no settling out in drums or storage tanks.
(3) Should be preferably in a single package.
(4) Should be easy to handle.
(5) Should lend itself to being worked with dry or damp run of the mine sand.
(6) Should be easy to mix with the sand.
(7) Should cause minimum of cleaning of mixing equipment.
(8) Should be slow to air dry.
(9) Should not drain to bottom of storage pile of the mixed sand.
(10) Should not impair the flowability of the sand mixture.
(11) Should not stick to walls of core box.
(12) Should lend itself to green strength control.
(13) Should be clean to handle.
(14) Should make patching easy.
(15) Should be easy to bake.
(16) Should not be sensitive to atmosphere in oven.
(17) Should be such that the baked cores will free themselves easily from drier or core plate.
(18) Should possess good warm strength.
(19) Should have low moisture absorption properties.
(20) Should confer ample strength, hardness and permeability on the cores.
(21) Should possess minimum quantity of gas.
(22) Should possess ample collapsibility.

(23) Should lend itself to hot strength control.
(24) Should possess minimum retained strength.

With the wide selection of core binders now on the market, one may control the manner in which the core binder functions at each of the many operations, whether it be concerning the raw material, mixing, making, baking, storing, pouring or shakeout. It encourages a foundryman after he understands each function of a core binder and masters the complete control of a core.

Value of Concentrated Form

A core binder should be in a concentrated form, that is, be strong so that only a small volume of core binder is necessary to bond a batch of sand. A core binder that will strongly bond a sand when an oil to sand ratio, for example, of 1 to 60 parts by volume or better is required, may be considered as being in the concentrated form. When an oil to sand ratio of 1 to 40 parts by volume or less is required, then the core binder is not in a concentrated form.

The disadvantage of using an oil that is not in the concentrated form is that freight, receiving and handling charges and also storage facilities are increased as compared to a concentrated core binder.

Settling Properties

A core binder that settles out in drums or in storage tanks is highly undesirable in that the ingredients of the core binder separate causing a nonuniform oil, resulting in scrap cores.

Single Package Binders

Core binders that are received in a single package and ready to use as delivered to the core room are desirable in that only one material needs to be purchased, received, handled, stored and measured at the time of mixing. Where the core binder consists of two or more separate ingredients, the supervision and labor are increased. It is also necessary to increase the storage and handling facilities. The operator at the sand mixer, with a single package, has only one ingredient to measure as compared with two or more ingredients, which increase chance for error when the core binder is not in a single package.

Ease of Handling

The ease of handling is an item to be considered in weighing the merits of a core binder. It should lend itself to easy handling, storing and measuring.

Value of Functioning Well Under Variable Conditions

Dried core sands have certain advantages, such as ease of moisture control in the mixed sand, and ease of measuring a definite quantity of sand per batch, as compared to the lower price run of the mine sand which is moist. Most plants use run of the mine sand, which requires that the core binder in itself contain no, or very small, quantity of water to avoid wetting a moist core sand to the heavy or wet side. The amount of water used in emulsified core binders should be very small. Where the core binder works with any type of sand, the supervision is materially reduced, which makes for a much more flexible operation.

Ease of Mixing

A core binder should be easily mixed with the core sand to save time in mixing and to insure that a uniform distribution of core binder is obtained in the minimum of time and with the minimum of mechanized effort and power.

Effect on Mixing Equipment

Sticky and gummy core binders, and those that air dry fast, create additional labor in keeping the mixing and measuring equipment clean, which increases the cost of operation.

Advantages of Slow Drying Binders

A core binder that air dries slowly allows greater freedom of operation in the core room. The mixed sand may be stored a longer time, thus allowing the mixing of sand in greater volume at one time and requiring less time of cleaning, mixing, measuring and coremaking equipment. Those core binders that air dry fast require cleaning of equipment when operations are halted for a short space of time to avoid having the sand dried hard and fast to the equipment. Precautions, such as placing damp sacks over mixed sand, need not be exercised when the core binder air dries slowly.

Effect of Binders Which Drain

Those core binders that drain or settle to the bottom of the stored sand in the hoppers, boxes or in the piles of stored sand on the floor, are very undesirable. The amount of drainage is increased as moisture content increases.

Influence on Flowability

Impairment of the flowability of the core sand by the core binder is an item to be considered. The flowability, or the ease with which a sand rams in a restricted portion of a core box, is frequently reduced by the core binder. The reduction of sand flowability may cause porous surfaces on the baked core, resulting in either scrap cores or in metal penetration, should the core be used.

Sticking

Sticking of the core sand to the interior surfaces of a core box causes considerable delay in coremaking. Frequently the sticking is caused by the core binder. Other factors affecting sticking are green strength, temperature of the core box surface, finish of the core box and moisture content of the sand. Increasing the green strength of the mixed core sand is a remedy for excessive sticking of the sand to the walls of the core box.

Green Strength Control

The core binder should impart to the mixed core sand a green strength of a constant value. The green strength conferred by core binder should not be too sensitive to the temper of the mixed sand. When the green strength conferred by a binder is consistent under operating conditions, then it is possible to add a definite amount of green strength imparting material.

Cleanliness of Handling

Good housekeeping is being practiced more each

day in the foundry. It requires that the core binder be as clean as possible and pleasant to the hands of the coremaker. In fact, coremakers seriously object to any core binder that is exceedingly dirty and sticky.

Booking and Patching

Many cores are booked where two halves of a core are folded together to form a single core. The binder should knit or bind the halves together tightly. Any flash air drying of a core binder will seriously handicap booking. A core binder should not affect the core in such a manner as to impair the possibility of good patching by hand tools.

Baking

A core binder should be easy to bake. In other words, the core binder should not be too sensitive to time or temperature of the baking operation. Neither should it be sensitive to degree of baking with reference to size of the core. Light sections of a core should not overbake by the time that the heavy sections of a core are thoroughly baked. The less sensitive a core binder is to degree of baking with reference to core size, the greater freedom is given the core room in baking small and large cores in the same oven.

Sensitivity to Oven Atmosphere

A few core binders are sensitive to the atmosphere within the core oven. A core binder should not be affected adversely by acid fumes from the combustion of the fuel used for heating the core ovens.

Adherence to Plates and Driers

Freedom from sticking of the baked cores in driers or on core plates is also an attribute desired of a core binder. Those core binders that cause additional effort in rapping cores from driers or from plates are not desired. In many foundries, the cores are removed from drier or plate while still quite warm. A core binder should possess a satisfactory warm strength at a temperature of, for example, 150 F (66 C) so that the cores may be rapped out while still warm. The warm strength of a core may be determined by testing the transverse strength of the core at 150 F (66 C). A satisfactory warm strength may be set at 75 per cent of the room temperature transverse strength. The tensile strength test also may be used to determine the warm strength.

Moisture Absorption

The tensile or transverse strength loss due to moisture absorption of the core during storage in the foundry, or while set in a mold for a period of 24 hr, should not exceed 60 per cent. Excessive strength loss due to moisture absorption requires that the additional amounts of core binder be used so that stored cores will still be strong enough after storage to avoid high breakage and metal penetration. High strength loss or surface softening due to moisture absorption often erases all other advantages of a core binder.

Physical Properties

A core binder should impart ample strength and core hardness when used in oil to sand ratios by volume in the range of 1 to 40 or 1 to 120. When oil to sand ratios lower than 1 to 40 are necessary, an excessive bulk of core binder is required, resulting in disadvantages as mentioned previously. The permeability of a core usually ought to be more than ample so as to insure free venting of the gases. Any serious reduction in permeability by a core binder is thus generally undesirable.

Gas Generation

Core binders that generate a considerable amount of core gas on pouring of the mold are looked upon with disfavor because additional mechanical venting must be provided to take care of the additional gases. The gas so generated by a core binder should not be too offensive nor should it condense on cooling, thereby depositing a gum on baking or flask equipment.

Collapsibility

The core binder should collapse, that is disintegrate or burn up, at a sufficient rate to allow the casting to contract while the metal is solidifying and cooling. The rate at which a core binder collapses may be measured exactly with a dilatometer as described in Chapter 13, PROCEDURES FOR DETERMINING THE PROPERTIES OF CORES AND CORE MIXTURES. The rate of core collapsibility is measured in minutes for fast, medium and slow collapsing cores. A fast collapsing core will collapse in 1 to 3 min when heated to 2500 F (1371 C). A medium collapsing core will require 4 to 6 min, while a slow collapsing core will require 8 to 12 min. The heavier the casting thickness and weight, the slower should the core binder collapse.

Some core binders do not collapse of their own accord after being subjected to temperature of 2500 F (1371 C) for a period of 12 min. When this is the case, the core under test is crushed by applying a load. The load required to crush the core is termed hot strength. Cores for many large castings in gray iron and steel require a hot strength range from 3 to 25 psi. Few liquid core binders possess hot strength. Some of the solid core binders, noticeably clay and bentonite, do possess hot strength.

Knockout

The ease with which a core knocks out depends upon the retained strength of the core after the casting is poured and cooled sufficiently to knock out. Retained strength of a core binder is measured by heating a test core specimen to various elevated temperatures and then cooling specimen to room temperature, after which the core specimens are crushed, thus determining this retained compressive strength. It is advantageous that a core binder possess no retained strength because this feature will decrease the cost of core knockout.

Chapter 4

CORE MIXTURES

INTRODUCTION

While there are certain rules for compounding core mixtures, the success or failure of a particular mix usually is not known until it is tried in the foundry. So many variables exist in this field of foundry practice that a mixture that may produce perfect castings in one section of the country may be decidedly inferior in another section. For example, sands available and the economics of the problem often influence the selection of a core mixture for a particular job.

REQUIREMENTS OF A CORE MIXTURE

A core mixture should be so designed that cores made from it will have the following qualities.

(1) Have a strength in proportion to the strength of the particular metal at elevated temperatures and during freezing. A core that maintains its strength over too long a period under heat may cause hot tears or cracked castings.

(2) Collapse at the proper time during the solidification of the particular metal. It has been determined that a core increases in strength up to a certain temperature, passes through a plastic range and finally decreases rapidly in strength. Theoretically, at least, the core should maintain its strength until the metal has formed a sufficient skin around it and then should lose its strength rapidly as the metal begins to contract, thus avoiding casting strains and possible hot tears and cracks. This is because metals are at their lowest strength immediately after solidification.

(3) Present the proper surface to the metal so that, because of high fluidity or other causes, metal will not penetrate the core.

(4) Be sufficiently hard to resist the flow of molten metal along or over its surface. Failure to do so may result in cuts, washes and other defects.

(5) Be resistant to the heat contained in the metal at its pouring temperature.

(6) Be unaffected by mold or other atmospheres generated by the molten metal. Little is known about the behavior of cores in the presence of various atmospheres, but it is thought that such atmospheres may exert an influence and core mixtures must be compounded to resist such possible reactions.

(7) Not lose too much strength during storage.

(8) Not absorb excessive moisture during storage or in the mold, if the mold stands for a considerable period before it is poured.

(9) Withstand required handling without breakage.

(10) Hold its proper shape both before and during the baking period.

(11) Bake as thoroughly and as rapidly as possible, thus requiring a minimum of core baking equipment.

(12) Produce as little gas as possible when the core comes in contact with the molten metal.

(13) Possess smoothness of surface which, in turn, may produce a smooth surface on the casting.

(14) Possess the proper degree of permeability to allow for egress of gases formed during the pouring operation.

(15) Be removed from the casting easily, thus keeping cleaning costs at a minimum.

(16) Not stick in, or otherwise foul, the core box in which the core is made.

Through the cooperation of various members of the American Foundrymen's Society, the author has collected information on core mixtures used in the several divisions of the industry. He wishes to acknowledge the assistance of those who so generously contributed.

CORE MIXTURES FOR STEEL CASTINGS

Mixtures vs. Section Size

For light metal sections of 7/16, 3/8 to 1/2-in. with all small cores, oil, resin, cereal and the blended binders may be used. Metal sections ranging from 5/8 to 1 in., with fairly large cores containing pockets requiring a green strength to hold pockets up, the following binders can be used: resin or oil with either cereal, clay or bentonite. Pitch and blended pitch binders also are used. Due to price fluctuation in cereal binders, bentonite or clay has taken their place in some cases, but cereal binder is preferable on light sections.

On heavy metal sections, using external cores, clay and bentonite binders can be used in the facing, which should be backed with a black core sand using clay binder. This mixture, using half clay and half bentonite, gives the castings a better peel than when clay is used alone.

TABLE 4.1 — CORE MIXTURES FOR STEEL CASTINGS

	Sands		Clays			Binders							
	New Silica Lb	Old Lb	Western Bentonite Qt—Lb	Core Oils Qt—Lb		Cereal Lb—Qt	Casein Qt	Natural Resin Lb	Silica Flour Lb	Pitch Lb	Synthetic Resin Lb	Proprietory Bond Lb	Iron Oxide Lb
Spinning, Heavy Castings	2000		20						120	20	40	40	
Spinning, Light Castings	2000		20						120	30	40		
Spinning, General	2000		20			20	40		120	30		40	
Valve Core	350	470		5½		9			32				
Light Castings	350	470					7½	25					8
Core Back Up Sand		2500				10				57			
Green Core	500	2500	25			25							
Cup Sand		1200		10				10			10		
General	1900			20		25			300				
Soft Core Mix	1640			15		70		40	240				
Blowing Core Mix	325		1	3		3							5
General	200	200	6							8			
Valve Body, Light	240		6	10		3							
Valve Body, Heavy	240		8	1½					90				
Spinning	2000		40	35		10			120	15			
Spinning	1300		25	5		3		40	50	20			
General	1300			5		16							16
Heavy	400		10		5½	2			100				
Light	1000			12									
Medium Weight Castings	96½		1	10		1							

For internal cores, where the metal sections are heavy, cereal and oil binders can be used. In some cases, where sections are heavy, clay-bentonite binder can be used to face the cores; in all such cases a soft backing sand is used behind the facing sand.

In making cores for large steel castings, care must be taken in selecting proper mixtures. Such cores must be rodded to withstand the pressure of metal, and the mixture must allow the core to decrease in strength fast enough to allow the casting to shrink as freely as possible. Chilling and nailing also must be considered.

In selecting a sand mixture, metal thickness and design of core are the important features. If a pocket of sand, which is used to lighten part of the casting, is completely surrounded with heavy metal, a high silica flour content sand may be used and the pockets should be well vented with small vents. On metal sections from 5 to 8 in., the walls and sides can be faced with a mixture of 4 parts sand and 1 part silica flour, but a higher silica content mixture should be used on all the fillets. The metal has a tendency to penetrate or burn in at the fillets and this is somewhat eliminated by using a higher silica content in the mixtures. It is essential that a good wash be used as a coating.

On cores that are completely surrounded with heavy metal sections from 6 to 20 in., such as a screw box core for a rolling mill housing, the core should be faced with a high silica flour content sand to a depth of about 6 in., and backed with a sand of lower silica flour content. The facing sand helps eliminate penetration on the surface and the backing sand gives the gases a chance to escape. Often it is desirable to use all facing in such a core as it is subjected to severe heat. This also applies to all heavy metal sections where pockets of sand are involved.

In most steel foundry work, it is desirable to make cores of medium strength and treat the surface with a spray or core wash or both to obtain surface toughness and resistance to the washing or cutting action of the metal. Such cores will perform their function well and be much easier to shake out and break up than will more rigid cores.

Table 4.1 gives typical steel casting core mixtures.

TABLE 4.2 — CORE MIXTURES FOR MALLEABLE IRON CASTINGS

Parts																
Sands				Binders												
Lake Sand	Bank Sand	Molding Sand	Washed and Dried Silica	Silica Flour	Core Oil	Resin	Cereal	Blended Binder	Moisture Per Cent	Grain Fineness	Green Permeability	Baked Permeability	Green Compression, Lb per Sq In.	Baked Tensile, Lb per Sq In.	Methods of Making	Type of Work
70	—	—	—	—	½	—	—	—	5.0	106	23	25	3.1	32	Machine	Mostly Misc.
20	75	—	—	—	½	—	1¼	—	4.2	99	44	55	1.8	32	Machine	Small to Medium
20	75	—	—	—	1	—	3	—	3.9	99	45	60	1.8	60	Machine	Small to Medium
—	—	—	95	—	4	—	—	—	.0	69	—	71	—	200	Bench	Strainer Cores
95	—	—	—	—	1½	—	4	—	2.8	59	160	195	—	127	Machine	Small Cores
90 (dry)	—	—	—	5	3½	—	2	—	1.0	63	150	155	—	170	Machine	Boss Cores
50	—	50	—	—	—	3	—	—	4.6	84	38	64	2.8	8	Machine	Collapsible Cores
—	—	—	90	—	2	—	3[1]	—	—	—	—	—	—	—	—	Small to Medium
—	15	—	45	—	—	3	1½	—	—	—	—	—	—	—	—	Misc.
—	—	—	1000[2]	—	8[2]	—	—	8[2]	—	—	—	—	—	—	—	—
—	—	—	1000[2]	—	—	—	—	20[2]	—	—	—	—	—	—	—	—

[1] More cereal binder can be added where high green strength is necessary.
[2] Pounds.

TABLE 4.3 — CORE MIXTURES FOR GRAY IRON CASTINGS

No. Type Castings	Sands: New Silica Lb.	New Silica Qts.	New Silica Parts	Old Lb.	Old Qts.	Old Parts	Burned Core, Lb.	Loam Lb.	Binders: Bentonite Lb.	Bentonite Qts.	Bentonite Parts	Core Oil Lb.	Core Oil Qts.	Core Oil Parts	Cereal Lb.	Cereal Qts.	Cereal Parts	Sulfite Li Parts
1. Runner Cup Cores						15												
2. Cover, Slab, etc., Cores			7			7												
3. Large	120						120											
4. Large							90	72										
5. Large	200						720		3									
6. Large			12			12												
7. Filler Sand, Large Cores						45												
8. Heavy	136[1]			48[3]									6			2		
9. Heavy		15[3] + 22[4]											1			½		
10. Heavy			40			40											1	
11. Heavy		224[5] + 56[6]														4		
12. Heavy	1000[5]															4		
13. Medium		21[7] + 28[4]														1		
14. Medium			80														2½	
15. Medium						70								0.7				
16. Medium			112											2				
17. Medium	750[5] + 250[3]																	
18. Automotive	1000[5]												4			2		
19. Automotive		180 + 210[9]			30[8]					1¼			6			8		
20. Automotive			250								2			2¾			5	
21. Automotive			450										8			5		
22. Automotive		520 + 280[3]											13		20			
23. Light			112											2				
24. Light			90											1			4	
25. Light		280[5]											5			4		
26. Light		1000											22			12		
27. Stock Cores			90[10]											1			3-4	
28. In-gate Cores			25[11]					200						1				
29. Pipe Fittings (4-24-in.)	400			400[12]														
30. Centrifugal Pipe	125			875[13]											4			
31. Centrifugal Pipe	175			875[13]											6	4-5		
32. Automotive, Agricultural, Diesel Cores		100[5] + 20[3]											1					
33. Heavy		25[14]			75[12]													
34.	1000											6						
35.	1000											8						
36.	900																	
37.	300			700														
38. Automotive—Slinger	730[1] + 300[3]								10				5½		8			
39. Automotive	900[1] + 100												4½		12			
40. Automotive	900[1] + 100[3]												8		10			
41. Automotive—Blower	700[1] + 300[3]								4				5½		9			
42.	800[1] + 200[3]												3		12			
43. 1-in. Metal Section	300			100	Albany							5						
44. 2-in. Metal Section	140			40	Bank							3			4			
45. 3-in. Metal Section				1200					1.2						1			
46. 4-in. Metal Section	1200									8			8					
47. Pocket Sand	800									4			12		12			12-qt. Fl
48. Medium	800																	
49. Medium	700	Lake Sand										10			6			
	200	Bank Sand										11			8			
50. Medium	100								1									

CORE MIXTURES FOR MALLEABLE CASTINGS

The sands used in malleable cores can be classified under three general types: lake, dune, or bank sand; crushed rock; and Ottawa or other silica sand.

Sand Fineness

The fineness of sand used will vary according to the class of work. The distribution of the sand should be such that at least 75 per cent of the grains will remain on any three consecutive sieves. The shape of the grain will vary from rounded to subangular.

In most cases, the sands are clay free. There are some instances in which a small percentage of natural bond is desirable.

A minimum sintering point of 2500 F (1371 C) is of advantage in preventing the sand from burning in. However, this is not a cure-all for this defect.

Binders

Sand to oil ratios will vary considerably due to the variations in the type of casting and the purpose for which the core is to be used in the fabrication of the casting. The average sand to oil ratio is about 80 to 1 (by weight).

For general malleable work, the cereal binder will run from 0.75 to 1.25 per cent (by weight).

It is not desirable to use an excessive amount of clay or bentonite in malleable core sands, due to the increased amount of oil which such sands require and excessive hot strength produced. Driers should be used

TABLE 4.3 — CORE MIXTURES FOR GRAY IRON CASTINGS

Type	Casein Type Qts.	Fire Clay, Lb.	Resin Type Lb.	Resin Type Qts.	Blended Binder, Lb.	Pitch Core Compound Lb.	Pitch Core Compound Qts.	Pitch Core Compound Parts	Saw Dust Lb.	Remarks
								1		1—
								1		2—Use open, new silica sand.
						12				3—
						6			12	4—
						5				5—
								1		6—
								1		7—
										8—[1]Lake sand—45 A.F.A. fineness. [2]Weak molding sand. Permeability, 20-30.
										9—[3]Bank sand. [4]Core sand.
								1		10—
							4			11—[5]Lake sand. [6]Albany sand.
	8									12—[5]Lake sand.
										13—[7]Bank sand—6% clay. [4]Core sand.
										14—
										15—Add 12.5% moisture.
										16—
	16									17—[5]Lake sand. [3]Bank sand.
	4									18—Motor housing cores. [5]Lake sand.
										19—[8]Reclaimed core sand. [9]Bank sand—Slinger rammed. Barrel core.
										20—Slinger rammed.
										21—Jacket cores.
										22—Gear box cores. [3]Bank sand.
										23—A.F.A. fineness—56.
										24—
							4			25—[5]Lake sand.
										26—
										27—[10]Open silica.
										28—[11]Fine silica.
			10							29—[12]Heap sand. Add 6% molasses water. Bake overnight at 375-450°F.
			4							30—Bell cores—8-in. [13]Returned sand. Moisture 6%. Bake 2 hr. at 350°F.
			4							31—Bell cores—12-in. [13]Returned sand. Moisture, 6%. Bake 2 hr. at 350°F.
				2						32—[5]Lake sand. [3]Bank sand. Moisture 2.5-4%. Transverse strength, over 25 lb. For cores to withstand considerable handling.
				6-8						33—[12]Heap sand. Temper with 6-8% sulfite liquor water. Strong, hard core that cleans easily. [14]Sand type, Millville gravel. Bake overnight at 400-450°F.
					8[14]					34—[14]Blended binder.
		20			10[14]					35—[14]Blended binder.
		100			30[15]					36—[15]Blended pitch binder.
					10[15]					37—[15]Blended pitch binder.
										38—[1]Lake sand. [3]Bank sand. Add 7 qts. water. Crankcase and transmission cores.
										39—[1]Lake sand. Add 8 qts. water. Small cylinder and transmission case cores.
										40—[1]Lake sand. [3]Bank sand. Add 5 qts. water. Large slab and gear end cores.
										41—[1]Lake sand. [3]Bank sand. Add 7 qts. water. Tappet Cores.
										42—[1]Lake sand. [2]Bank sand. Add 9 qts. water. Small assembly cores.
					8					43—
										44—
						3.6				45—
				24						46—
		36				49+	Graphite			47—
										48—Lake sand.
									4	49—
									2	
						1			1	50—Western bentonite.

wherever possible to keep the green bond at a minimum. Five-tenths of 1 per cent (0.5) or less by weight of binder should produce the necessary green bond or stiffness in the sand.

Moisture

Moisture contents will vary, depending on the method of making the core. In blowing machine work, where maximum flowability is desirable, the moisture content will vary from 2.5 to 3.5 per cent. However, there have been instances where moistures of 5.0 to 6.0 per cent have produced a high quality core. In bench work or non-blowing machine work, the moisture usually will average 5 per cent or more. All core sands should be dried before being used to insure accurate moisture control.

Table 4.2 shows typical malleable core mixtures.

CORE MIXTURES FOR GRAY IRON CASTINGS

Core mixtures used in the gray iron foundries may be divided into two classes. The more general is the oil-sand cores which are used for all general light and medium gray iron castings. The other class of cores is spoken of as black cores, because they are bonded with pitch. Oil-sand cores also may be used for heavy castings, provided a small portion of clay substance is added to increase the life of the core at elevated temperatures.

Some of the core mixtures that are found in use in gray iron foundries are shown in Table 4.3. When using mix 29 and when cores air dry all day and are

baked at night, it is good practice to spray cores well with glutrin or molasses water late in the afternoon or just before putting them in the oven. This insures a good hard surface and sharp edges.

Mix 33 indicates that resins are used logically in heavy cores with gravel sands containing clay. A core made from that mix will be strong and hard, yet will clean easily, since the heat of pouring does not harden it further. Some foundries use resin binder in combination with pitch, adding the latter to obtain more resistance to heat in heavy section work. By a few trials, they work out a balanced core which is tough enough to stand the heat of pouring, yet which cleans out readily.

Mixes 38, 39, 40, 41 and 42 are core mixtures used in an automotive foundry. Mix 38 is a slinger sand used for crankcase and transmission cores. It has the following properties: green shear strength, 1.10 lb; green permeability, 120; dry permeability, 150; tensile strength, 92.5 psi; and produces cores with a hardness of 60 to 75. Mix 39 is for hand-rammed small cylinder block and transmission case cores. This mixture has the following properties: green shear strength, 0.4 lb; green permeability, 210; dry permeability, 240; tensile strength, 123.5 psi; and produces a core hardness of 75 to 82.

Mix 40 is used for large hand-rammed slab and gear end cores. It has the following properties: green shear strength, 0.60 lb; green permeability, 180; dry permeability, 210; tensile strength, 165 psi; and produces a core hardness of 72 to 88. Mix 41 is a core blower mixture used for tappet cores. It has the following properties: green shear strength, 0.90 lb; green permeability, 130; dry permeability, 150; tensile strength, 130.5 psi; and produces cores with a hardness of 80 to 87. Mix 42 is used for small bench-made assembly cores. This mixture produces cores of the following properties: green shear strength, 0.40 lb; green permeability, 240; dry permeability, 260; tensile strength, 178.5 psi; and gives a core hardness, 72 to 84.

The sieve analyses of the lake, bank and silica sands used in core mixtures 38, 39, 40, 41 and 42 are shown in Table 4.4.

TABLE 4.4 — TYPICAL SIEVE ANALYSES OF SANDS USED IN MIXTURES 38, 39, 40, 41 AND 42, TABLE 4.3

Sieve No.	Lake Sand	Bank Sand	Silica Sand
6	0.0	0.0	0.0
10	0.0	0.0	0.0
20	0.0	0.0	0.0
28	0.60	0.0	1.00
35	4.80	1.00	38.80
48	25.00	5.60	45.80
65	46.80	17.40	14.60
100	20.60	29.60	1.80
150	0.80	21.80	0.00
200	0.60	15.60	0.00
270	0.20	5.60	0.00
Pan	0.40	1.40	0.00
AFS Clay, per cent	0.20	1.00	0.00
AFS Clay Class	A	B	A
AFS Grain Fineness No.	49	92	35
AFS Fineness Class	6	4	7

CORE MIXTURES FOR BRASS AND BRONZE CASTINGS

The usual recommendation for cores for brass and bronze alloys is "use new sharp silica sand and a straight oil binder." Many foundries use a mixture of molding sand and silica sand for cores. A specification for silica core sand, recommended by the Brass and Bronze Ingot Institute,* is shown in Table 4.5.

If the sand meets the suggested specifications, it will not contain large coarse particles nor a large proportion of fines. The core sand should not contain materials which will expand unevenly on heating, causing small defects in the cored surfaces of the casting. Such materials may be either of an organic nature or may be in the form of mica or micaceous minerals.

The best permeability of the core is obtained when all the sand is fairly uniform in size and fairly coarse, but it is obtained at the sacrifice of some green strength. Some improvement in green strength and surface finish of the casting results if some fine silica sand or sandblast dust is mixed with the core sand. These advantages are obtained at the sacrifice of permeability.

Silica sands used for brass and bronze castings may be classified into three grades.

(1) Fine silica sand with AFS Grain Fineness Numbers from 130 to 160.

(2) Medium silica sand with AFS Grain Fineness Numbers from 90 to 120.

(3) Coarse silica sand with AFS Grain Fineness Numbers from 55 to 80.

Oil Sand Ratios

Generally the amount of core oil used should be kept at a minimum and a ratio of over one of oil to 40 of sand is rarely necessary. Wherever possible, the ratio of core oil used should be reduced to one of oil to 60 or 80 of sand. If the oil and sand are mixed properly and intensively, the amount of oil required will be less than if such mixing is not followed. Each grain of sand requires a thin film of oil, but no surplus oil need be between sand grains. This uniform surface distribution is obtainable in a muller type mixer.

TABLE 4.5 — SPECIFICATION FOR NONFERROUS CORE SAND*

Sieve No.	Percentage Retained Min.	Max.
6	—	10
12	—	10
20	—	10
30	—	10
40	—	20
50	20	—
70	20	—
100	—	20
140	—	10
200	—	5
270	—	2
Pan	—	1
Clay	—	3
Fineness	50-80	

*Recommended by Brass and Bronze Ingot Institute for brass and bronze cores.

*"Ingot Brass and Bronze," Section 5, p. 12.

TABLE 4.6 — CORE MIXTURES FOR BRASS AND BRONZE CASTINGS*

	Parts																	
	Sands						Binders											
	Lake	Beach	Bank	Molding	Washed and Dried Silica	Silica Flour	Core Oil	Cereal Binder	Resin Binder	Core Compound	Moisture, Per Cent	Grain Fineness	Green Permeability	Baked Permeability	Green Compression, Strength, psi	Baked Tensile, Strength, psi	Driers Used	Method of Making	Type of Work
1.	60	—	—	—	—	40	3	—	—	—	2.9	138	11	17	4.9	50	no	Bench	Long thin cores
2.	70	—	—	—	—	30	1	—	—	—	5.0	106	21	23	4.1	32	no	Bench	Valves
3.	20	—	75	—	—	5	2	1	2	—	3.2	99	46	55	1.8	87	yes	Machine	Valve and Misc.
4.	—	—	—	—	95	5	3½	—	—	—	.0	69	—	63	—	257	yes	Bench	Valves
5.	90[15]	—	—	—	—	10	3½	—	2	—	1.0	63	150	155	—	170	yes	Machine	Boss cores
6.	95[15]	—	—	—	—	5	3	—	—	—	.0	59	—	134	—	215	yes	Machine	Strong small cores
7.	50	—	—	50	—	—	—	⅛	3	—	4.1	84	42	52	2.9	9	no	Bench	Collapsible cores
8.	138[1]	—	20[1]	12[1]	—	—	1⅔[2]	—	—	4[3]	—	—	—	—	—	—	—	—	Small
9.	230[1]	—	40[1]	—	—	—	2[2]	—	—	3¾[3]	—	—	—	—	—	—	—	—	Small
10.	—	9[12]	7[2]	—	—	—	2[2]	—	—	—	3.5	—	—	—	—	—	—	Machine[4]	Small Plumbing
11.	—	49[2]	49[2]	—	—	—	2¼[2]	—	—	—	3.0	—	—	—	—	—	—	Machine[4]	Valve Bodies[5]
12.	—	28[2]	70[2]	—	—	—	2[2]	—	—	—	3.5	—	—	—	—	—	—	Machine[4]	Valve Bodies[6]
13.	—	7[2]	9[12]	—	—	—	2[2]	—	—	—	10[2]	—	—	—	—	—	—	Bench	Small Plumbing[7]
14.	—	14[2]	84[2]	—	—	—	1½[2]	—	—	—	12[2]	—	—	—	—	—	—	Bench	Large Bodies or Fittings
15.[12]	920[1]	—	—	—	—	—	4[2]	—	—	—	3.5	—	140	160	0.1	85	yes	Bench	[8]
16.[12]	620[1]	—	220[1]	—	—	—	4, 8 or 12[2]	—	—	—	3.5	—	95-90-85	110-105-100	0.5	85-160-250	yes	Bench	[9]
17.[12]	—	—	840[1] 10	—	—	—	8, 12 or 16[2]	—	—	—	3.0	—	35-30-25	40-35-30	3.0-2.5-2.0	85-150-225	no	Bench	[11]
18.	—	—	—	—	120[2]	—	—	2[2]	4[2]	—	5.0	—	—	—	—	—	—	—	Bronze Bushings[13]
19.	—	—	—	30[2]	90[2]	—	—	—	5 to 6	—	5.0 to 6.0	—	—	—	—	—	—	—	[14]
20.	—	—	—	—	80	—	1	2	—	—	—	—	—	—	—	—	—	—	Misc. Brass
21.	—	—	—	4	14	—	—	1	—	—	—	—	—	—	—	—	—	—	Center Cores for Bronze Bushings
22.	70[2]	—	30[2]	—	—	—	1.5[2]		—	—	5[2]	—	—	—	—	—	yes	—	—
23.	60[2]	—	40[2]	—	—	—	1[2]	1.5[1]	—	—	4[2]	—	—	—	—	—	—	—	—
24.	500	—	—	—	—	20	11	—	—	—	—	—	—	—	—	—	—	—	High tin Bronze
25.	—	—	—	—	1000	—	120 Cement	—	—	—	—	—	—	—	—	—	—	—	Bronze, large
26.	100	—	—	200	—	—	—	4.5	—	—	—	2 Resin	—	—	—	—	—	—	Bronze, large

*Unless specifically mentioned, these core mixtures are used in brass casting cores.
[1]Pounds.
[2]Quarts.
[3]Pints.
[4]Core blowing machine.
[5]½ to 1 in. size.
[6]1¼ to 2 in. size.
[7]From ¼ to 2 in.
[8]For small or large castings with large cored area and small openings. Cores meet very high permeability requirements.
[9]For small or large castings which require moderately high permeability cores.
[10]3 to 4% clay, AFS Fineness No. 118.
[11]For small or medium sized castings which do not require very permeable cores. For cores usually referred to as "stand-up work."
[12]Can be used in machines when low moistures are used. From 0.5 to 1.5 per cent cereal binder replaces part of the oil.
[13]Bake 1 hr at 400 F.
[14]Bake 1 hr at 400 to 450 F.
[15]Dry.

Moisture

Some moisture, usually 3 to 4 per cent, is necessary in a straight oil and sand mixture. Whether the moisture is in the sand before the oil is added, or whether the oil should be added to dry sand and the moisture added later, is somewhat controversial and is discussed elsewhere in this volume.

Properties

Maximum strength after baking is obtained in straight oil–sand cores. Such a mix has low green strength and high permeability. The addition of some fine silica sand, or molding sand, to the core sand mixture, produces a greater green strength with less permeability and a core which, after baking, is not as hard as those made of straight oil and sand. However, the hot strength is increased, which may cause hot tears in the casting.

Other Binders

Other bonding agents are sometimes used with core oil, or to completely replace core oil. Numerous core binding materials are available. Some are water soluble, such as cereal binders; some of animal origin, such as glue binders; and some are of mineral origin, such as pitch binders or resins. Table 4.6 shows some core mixtures used for brass and bronze cores. Cores for difficult bronze brushings may be made from carbon rods.

Resin binders are used in either combination with cereal binders or mixtures containing some molding sand. Typical examples are shown in mixtures 18 and 19, Table 4.6.

For aluminum, the mixture given above for brass and bronze may be used, making a weaker core to insure quicker collapsibility. In some cores for bronze castings, it may be desirable to add 1 quart core oil to provide additional strength and resistance to cutting.

When a core mix is made by the addition of molding sand to a straight core sand, a certain amount of clay binder is introduced with the molding sand. This clay binder normally requires water and it adds considerable green strength. If enough water is not supplied, an excessive amount of core oil is necessary. In some foundries, as much as 25 or 30 per cent of molding sand is used with the core sand with satisfactory results. In such cases, the moisture content is often increased from 4 to 5 per cent.

CORE MIXTURES FOR COPPER CASTINGS

Before discussing the core requirements for copper castings, it might be appropriate to mention some of the characteristics of the metal as it relates to these requirements. Copper is a very ductile metal after it solidifies, but at the point when it changes from the liquid to the solid state, the metal is very brittle. During this state of embrittlement, it fractures easily if the backing sand does not contract readily.

Copper, in heavy sections, is extremely susceptible to mold and core gases; probably this is due to its higher relative conductivity which prevents the forma-

tion of an impervious shell at the core or mold surface immediately after pouring. The lack of this shell causes the metal to absorb readily any gases emanating from the core or mold surface adjacent to the metal itself.

It is desirable that sand for copper cores be high in permeability and of the rounded grain class to facilitate their collapsibility. Finish is obtained by having a high percentage of grains on two or three adjacent sieves and also by use of adequate core washes.

Oil or cereal binders are recommended and in many cases only about 15 per cent clay is used as a binder. The main requirement is to use only sufficient binder to hold the core together, as core arbors are used and dependence is placed on them rather than upon the strength provided by the binder. An oil-sand ratio of 75 to 1 is used where the green strength of the core is not a requirement. When a higher green strength is required, cereal binder in about a 75 to 1 ratio is used.

Two core mixtures for copper castings that have proved satisfactory are shown in Table 4.7.

TABLE 4.7 — CORE MIXTURES FOR COPPER CASTINGS

	Sands				Binders			
	Silica		Old Core,	Bank	Casein	Oil,	Cereal,	Sawdust,
	Lb	Parts	Lb	Parts	Qt	Parts	Parts	Qt
1.....	500	—	500	—	6	—	—	50
2.....	—	32	—	64	—	3	1½	—

CORE MIXTURES FOR ALUMINUM CASTINGS

The general methods of making cores and molds used with other metals are quite suitable for aluminum alloys. Methods for handling and conditioning sand and practices of coremaking are quite similar regardless of the metal used. However, the properties of aluminum alloys establish certain preferred core characteristics which differ somewhat from those suited to other metals. The making of cores for the casting of aluminum alloys is not difficult where the characteristics of the metal are understood.

One of the most significant characteristics of aluminum alloys which influences core practices is their light weight. Aluminum alloys weigh approximately one-third as much as brass, cast iron or steel. This characteristic is of distinct advantage in that it lowers mold pressures and permits the use of lower strength cores. On the other hand, the low density of aluminum makes it somewhat more difficult for the metal to drive off mold and core gases than is the case with the heavier metals. Permeability of the core therefore assumes greater significance to insure the exit of the core gases.

A second characteristic of aluminum alloys which demands consideration during casting is their hot shortness. At temperatures just below those at which the metal solidifies, the strength of aluminum alloys is quite low. Any abnormal resistance to contraction, while a casting is passing through this temperature range, may result in cracks.

The aluminum-silicon alloys are much less hot short than the aluminum-copper alloys, particularly those alloys containing less than 5 per cent copper. Proper choice of alloy, as well as care in making cores to insure minimum resistance to contraction, is effective in overcoming casting cracks from this cause.

Selection and Control of Sand

The proper selection and control of core sands are important because of their relation to the various inherent properties of the metal and because of their effect on the surface appearance of the castings.

Cores for aluminum alloy castings consist of mixtures of silica sands and sometimes molding sands, together with a bonding material and water. The usual bonding materials are made chiefly from linseed and

TABLE 4.8 — CORE MIXTURES FOR ALUMINUM CASTINGS

	Sand					Binder						AFS	AFS	
	Silica		Bank,	Burned Core,	Molding	Core Oil,	Casein Type,	Dextrin Base,	Pitch Base,	Resin,	Cereal,	Permeability	Comp. Strength	
	Parts	Lb	Parts	Parts	Parts	Parts	Parts	Parts	Parts	Parts	Parts	(Approx.)	Psi	General Use
1.	50[2]		50			1		1[1]				50	200	Small to medium castings requiring very smooth surface
2.	100[3]					1		1½[4]				150	550	Jacket cores and cores with thin section
3.	66		34			1½						85	350	General run of small cores
4.			37	63					2			40	100	Large body and housing cores
5.			25	63	12			3[1]				25	325	Side cores in contact with metal on one side only
6.			64			1		2						Miscellaneous
7.			32			1½								Soft cores
8.		1000					10							
9.	3				1					1-15 or 20[5]				Note 6
10.	10				10[7] + 30[8]						1			
11.	80					1					2			
12.		1500				9 qt								Cylinders
13.		800	200 lb			7 qt	18					100	2.5	Large castings
14.		300		100 lb	Silica flour	8 qt								
15.		700	300 lb			10 lb Plastic								

[1]Dry bond.
[2]AFS Grain Fineness No. 85.
[3]AFS Grain Fineness No. 65.
[4]Green bond.
[5]Ratio.
[6]Cores to be sprayed with molasses water.
[7]New molding sand.
[8]Foundry sweeping.

other oils, resins, starch, pitch, flour or combinations of these materials. The properties of cores may be regulated by varying the percentage as well as the kind of binder used. The properties and uses of a few typical core mixtures are given in Table 4.8.

The sands used in the first five mixtures listed in Table 4.8, have the characteristics shown in Table 4.9.

TABLE 4.9 — SAND CHARACTERISTICS

Sand	Grain Shape	Grain Fineness No.
Bank Sand	Subangular	90
Washed Silica Sand	Rounded	85
Washed Silica Sand	Rounded	65
Sharp Sand	Angular	55
Molding Sand	Subangular	270

Cores should be as soft as is consistent with safe handling. Hot shortness of aluminum alloys requires the use of body and housing cores that are soft enough to be crushed easily by the casting as it solidifies and contracts.

The light weight of aluminum alloys makes high core permeability necessary. Thorough venting of cores is important in minimizing the occurrence of blows and porosity in castings.

CORE MIXTURES FOR MAGNESIUM CASTINGS

Cores for magnesium castings should be made from an open sharp sand, and should be provided with adequate vents to facilitate removal of hot gases. Most core troubles can be traced to lack of attention to details insuring a minimum of gas evolution or to failure to provide venting of the gas which is formed.

Binders

Generally, any good quality core oil is suitable for use, but preference should be given to those forming a minimum of gas. Cereal binders find a limited application. As they tend to absorb moisture, especial care is necessary to keep cereal-bonded cores warm and dry before use. In choosing a core binder, consideration must be given also to the ease with which the cores can be removed from the casting, as determined by trial. Ordinary ratings of this characteristic may not apply in casting magnesium alloys, as the temperature and heat capacity of the light metal surrounding the core is low and the core bond will not be burned out as in the casting of heavier metals.

Use of Inhibitor

It is necessary that the core sand be treated with an inhibitor to prevent burning of heavy metal sections. Two types of practice have been developed for obtaining this protection. In one case, low percentages of sulfur and boric acid are mixed with the core sand, while in the other type, the baked cores are sprayed with an aqueous solution of a fluoride. In the latter case, it is necessary to return the sprayed cores to the oven for a short drying period (30-60 min) after the spraying operation. The fluoride spray is used also on the cores containing sulfur and boric acid where very heavy metal sections contact the core. Additional protection is sometimes obtained by painting parts of cores with a suspension of sulfur in alcohol. This is used to a limited extent, however, due to the danger of too heavy a coating of sulfur remaining on the core and causing trouble by bubbles of gas passing through the metal if proper venting of the core is not attained.

Core Mixtures

A typical core sand mixture for general use is given in Table 4.10.

TABLE 4.10 — TYPICAL CORE SAND MIXTURE

	Parts by Volume
Sand*	1000
Oil	12
Cereal	8
Sulfur	13
Boric Acid	13

The sand* is a mixture of 40 per cent, with 100 average grain fineness, and 60 per cent with 65 average grain fineness. Moisture content is 6.5 per cent by weight.

Standard AFS specimens, before and after baking 2 hours at 420 F (215 C) will have approximately the properties shown in Table 4.11.

TABLE 4.11

Green Compressive Strength, psi	0.3
Baked Tensile Strength, psi	120
Hardness	85
Permeability	85

TABLE 4.12 — CORE MIXTURES FOR MAGNESIUM CASTINGS, LB

No.	Washed and Dried Silica Sand	Bank Sand	Lake Sand	Linseed Base Core Oil	Plastic Core Binder	Cereal Binder	Casein	Sulfur	Boric Acid	Potassium Fluo Borate	Kerosene	Fly Ash
1.		2500			19	19		12.5	12.5			
2.		2500				19	50	12.5	12.5			
3.		2500			32	19		12.5	12.5			
4.	600				8	5		3	2			30
5.	1000				10	10		5	10			
6.			900	6	9			4.5	4.5			45
7.	1000				10	5		5	5		5	
8.	1000				10	10		2	5	5		
9.		36	66	1		1.5		1	1			

TABLE 4.13 — WEIGHT OF BINDER FOR DIFFERENT RATIOS*

Bond, Ratio by Volume	Binder, gal per ton Sand	Core Oil, (7.5 lb per gal) lb	Wheat Flour, (5.5 lb per gal) lb	Corn Flour, (4 lb per gal) lb	Sulfite Liquor, (5 lb per gal) lb	Pitch, (4 lb per gal) lb	Resin, (9 lb per gal) lb
1 to 10	13.5	102.5	74.25	54.0	67.5	54.0	121.5
1 to 20	6.75	50.60	37.1	27.0	33.75	27.0	60.75
1 to 30	4.5	33.8	24.75	18.0	22.5	18.0	40.5
1 to 40	3.4	25.5	18.9	13.6	17.0	13.6	30.6
1 to 50	2.7	20.25	14.9	10.8	13.5	10.8	24.3
1 to 60	2.25	16.9	12.4	9.0	11.25	9.0	20.25
1 to 70	1.9	14.25	10.5	7.6	9.5	7.6	17.1
1 to 80	1.7	12.75	9.4	6.8	8.5	6.8	15.3
1 to 90	1.5	11.25	8.25	6.0	7.5	6.0	13.5
1 to 100	1.35	10.25	7.4	5.4	6.75	5.4	12.0
1 to 110	1.2	9.00	6.6	4.8	6.0	4.8	10.8
1 to 120	1.1	8.25	6.1	4.4	5.5	4.4	9.9
1 to 130	1.0	7.5	5.5	4.0	5.0	4.0	9.0
1 to 140	0.9	6.75	5.0	3.6	4.5	3.6	8.1

*Before using these data, see accompanying paragraphs.

By addition of more oil, the strength can be raised as desired, but care should be taken to avoid excessively strong internal cores as they may cause casting cracks. Softer cores may be made by reducing the amount of oil, with, of course, increased fragility and difficulty in handling. The addition of 5 parts (volume) of bentonite raises the green compressive strength to about 1.0 psi and may be desirable for certain jobs. However, additional oil will be required to maintain the desired baked strength.

DATA FOR RAPID CALCULATION OF CORE MIXTURES

As an aid in rapidly calculating proportion of binder for difficult ratios of sand to binder, Tables 4.13 and 4.14 are given.

While Table 4.13 includes the binders which are used alone as binders, it can be used also to determine the weight of binder in sand mixes having several bonds.

It is interesting to note that the data presented in Tables 4.13 and 4.14 are based on the assumption that one gal of sand weighs 14.5 lb. There appears to be considerable difference of opinion concerning this figure. It should also be pointed out that, in Table 4.13, the weights per gal of the various materials do not hold for all materials of the class indicated. As an example, the weight per gal of resin varies considerably with the degree of pulverization. The figure given in Table 4.13 for that material appears to be based on solid resin. When pulverized to pass a 200 mesh sieve, resin weighs approximately 4 lb per gal.

Tables 4.13 and 4.14 have been criticized by one individual who states that, from data acquired from many tests over a long period of time, the weight of core sand varies from 11 to 13 lb per gal with an average of 12 lb per gal. This same statement has been certified by another individual who uses 12 lb per gal as a basis for calculating mixtures for testing various core binding materials. On the other hand, a large manufacturer of automotive equipment gives the following weights per gal for dry lake, silica and bank sands respectively, 14.0, 14.5 and 12.5 lb. This seems to verify somewhat the weight of 14.5 lb per gal on which Tables 4.13 and 4.14 are based.

However, this very confusion is enlightening as it shows the fallacy of measuring instead of weighing the constituents of a core mixture. There are too many variables that may affect a core mixture when the ingredients are measured. The goal of every foundryman should be to duplicate conditions as closely as possible from day to day. To accomplish this in the core room requires that the ingredients of core mixtures be weighed instead of measured.

Although there appears to be a divergence of opinion concerning the weight of both sand and binder per gal on which the data in Tables 4.13 and 4.14 are based, these tables are presented for what they may be worth as a guide.

TABLE 4.14 — CONVERSION TABLE FOR BOND RATIOS*

Bond Ratio, Bond to Sand by Volume	Gal per ton sand	Gal per cu yd sand
1 to 10	13.5	20.25
1 to 20	6.75	10.125
1 to 30	4.5	6.75
1 to 40	3.4	5.1
1 to 50	2.7	4.0
1 to 60	2.25	3.375
1 to 70	1.9	2.85
1 to 80	1.7	2.5
1 to 90	1.5	2.25
1 to 100	1.35	2.0
1 to 110	1.2	1.8
1 to 120	1.1	1.6
1 to 130	1.0	1.5
1 to 140	0.9	1.4

*Before using these data, see accompanying paragraphs.

TABLE 4.15 — APPROXIMATE SAND MEASURES*

1 cu yd = 202 gal = 3,000 lb = 27 cu ft.
1 cu ft = 7.5 gal = 90 lb.
1 ton sand = 135 gal.
1 gal = 231 cu in. = 14.5 lb = 4 qt = 8 pt = 32 gills.

*Before using these data, see accompanying paragraphs.

Chapter 5

STORAGE AND CONDITIONING OF CORE MATERIALS

INTRODUCTION

Core sand storage, sufficient to assure a continuous supply of sand to the core room, is vital and, if best results are to be obtained in the core room, the sand should be covered. Reinforced concrete makes the best bins where any great amount of sand is to be stored. Steel plates often are used, but with continued use of this type of bin, the partitions will soon rust, thus necessitating expensive replacements. Planking may be used, but usually difficulties are encountered due to their rotting and the development of cracks between them. These cracks allow sand seepage through them, which is undesirable.

In hopper construction, steel generally is used. Considerable care should be exercised in determining the proper slip angles of the sands used so that the sides of the hopper can be designed at a sufficient angle to feed the sands through the hoppers readily.

A convenient storage for small users of core sand consists of covered concrete bins into which trucks or railway cars may be emptied. Openings on the opposite side of the bins permit removal of the stored sand by gravity feed or shoveling into a measuring or weighing device before it is placed in the mixer.

SAND HANDLING

Various means of handling the sand may be employed, depending upon the volume of sand required.

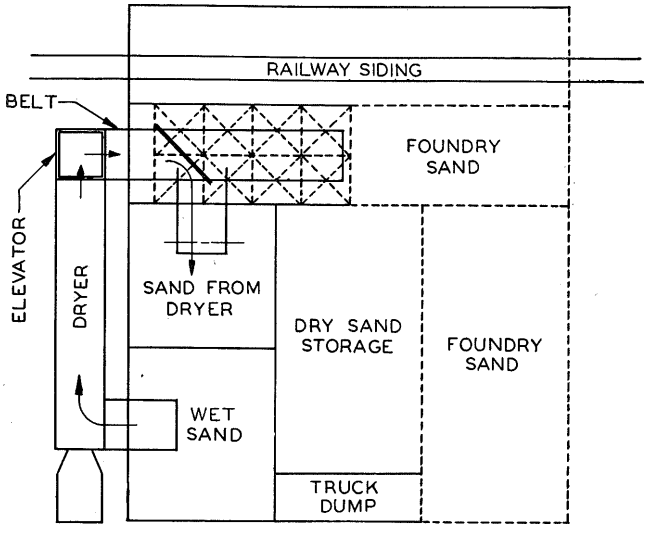


Fig. 5.1 — Sketch of a sand storage arrangement.

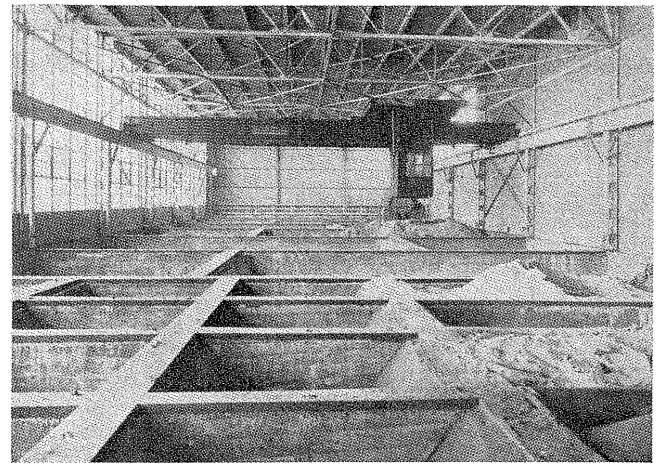


Fig. 5.2 — Interior view of a sand storage unit.

To large users of core sand, this is extremely important. One foundry installed a traveling overhead crane with a clamshell to unload and transfer sand within the sand storage, drier, and mixing building. With this equipment, which is housed under a large sand storage building, freight cars may be unloaded out of the weather from one end of the building, while trucks may be unloaded from the other end. By the installation of suitable partitions and hoppers within the storage building, various kinds of core and foundry sands and their ingredients are housed under a single roof and handled by a single crane. Figure 5.1 shows a sketch of this type of arrangement while Fig. 5.2 shows the interior of such a building. Variations of this method may be used to suit individual conditions.

In smaller foundries, a tramrail system, located over the railroad siding and connecting with the storage bins by means of a transfer bridge or tramrail and switches, is practical, as a bucket handling carrier can be used which will travel over the system above the railroad siding, pick up a load of sand and distribute it to the bins.

Bins should be located adjacent to the coremaking department and designed with an adjustable hopper gate at the bottom to permit the sand to fall directly into the mixers or into a bucket which will deliver it to the mixers. A belt conveyor also can be used to deliver the sand if only one mixing machine is used. Where the sand storage is some distance from the mixers, the same arrangement may be used or the sand

may be discharged from the bins into some conveyance which delivers the sand to the mixers.

Where very small quantities of core sand are used, bins may be constructed to permit shoveling the sand from them.

IMPORTANCE OF DRYING CORE SAND

Unless core sand is thoroughly or accurately dried to a certain percentage of moisture, no precise control of core sand mixtures can be maintained. If the moisture varies in a core sand mixture, the baked strength, green strength, etc., also will vary, even though other ingredients are maintained in the same proportions.

When moistened with the right amount of water, damp sand will weigh less than an equal volume of dry sand; the grains of the dry sand pack more closely together. Therefore, precise control of a core sand mixture cannot be maintained unless the moisture is controlled accurately. Water, which is a standard material in any core sand mixture, is the largest single factor in the baking of a core.

Before a core bakes in an oven, all the moisture must be driven off after which the binder will oxidize, polymerize, coke or melt, depending upon the type of material used. Therefore, the more sparingly water is used in a core mixture, the faster the core may be baked. An additional advantage is the reduction in the total heat and air circulation required for the removal of the water and the baking of the core.

DRYING AND COOLING CORE SAND

Sand drying and accurate control of moisture makes possible more uniform baking time and will do much toward eliminating castings lost due to over- and underbaked cores in that the amount of moisture affects the rate at which a core bakes. Moisture also affects the flowability, green strength, baked strength and core hardness.

Due to weather conditions, the moisture content of core sands arriving from the pits is certain to vary several per cent from time to time, thus making the drying process essential for precise control. In the winter, in many localities, sand arrives from the pits in hard frozen lumps. If this sand is not dried, considerable trouble will be experienced in its use.

Some foundries find it advantageous to purchase washed and dried sand in preference to drying all of their own sand. This washed and dried sand may be used alone or with a suitable local sand. If used with a wet local sand, some degree of moisture control may be attained, although it will not give a control comparable with that obtained with all dried sand. Then, too, it is likely that the washed and dried sand will have a grain distribution entirely different from the local sand. Mixing varying percentages of dried sand and local sand to obtain the desired moisture content would give varying ultimate grain distribution, which is undesirable. Unless the grain distribution is maintained within fairly close limits, considerable variation in both green and baked strengths will result.

IMPORTANCE OF COOLING CORE SAND AFTER DRYING

If core sand is dried in a sand drier, it is essential that the dried sand be cooled to approximately room temperature before using it in core sand mixtures. If hot, or even warm, sand is used in making core sand mixtures, difficulty will be encountered in controlling the final moisture content of the batch of sand due to the increased evaporation at the higher temperature. Warm sand used in a core sand mixture will cause the mixture to be sticky.

Apparently the moisture in the warm sand mixture condenses upon coming in contact with the cooler core box surfaces and results in the stickiness. Sticky sand in the hands of a coremaker, or in a core machine, will cause considerable trouble. The core box surface will have to be cleaned more often to insure good cores and to avoid parting cracks. Parting cracks originate while drawing the core box from the core. This is due to greater cohesion between the sand and the core box surfaces. These small parting cracks open up under the core oven heat and often necessitate scrapping the cores.

CORE SAND DRIERS AND COOLERS

Core sand coolers and driers have become essential equipment in many of the large foundries where high production must be maintained. The designs are fairly well standardized. The general types are: (1) the parallel flow; (2) counter flow; and (3) the through flow types. Figures 5.3, 5.4 and 5.5 are sketches of each of these standard types and a combination of the parallel flow and counter flow types is shown in Fig. 5.7.

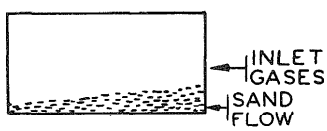


Fig. 5.3 — (Right) Sketch showing principle of parallel flow sand drier.

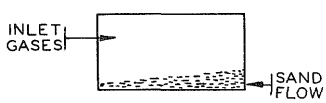


Fig. 5.4 — (Left) Sketch showing principle of counter flow sand drier.

Sand driers generally are composed of drying and cooling sections. Some companies prefer to connect the sections as integral equipment (Fig. 5.6), while others use separate sections with suitable equipment for the transfer of the sand from the drier to the cooling section (Fig. 5.5). A large receiving hopper feeds sand to a suitable device that will maintain a constant flow of sand into the drier.

Gravity feeds are not practical in feeding wet sand into a sand drier as the variation in the moisture content of the sand makes uniform feeding impossible. The feed hopper should be protected by a coarse grating to keep any oversized pieces of foreign material or frozen sand from entering the drier. Drying of the sand is accomplished in a rotary horizontal kiln of one of the previously mentioned types. By the use of a suitable drive, the drum is rotated at the desired speed.

Parallel Flow Driers

The parallel flow drier works on the principle shown in Fig. 5.3. The sand travels through the cylinder to the discharge end, due to the drum's rotation and the angle the drum makes with the horizontal. The hot gases flow parallel with the sand flow. In this type, it is necessary to maintain a comparatively high

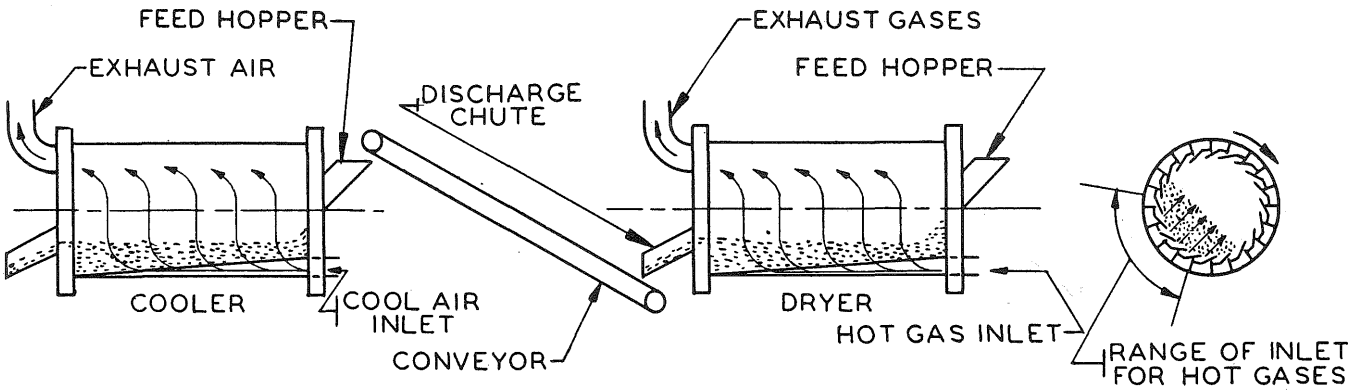


Fig. 5.5 — Sketch of through flow core sand drier.

stack temperature, thus accounting for considerable heat loss through the exhaust stack. Unless the stack temperature is maintained comparatively high, the drying gases will become saturated with moisture and will not carry away sufficient moisture to completely dry the sand.

Counter Flow Driers

In the counter flow drier (Fig. 5.4), the sand travels through the cylinder to the discharge end, due to the drum's rotation, and the angle the drum makes with the horizontal, the same as in the parallel flow type. However, the hot gases enter at the discharge end of the drier and pass through the tube to be ejected at the end the sand enters. In this type, since the heating gases enter at the sand discharge end, the sand emerges from the drier at a high temperature which makes cooling of the sand much more difficult and expensive than is true of the other types.

The parallel flow and the counter flow type driers both have proved quite inefficient, due to the reasons mentioned. As a result of this inefficiency, the two best types of sand driers on the market at present are the through flow type shown in Figs. 5.5 and 5.6, and the combination parallel flow and counter flow types in Fig. 5.7. These driers are discussed in the following paragraphs.

Through Flow Driers

Through flow driers are so constructed that the gases from the fire box pass through a series of internal channels near the circumference of the drum, as shown in Fig. 5.5. The channels are covered by overlapping plates as shown. This allows the hot gases to pass from the channels, through the sand, and into the inside of the drum and out the exhaust duct.

Due to the arrangement, the hot gases are admitted only to the channels directly underneath the sand, and not to any of the others. The hot air inlet consists of a circular duct, which widens out to a specifically shaped mouth corresponding to the open ends of about one-fifth of the gas channels, the rest of the channels being sealed from the inlet. As the drum rotates at the desired speed, the sand builds up on one side with the uppermost grains rolling or tumbling over each other as they reach their angle of repose. A constant position of bed is thus maintained with the grains always mixing, and the bed constantly covering about one-half of the louvres and gas channels. The actual depth of the bed is controlled by the height of the discharge opening and is maintained at such a depth that the requisite number of gas channels are always covered.

This type of drier utilizes practically all the heat from the hot gases. The hot gases come into intimate

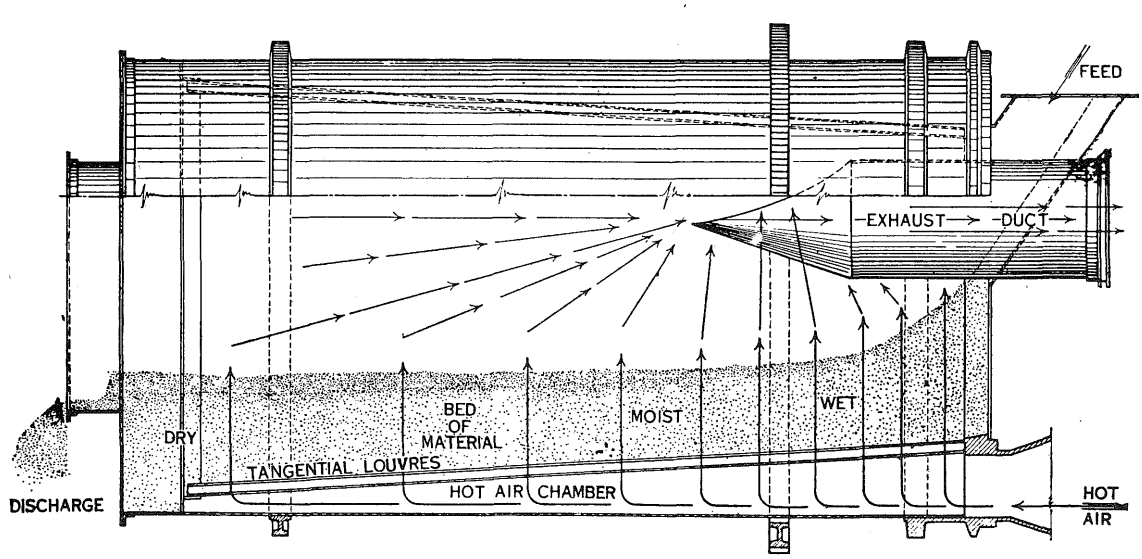


Fig. 5.6 — Cross-section of through flow drier showing bed of material and direction of air currents.

contact with all the particles of the sand, giving an efficient heat transfer and resulting in thorough and uniform drying.

It is claimed by one manufacturer of this equipment that the sand can leave the drier with 0.5 per cent moisture. It is recommended that the sand be cooled in equipment of the same type, where additional moisture is removed before it is stored.

Combination Parallel and Counter Flow Drier

The combination parallel flow and counter flow drier (Fig. 5.7) consists of an outer shell of riveted steel plate and an inner shell. The outer shell has a series of baffles connected to the inner wall. The inner shell or tube is made with baffles on the outer surface. The baffles on the outer shell carry the sand up the walls to an almost vertical position before permitting it to fall in a thin spray through the return heating gases before they are ejected from the stack, and then over the baffles of the inner shell to absorb heat from the shell, thus keeping the incoming gases from overheating the head end of the inner tube.

The inner tube extends nearly to the end of the drier section, thus allowing the heating gases to be cooled appreciably before coming in direct contact with the sand as they return between the inner and outer shells to a stack, which is located at the same end as the combustion chamber. The sand in the outer tube, upon reaching the end of the drier section, passes through a feed scoop which acts as a baffle between the heating and cooling sections. A thermocouple placed at a point just inside the cooling section detects the sand temperature at this point and controls the heat input to the combustion chamber.

The temperature of the sand is approximately 200 F (93 C), as it enters the cooling chamber, and contains approximately one per cent moisture. In the cooling section, which is usually shorter than the drier section, cool air is blown in at the discharge end through an inner tube extending nearly to the baffle between the drier and the cooling section. This air then doubles back between the tube and the outer shell, cooling the sand in its passage, and escaping out a stack at the same end it entered. Much of the cooling is directed by the evaporation of the moisture left in the sand as it passes through the cooling section.

The sand discharged from the cooling section is slightly higher than room temperature (70–80 F — 21–27 C) and the moisture is said to be less than 0.1 per cent. In addition to the removal of the exhaust gases, the stacks eject a certain amount of fines from the sand, which is beneficial to most sands. These fines could be retained by suitable barriers if they proved advantageous to a particular sand.

Control of the sand drying unit is automatic and is effected through the thermocouple, mentioned previously, in conjunction with automatic regulating instruments. A second couple is located where the gases from the combustion chamber enter the inner drier tube and maintains a constant temperature of the gases at this point. This latter point controls the temperature of the gases only as they enter the drier, while the couple just inside the cooler section controls the quantity of gases necessary to accomplish the required drying.

The conditioned sand from the drier is screened through a vibrating screen to eliminate any oversized particles, which are usually foreign particles. The screened sand descends to a belt or suitable dry sand conveyor and is transferred to the dry sand storage bins or directly to hoppers over the core sand mixers.

Counter Flow Drier

A complete core sand drying unit with sand storage hoppers is illustrated in Fig. 5.8. The wet sand is loaded into the storage bins with a clam. It is fed into the driers, each 48 in. in diameter by 20 ft long with variable speed feeders. The dried sand is discharged on to a belt conveyor, is carried to the elevator, and then to the core room on a second belt conveyor. The burners are automatically controlled to save fuel, and to assure the discharge of a sand of uniform dryness regardless of variations in the rate, or moisture content of the feed. Fines are caught in a cyclone dust collector and returned to the system.

Vertical Driers

Driers of the vertical type are built. With this type

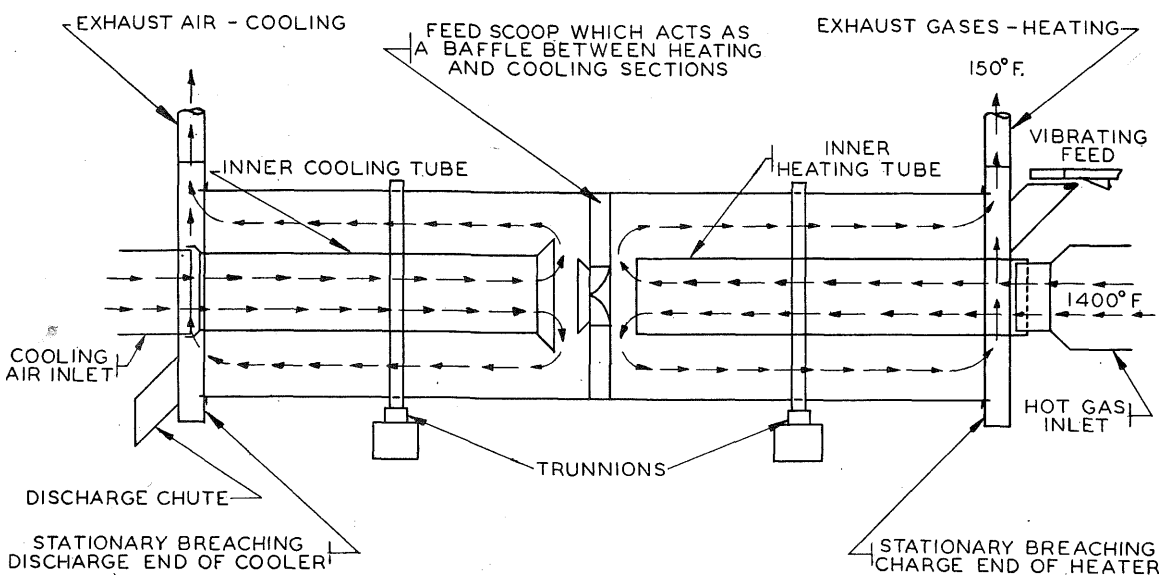


Fig. 5.7 — Sketch of combination parallel and counter flow sand drier and cooler.

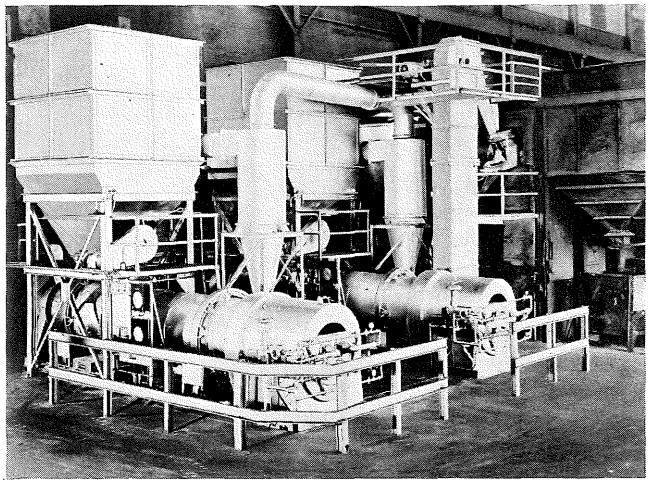


Fig. 5.8 — Counter flow drying unit.

the sand is elevated to the top of the drier and as it travels down, is dried, cooled and discharged from the bottom.

STORAGE OF CORE BINDERS

Core Oils

No special precautions need be taken in the storage of oil in tanks, other than to clean the accumulated sludge from tanks at intervals and to be certain that the air vent is hooded to prevent entrance of rain water. Water and moisture must be kept away from core oils. If resin is used in the oil, as little as 1.0 per cent moisture may cause the resin to separate.

Certain oils tend to separate into layers of their constituent parts in storage and a stirring device may be necessary for best results. Where the oil is stored in drums, the drums should be kept under cover so that rain, snow or other moisture will have no access to them. If not stored under cover, a small amount of water may seep through either the bung or air hole with deleterious effects. If resin is used in the core oil and a small proportion of moisture leaks into the container, resulting in a very small separation of the resin, it is possible to bring much of the resin back into the solution by heating the drum to not over 175 F (79 C).

The distribution ability of an oil depends partly upon viscosity which, in turn, depends on oil temperature. It is desirable to store oil in drums in a warm place, for at least a brief period before use. Some emulsified oils may freeze in outdoor storage.

Dry Binders

Some dry binders are definitely hygroscopic and should be stored in a warm, dry place. Dry binders containing pitches will soften under heat and should be stored in a cool, dry place. Care also should be taken not to stack such binders too high or to place heavy objects on top of stacked bags.

Some core binders containing cereals are attractive to rodents and it may be necessary to protect the binders in a wire enclosure. One manufacturer recommends the storage of such binders on skids or a subfloor. Cereal binders generally are shipped in bags.

The efficiency of most dry core binders depends upon the rate at which they distribute through sand. The rate is reduced when binders become damp. Core binders should not be stored in any damp place and, in particular, they should not be stored directly upon a damp floor. This leads to lumping of the binder and rapid disintegration of the bag.

Molasses keeps well in full, unopened packages but upon exposure to the air, and especially after dilution with water, it ferments and supports mold growth, which gradually reduces its value as a binder. Users of molasses in quantity may benefit by adopting the practice of adding a small amount of some preservative, such as sodium benzoate or cresol, to the molasses water.

Clays and bentonites require no particular care in storage other than keeping them dry. Their moisture content is usually so low that there is no danger of freezing.

Certain types of binders, such as the rubber cement type, may contain inflammable ingredients. In such cases, storage in a place away from possible sources of ignition are mandatory.

Chapter 6

HANDLING OF CORE SAND

MIXING EQUIPMENT

Types

The mixing of core sand used to be a haphazard procedure in many foundries, but now equipment is available which gives more accurate control of the amount and uniformity of addition of the various ingredients. Four types of equipment are in general use for the mixing of core sands. These are: (1) shovel and riddle; (2) paddle mixers; (3) muller mixers; and (4) kneading mixers.

Shovel and Riddle

Where the amount of core sand used is small, many foundrymen spread a number of shovelsful or pansful of sand on the floor, add the binder and water, cut-over and mix the ingredients with a shovel, and finally riddle the mixture with a hand or power riddle. The success of this method depends on the care and skill of the individual who is mixing the sand. Some claim that this mixing method is the least economical of the four mentioned.

Paddle Mixer

This is a motor-driven machine which has a number of paddles mounted on a horizontal central shaft which rotates in a shell of proper design. Figure 6.1 shows a typical installation of a machine of this type. Mixing sand in this manner is a distinct improvement over shovel and riddle mixing.

Muller Mixers

The machine consists of a circular pan on the bottom of which rotate one or more large diameter rollers, called mullers. The mullers are free to revolve about a horizontal shaft which is fastened to a vertical drive shaft at the center of the pan. Also attached to the central shaft are plows which push the sand into

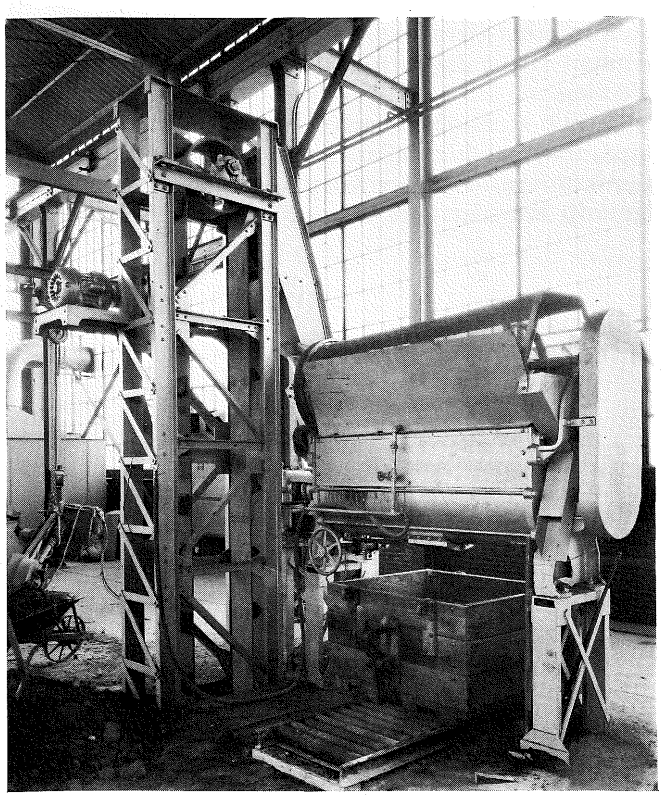


Fig. 6.1 — Paddle mixer for core sands.

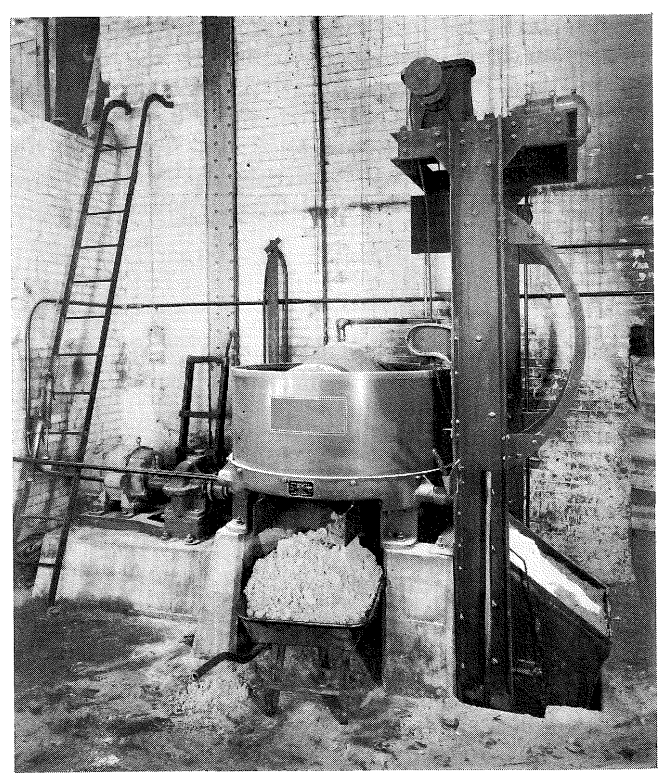


Fig. 6.2 — Muller mixer in which mullers revolve and the pan is stationary. This mixer is installed in a small foundry.

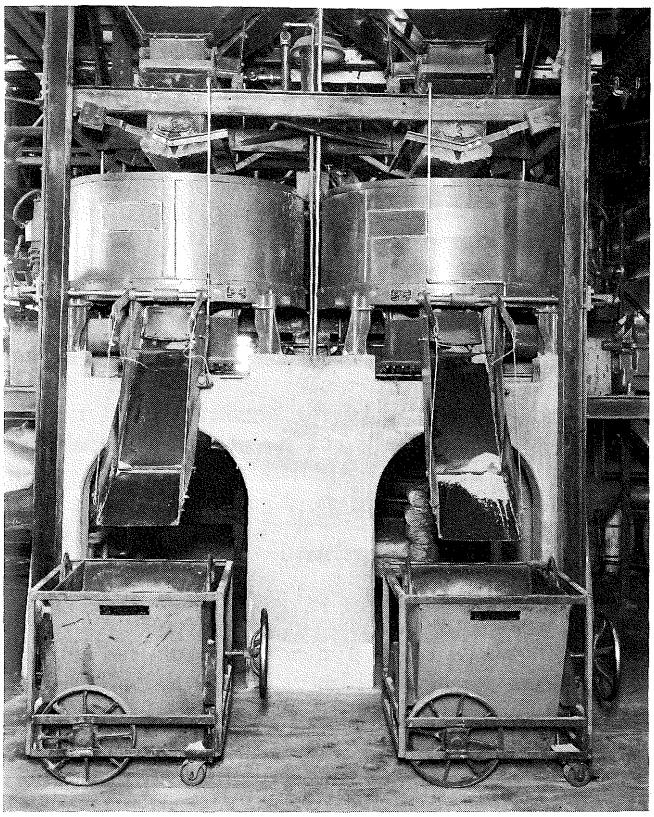


Fig. 6.3 — Same type muller mixer as shown in Fig. 6.2 installed in production foundry.

the path of the mullers as the shaft rotates. Some muller mixers are manufactured so that the height of the rollers above the pan can be adjusted, and, when it is empty, the mullers do not rest on the pan. In others, the horizontal shafts on which the rollers are mounted, have an up-and-down, free, vertical action by means of which the height of the rollers is adjusted by the depth of the sand beneath them. It is claimed that adjustment of muller height above the pan prevents grinding of the sand grains. Since the mullers have a packing effect on the sand, one manufacturer of such equipment recommends use of an aerator to open the mixture.

Mixing core sands in a muller mixer has been found very effective for mixtures containing cereal, molding sand, clay and bentonite. Figures 6.2, 6.3, 6.4, 6.5, 6.6 and 6.7 show installations of various types of mixing machines using the muller principle.

In Figs. 6.2 and 6.3, the mechanism inside the pan rotates. In Fig. 6.4, the vertical shaft is stationary and the pan revolves under the mullers. Figure 6.5 shows a muller mixer with a counter-current mixing action.

Figures 6.6 and 6.7 show a muller mixer which operates at higher speeds than the conventional muller mixers and faster mixing time is claimed. Tests show that sand from this type machine has considerably higher permeability than sand from the conventional muller mixer when the sand is not aerated.

As in many other mixers of the muller type, the pan is circular with vertical sides. However, as distinct from others described, the mullers do not come in contact with the pan at the bottom but revolve freely on the sides. The mulling mechanism revolves around a vertical turret, powered by a vertical drive shaft which rotates the plows and the mechanism on which the mulling wheels are mounted with their faces in a vertical position. As the vertical drive shaft revolves rapidly, the centrifugal force created pushes the wheels

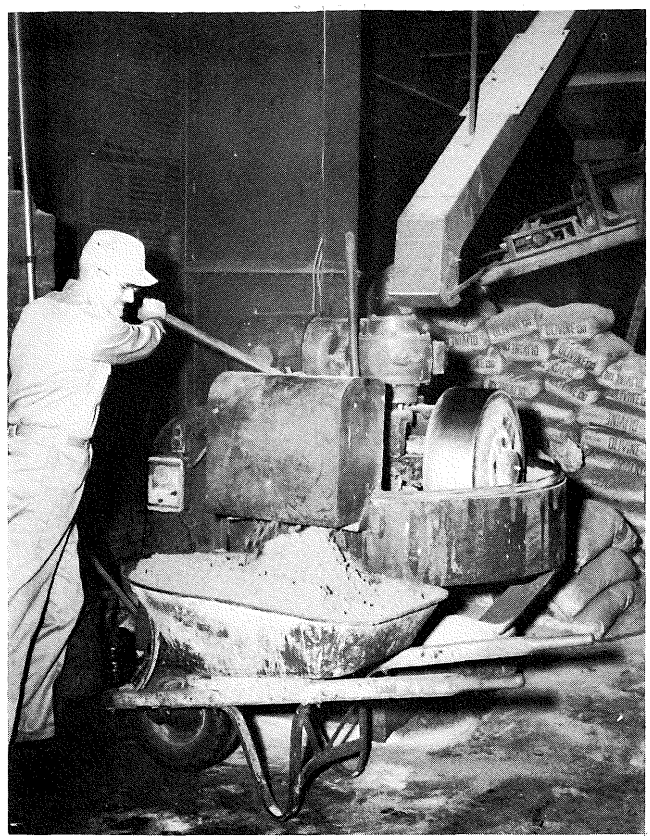


Fig. 6.4 — Muller mixer in which the vertical shaft is stationary and the pan revolves.

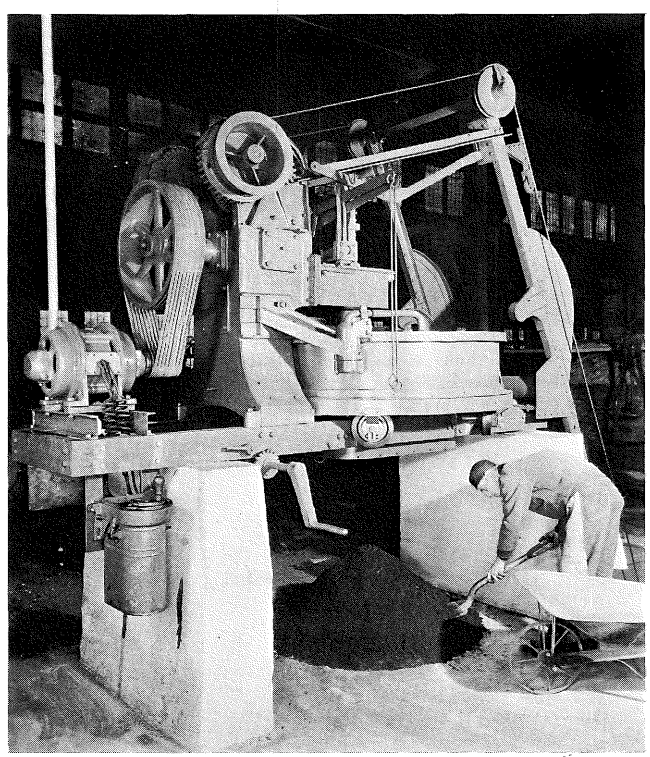


Fig. 6.5 — Muller mixer which operates on the counter-current principle.

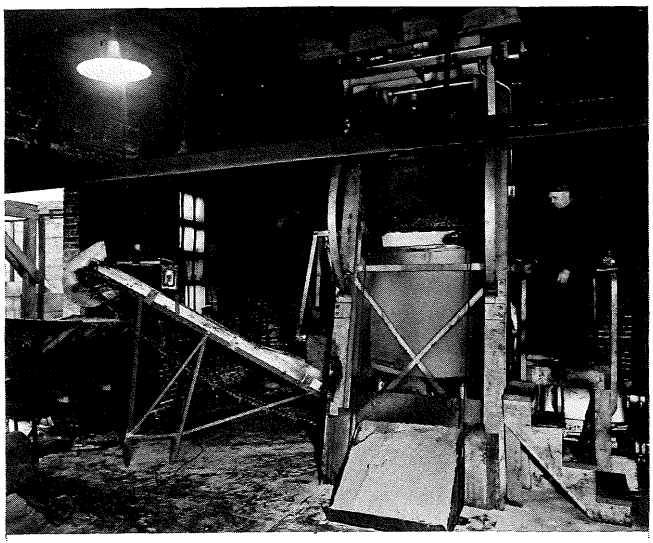


Fig. 6.6 — Muller mixer which is installed in a small foundry. This machine makes use of centrifugal force in mulling sand on the sides of the mixer.

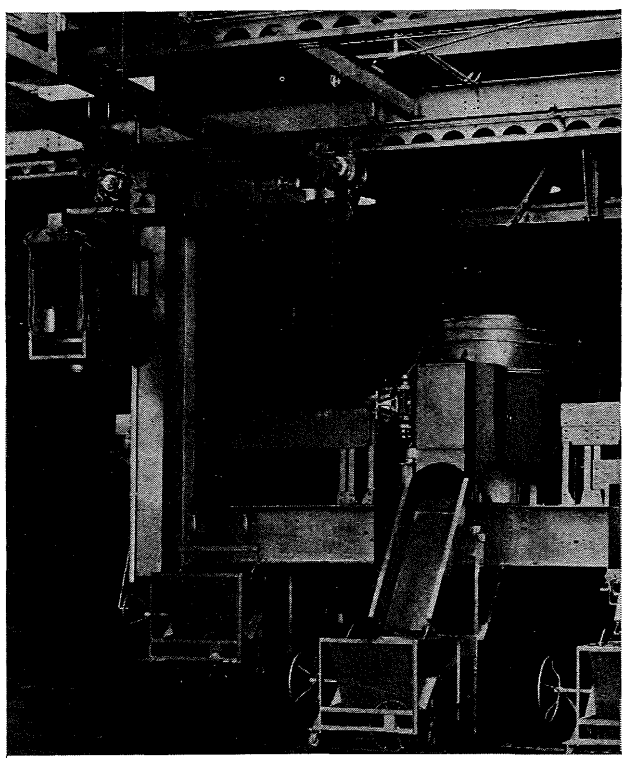


Fig. 6.7 — Installation in a large foundry of the same type of muller mixer shown in Fig. 6.6. The illustration also shows the sand handling equipment used.

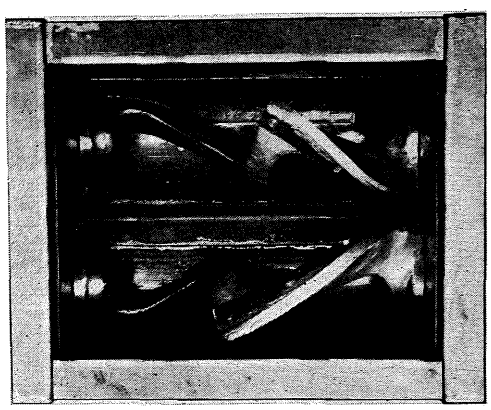


Fig. 6.8—Sigma-shaped blades in kneading mixer.

outward against the walls of the mixer. Both the mullers and the sides of the machine are rubber covered.

The plows extend from the vertical drive shaft, to which they are attached, to the side walls of the pan. As the plows revolve, the sand is forced along the plow blade by centrifugal force toward the end of the plow and the sides of the machine. The plow blade is so shaped that when the sand reaches the plow end, it is thrown upward to come in contact with the mullers and thus be mixed.

Kneading Machine

A core sand mixing machine is available whose action is said to be threefold: rubbing, stirring and kneading. The shape of the shell and the moving parts is such that the above mentioned threefold action results, distributing uniformly a thin layer of bond around each of the sand grains. The sand leaving this machine is said to have high permeability and not to require riddling.

The machine shown in Fig. 6.9 has two sigma-shaped shafts (Fig. 6.8) which rotate toward each other at differential speed and which cause the sand to travel from one end of the shaft to the other. Differential speed of the shafts gives the kneading action.

WEIGHING AND MEASURING EQUIPMENT

The mixing equipment can be the best obtainable, but if the ingredients of a core mixture are not accurately measured or weighed, it is impossible to have uniform cores.

Measuring the Sand

A common measuring method is to use the shovel, but a shovelful of sand is a very uncertain quantity. Records kept on the basis of shovel measurement depend on the size of the shovel, the moisture of the sand, and the operator. Therefore, such records can be inaccurate.

Another method is the use of a pan, box, or wheelbarrow, but there is possibility of a wide variation in the amount of sand contained in each of such measuring devices.

For larger quantities, the sliding drawer or pusher type measuring gate has been used, with an air cylinder to push the drawer. When the drawer is under the

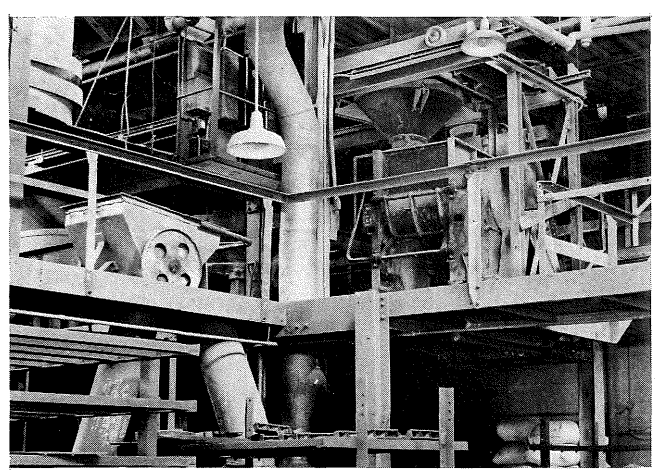


Fig. 6.9 — Kneading core sand mixer. Note method of distributing mixed sand to coremakers.

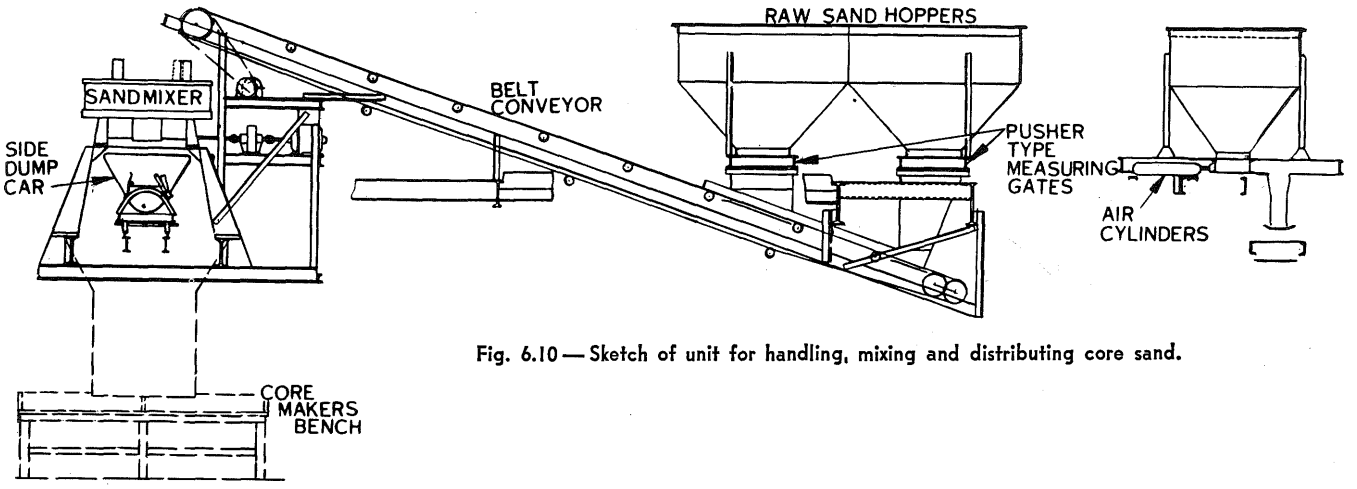


Fig. 6.10 — Sketch of unit for handling, mixing and distributing core sand.

sand hopper, the sand is supposed to fill it, but the amount of moisture contained in the sand will make a variation. It is said to be difficult to keep dry sand from leaking with this type equipment. Figure 6.10 is a sketch of an installation using the sliding drawer measuring gate.

Another measuring device consists of a measuring hopper with two slide gates so arranged that, when the upper gate is open, the sand fills the space between them. Closing the upper gate and opening the lower delivers the sand into the mixer. This method is said to have the same defects as the pusher type. A third method is to use pan or belt conveyor feeders, depending on the movement of the conveyor to give the correct amount of sand. Variation of sand moisture will cause the amount of sand delivered to vary.

The most accurate method is to weigh the sand and dry ingredients. The tendency of some sands to pack causes variation in any of the volume methods and does not affect the weight method.

Figure 6.11 shows a core sand mixing installation equipped with weigh hopper, photoelectric cells and control panel for operating electric vibrating feeders shown at the upper left of the illustration. When the hopper is nearly filled, the pointer on the dial of the scale passes one photoelectric cell and automatically slows the feeder down to a dribble feed so that there will not be so much sand in the air between the end of the feeder and the hopper as there would be with the fast discharge of the feeder. With dry sand, the photo cells are said to have duplicated weights with a variation of $\frac{1}{10}$ of one per cent. With the multiple scale, the beams can be set so that the operator uses only the necessary beams.

Figure 6.12 shows the layout of an installation of equipment, based on more or less the same principle, which is used in a large malleable foundry. The sand from the storage bins is fed to a traveling weigh hopper above the mixers. When the proper amount of sand is in the weighing hopper, it is dumped into the proper mixer. In this manner, a definite weight of sand is used in each core mixture batch.

An undercut gate, arranged with two positions of opening and controlled by solenoids to obtain the dribble feed that will work only with dry sand also is manufactured. Several types of electric vibrating feeders, which are particularly adapted to work with automatic weighing equipment, are made. One is shown,

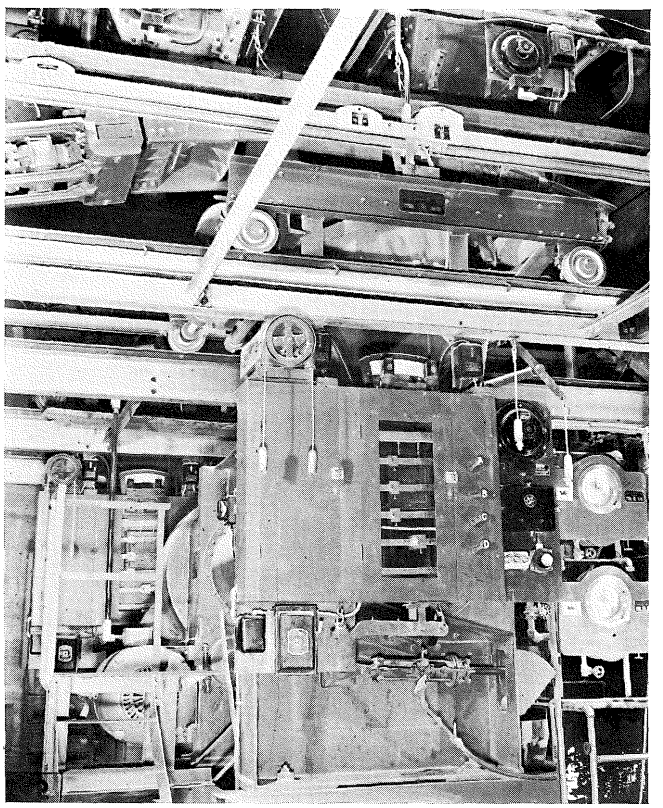


Fig. 6.11 — Installation of automatic weighing equipment for core sand mixing. In the foreground is the equipment for weighing the sand and dry binders. At the left are the measuring meters for water and liquid binders.

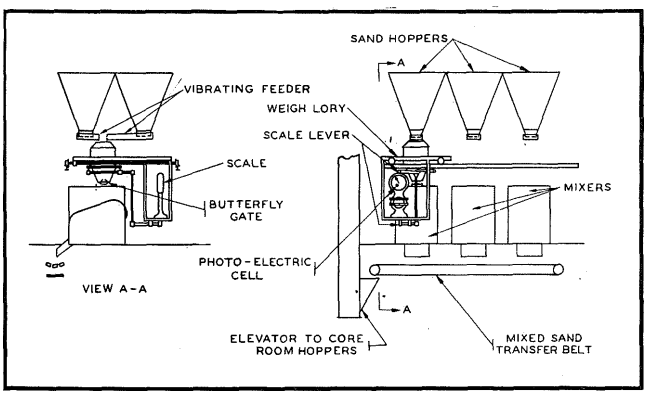


Fig. 6.12 — Sketch of same type of equipment as shown in Fig. 6.11. This equipment was installed in a large malleable foundry.

attached to the bottom of the sand storage tank, in Fig. 6.13. This is an installation in a large automotive foundry.

Measuring Liquids

The tin measuring cup and sprinkling can are used commonly for proportioning the liquid constituents of a core mixture. It is impossible for the operator to use these measures without spilling oil on the floor, which makes the mixing room a dirty, dangerous place with a considerable fire risk. Other measuring devices include calibrated tanks, either with or without air discharge. Most of this apparatus depends on the operator shutting the discharge valve at the right time.

Meters with large dials have been used where the operator stops the flow when the pointer reaches the correct position. A flow control apparatus between the automatic weighing device and the mixers, that will automatically stop the flow of the liquid at the point set is shown in Fig. 6.14. This control allows the operator to go on with other work and its accuracy is said to be within 0.05 per cent.

Measuring Dry Binders

The measuring methods used in the foundry for dry core binders may be either economical or wasteful, depending on the method used. Many foundries weigh the sand dry, proportion the oil binder carefully and then introduce a variable factor which mitigates against duplication of core properties by using improper methods for measuring dry binders. The proper and most accurate method of proportioning dry binders is by weighing.

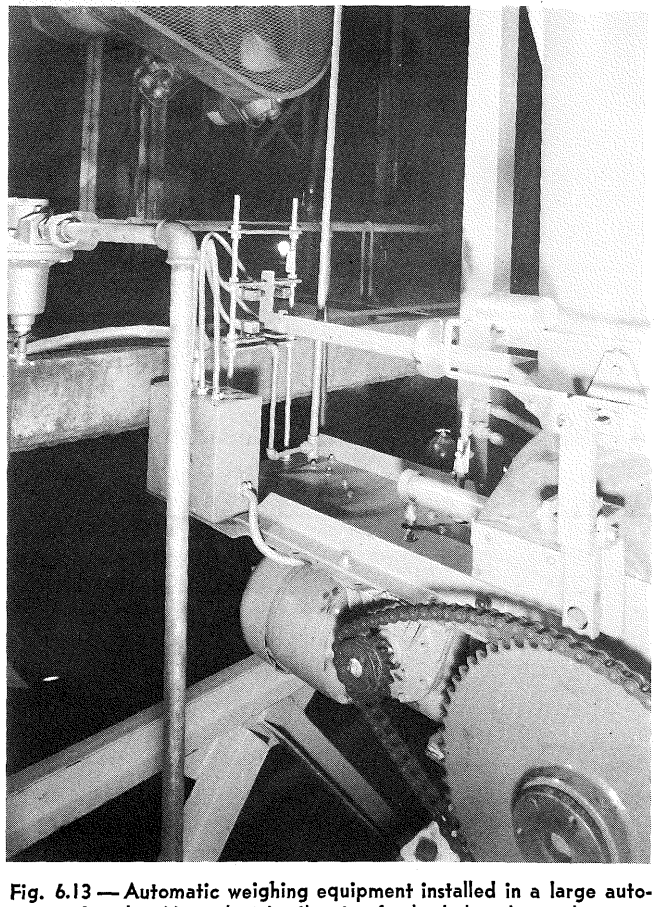


Fig. 6.13 — Automatic weighing equipment installed in a large automotive foundry. Note electric vibrating feeder below the sand storage tank.

Many dry binders vary in bulk with moisture. If a measuring cup or can is used, tapping the device will pack the binder and the amount contained will vary from batch to batch, depending on how often the cup or can is tapped. Thus, by the use of a measuring can or cup, two variables in the amount of dry binder added to a core sand mixture are introduced; the variable due to any differences in moisture content from day to day which influences the bulking of the binder, and the variable packing of the binder in the measuring device.

From the previous paragraph, it is evident that the proper method of proportioning dry binders in a core mixture is by weighing.

Determining Apparent Density of Core Binders

For accurate control of the ingredients of a core sand mixture, the apparent density of the core binders used in their mixtures is of importance. One laboratory, engaged in the testing of core binding materials, has used the methods shown in the table for determining that property.

METHODS FOR DETERMINING WEIGHT PER GALLON OF CORE BINDERS

A. Method for Liquid Binders
Weigh 100 cc graduate, empty and dry to 0.1 gram
Weigh filled to 100 cc with water
Weigh filled to same with liquid binders
Example: Weight graduate empty—114.0 grams
Weight graduate plus water—213.9 grams
Weight graduate plus liquid binder—207.2 grams
Then: 207.2 − 114 = 93.2 grams (weight of liquid binder)
213.9 − 114 = 99.9 grams (weight of water)
$\frac{93.2}{99.9} = 0.93$ (apparent specific gravity)
$0.93 \times 8.33^* = 7.75$ lb per gallon

B. Method for Dry Binders
Prepare suitable measuring container by cutting top off ½-pint pressure top tin can.
1. Weigh can empty and dry to nearest 0.1 gram.
2. Place can on level balance pan and fill with water until full. Weigh full.
3. Place dry can on bench. Hold 4 mesh riddle 3 in. above can. Pour dry binder through riddle until can fills and binder flows over top. Strike off with a ruler to obtain full can. Reweigh to 0.1 gram.

Example: Weight of can empty—72.4 grams
Weight of can plus water—326.2 grams
Weight of can plus dry binder—201.2 grams
Then: 326.2 − 72.4 = 253.8 grams weight of water
201.2 − 72.4 = 128.8 grams weight of try binder
$\frac{128.8}{253.8} = 0.507$ (apparent specific gravity)
$0.507 \times 8.33^* = 4.12$ lb per gallon

*Weight of one gallon of water at 70 F (11 C) = 8.33 lb.

PROCEDURE FOR ADDING INGREDIENTS

In general, it may be stated that the dry ingredients of a core mixture should be added to the sand during the mixing period before the liquid ingredients are introduced. In operating a mixer, it is advisable to have the mixer running and then (1) dump in the sand, (2) add the dry ingredients, if any are required,

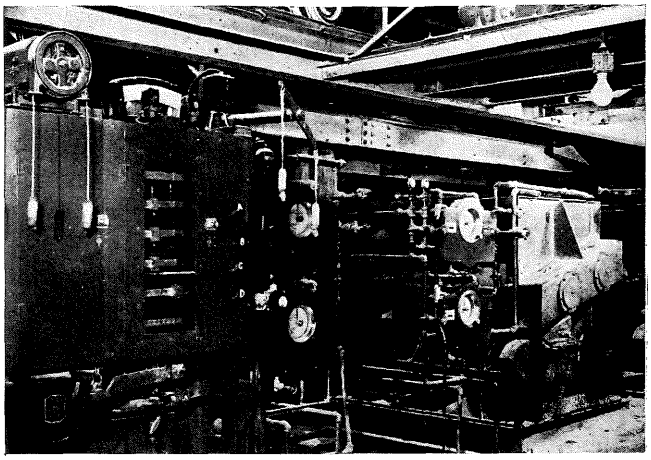


Fig. 6.14 — Installation of automatic sand and binder weighing equipment with meters for water and core oils connected to mixers.

(3) run the mixture dry for a short time, and (4) introduce the liquid constituents.

In connection with the mixing of the dry ingredients, if cereal binder is used, the batch must not be mixed too long before adding the liquid ingredients as the mixture is likely to become sticky and considerably increase the time necessary to bring the batch to proper condition. Manufacturers of these binders recommend that they be added first if used in combination with pitch or resin binders.

With regard to the introduction of oil and water into the mixture, there seems to be a lack of agreement on whether the oil or the water should be added to a core mixture first during the mixing operation.

In an attempt to determine the relative effects of adding oil to the core sand mixture during the mixing period before the water and vice versa, the author recently conducted a series of tests using a Michigan dune sand and the AFS standard silica sand. His results indicate that when oil is added to the mixture before the water, more consistent results are obtained. When water is added first, apparently the oil does not have an opportunity to coat the sand grains as uniformly as when the water is absent.

In the case of the dune sand cores, the author found that the average strength was two per cent higher when water was added before the oil; but the strength readings were erratic as compared to results obtained when those liquids were added in opposite sequence. These results show that although the average strengths were much the same, more uniform results are possible when oil is added before the water during the mixing of core sands.

In some instances local conditions may determine the order in which oil and water ingredients should be added to the core sand mixture.

DISTRIBUTION OF MIXED SAND

After the sand has been mixed to produce the correct properties, the next problem is to distribute it to the coremakers. A common practice is to wheel the mixed sand to the core room and shovel it onto the core benches. Others arrange the core room so that the sand may be wheeled back of the benches and shoveled onto them without interfering with the coremakers, as does the first method.

Still others arrange for either a second floor or a series of runways above the benches (see Fig. 6.9) and the sand is carried in a car on a track, a bottom dump hand cart, by a monorail crane or by conveyers, and dumped into hoppers that bring the sand directly to the coremaker's bench.

In one large foundry several different core mixtures are employed, but they all contain varying amounts of flour, core oil and water. The flour is added by weighing, while the oil and water are measured by meters which are graduated in pounds. After the various ingredients are mixed for a suitable time, the mixer gate is opened and the prepared sand falls on a conveyor belt which transports the sand to the core department. A remote control system permits the core sand to be discharged into any one section of an eight-compartment storage hopper. From that hopper, the sand is conveyed by electric truck to the various coremaking stations.

Often the distance from the mixing machines to the coremaking machines or benches is such that economical transportation by floor operated equipment is not always possible, because aisles must be provided for

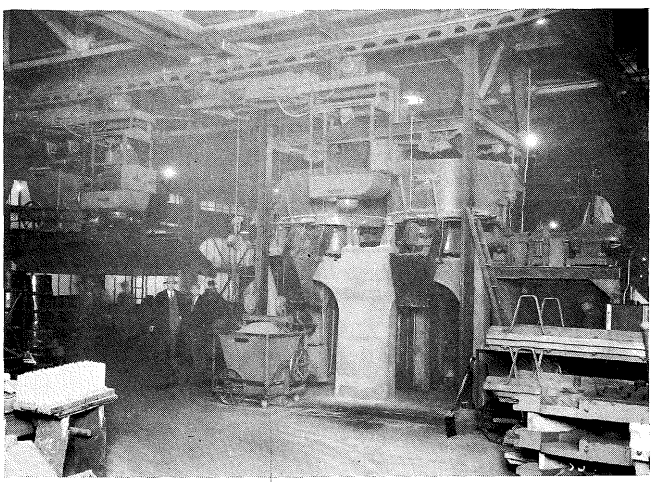


Fig. 6.15 — Illustration of handling mixed core sand from the mixer to coremakers.

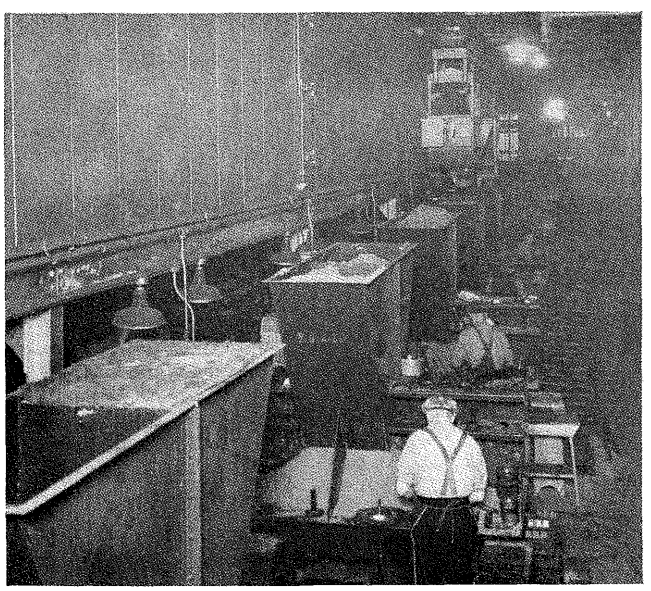


Fig. 6.16 — Delivering mixed core sand to hoppers over the benches of the coremakers.

the passage of such equipment from the sand mixer to the coremaking department, resulting in loss of space.

A method for handling mixed core sand is illustrated in Fig. 6.15, which shows overhead tramrail carriers provided with a hoisting arrangement capable of picking up a bucket loaded with approximately 1500 lb of sand and transporting same to hopper over core benches, as shown in Fig. 6.16.

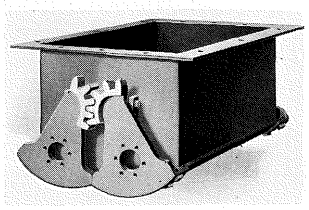
Control Testing

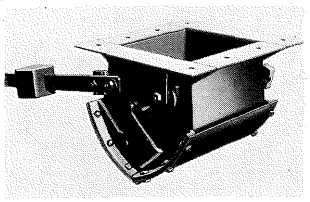
In one large foundry, control of core sand properties is maintained through hourly testing of each type core sand mixture for moisture and green compressive strength. Twice a day, determinations of baked tensile strength and baked permeability are made. Once a day grain distribution tests are made on the raw dry sand from the storage bins. Each carload of flour purchased is sampled by quartering, and a portion of the resulting sample is mixed with a standard sand in the laboratory. The batch thus made is tested for green strength, and it must meet requirements based on previous experimental and practical results. The same procedure is followed with each carload of core oil.

Storage Hoppers for Mixed Core Sands

Storing a suitable supply of prepared core sand at coremakers' locations presents a number of problems. The variety of binders and mixes requires individual study to design for proper handling. Mixed core sand has been of such sticky character that, for the most part, distribution has been by bucket on monorail, or still more frequently by wheelbarrow. The handling and storage problem is related to quantity as well as quality, and it would be manifestly absurd to provide costly overhead distribution for quantities so small as to make the operation expensive on account of first cost and consequent depreciation charges.

The necessity of making many complete molds from





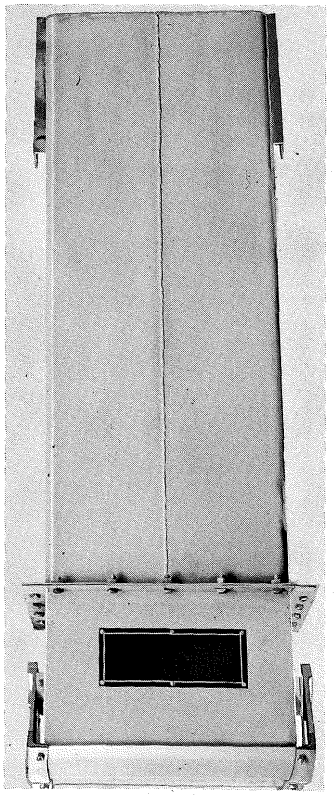


Fig. 6.17 — (Above left) Double undercut geared gate for core sand storage hoppers.

Fig. 6.18 — (Lower left) More easily controlled core sand storage hopper gate than shown in Fig. 6.17.

Fig. 6.19 — (Right) Core sand storage hopper with three vertical sides.

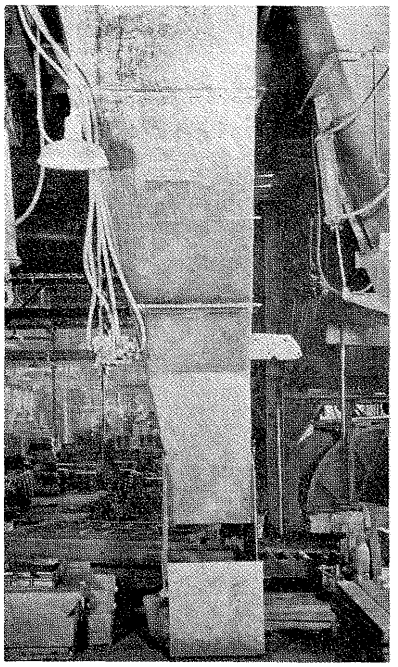


Fig. 6.20 — Shoveling or hand controlled feed for core sand storage hoppers.

cores, and the larger tonnages involved, has made storage important. The design of hoppers for this work presents the same problem as servicing molding machines of moderate size. Such hoppers should be designed larger at the gate end than at the top and, where this is not possible on account of the size of the work, then the hoppers should have at least two and preferably three vertical sides.

The same difficulty is encountered where core blowing machines are installed, since the rate of prepared sand consumption is such as to require storage. In general, such hoppers should be designed for minimum rather than maximum storage. This is true since many mixtures used are unstable and therefore only should be stored for minimum time.

Because the lowest resistance to flow in hoppers is important, they are designed without laps or rivets, and are of welded construction. Certain paints are used on the interior to resist tendency to rust due to moisture in the product. Rounded corners are recommended where possible as presenting less friction than square corners.

Several types of gates have been designed for use in connection with hoppers, and are shown in Figs. 6.17, 6.18 and 6.19. Where the quantity of sand per core is small, it is often desirable to omit the gate and furnish a shelf from which the coremaker draws his supply by means of his hands, illustrated in Fig. 6.20.

The airplane engine foundries making cylinder heads in dried sand molds give another instance where quantity core sand storage is large. In many cases, distribution of this material is by truck or lorry, to involve less handling.

Illustrations show the types of gates recommended, and also a shoveling shelf which is used successfully and quite frequently. The ordinary double undercut gate, illustrated in Fig. 6.17, is used where sand in considerable quantities is needed. Figure 6.18 shows a gate from which the sand flows under better control. Figure 6.19 illustrates hopper with three vertical sides which is usually recommended. Figure 6.20 shows shoveling or hand controlled feed.

Chapter 7

COREMAKING (METHODS AND EQUIPMENT)

INTRODUCTION

The most common method of forming cores is to use a core box which is a piece of metal or wood containing a cavity the shape of the desired core. This core box is rammed full of sand to form the core. After ramming, the core box is removed from the core, which is on a plate. The core plate supports the core so that it may be baked.

CORE BOXES

In making a simple core, no equipment other than a core box and core plate may be required. In more complicated cores other equipment may be necessary in forming, supporting, reinforcing, venting, and handling the cores.

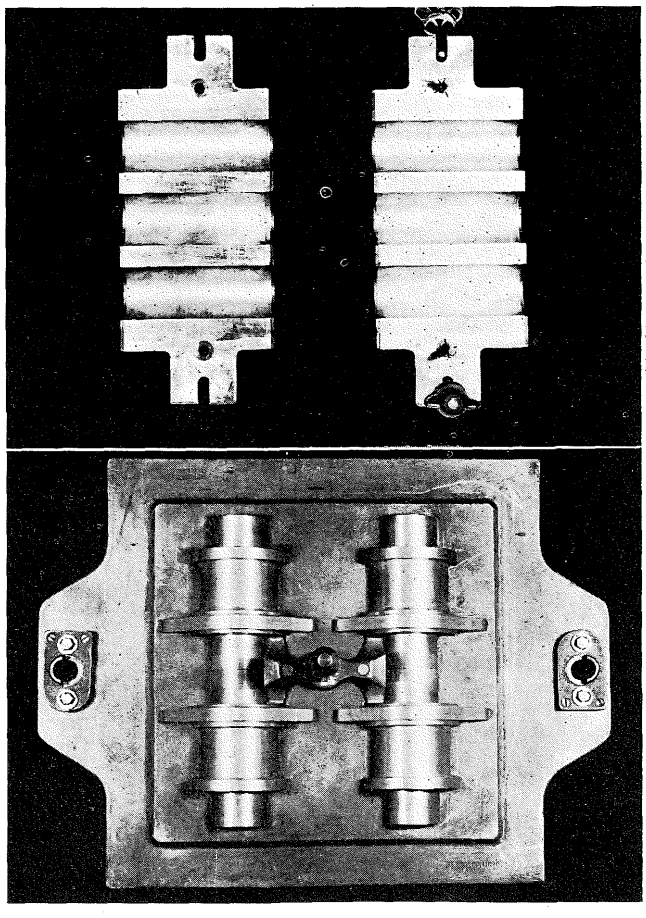


Fig. 7.1 — (Top) simple gang core box. (Bottom) matchplate pattern.

In complicated shaped castings, a large number of cores may be required for each casting, as in the case of an automobile cylinder block. Core boxes also may be simple in design or composed of several pieces to form an intricately shaped core. Figure 7.1 shows a gang core box and patterns for a simple casting. The two parts of the core box are placed together and held in place by the wing nuts shown. Figure 7.2 shows another simple core box and the pattern with which the core is used.

Figure 7.3 includes the pattern and core box for a simple manifold casting. The core equipment is hinged to facilitate booking the core. Figure 7.4 shows the cope and drag of a pattern for which several cores and driers, which may be made of cast aluminum or cast iron, are required. Figure 7.5 is the main core box. When the box is made of either aluminum or magnesium, the core box is faced with a steel plate. The four core prints, shown on one side of half the core box, fit into the two outside and two center core prints on one side of the drag, as shown on the pattern (Fig. 7.4 — Top). The single core print, on the opposite end of the core, fits into the single core print

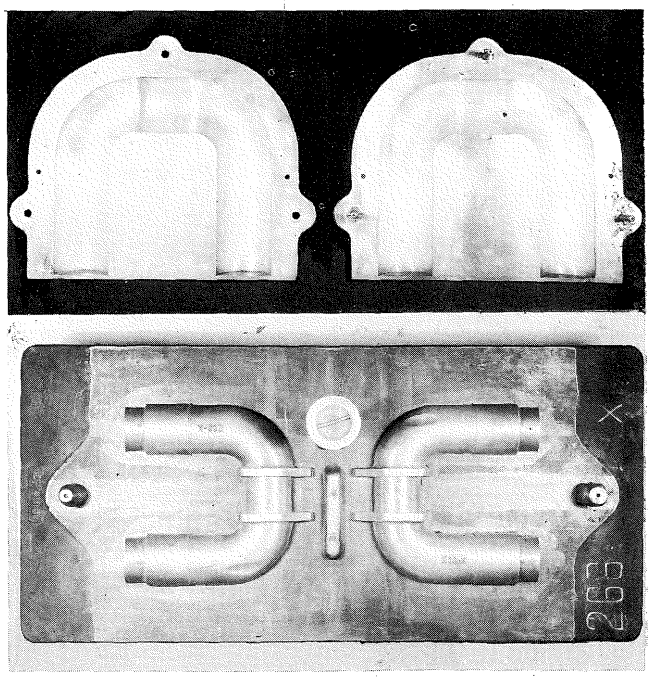


Fig. 7.2 — (Top) core box and pattern equipment (bottom) for an angle fitting.

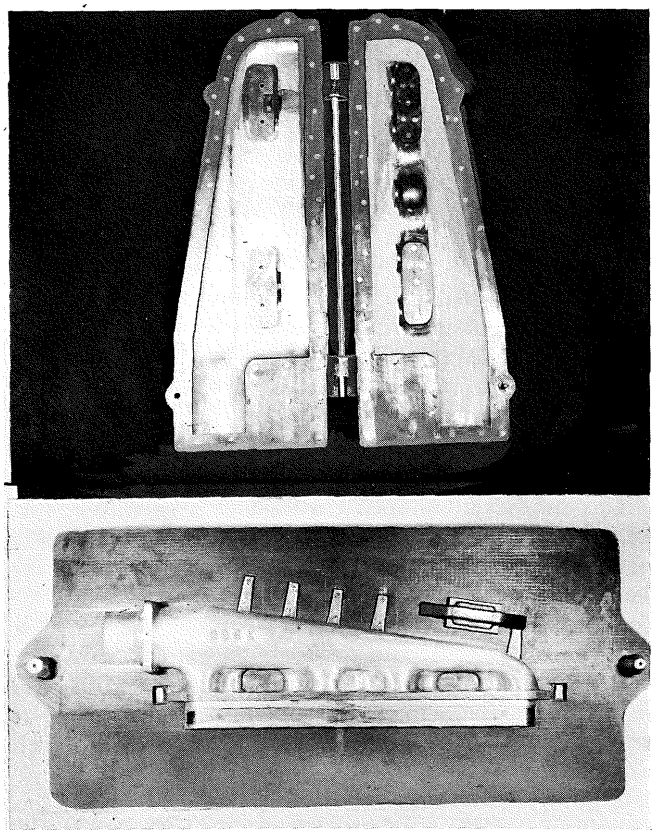


Fig. 7.3 — (Top) hinged core box and pattern equipment (bottom) for manifold casting.

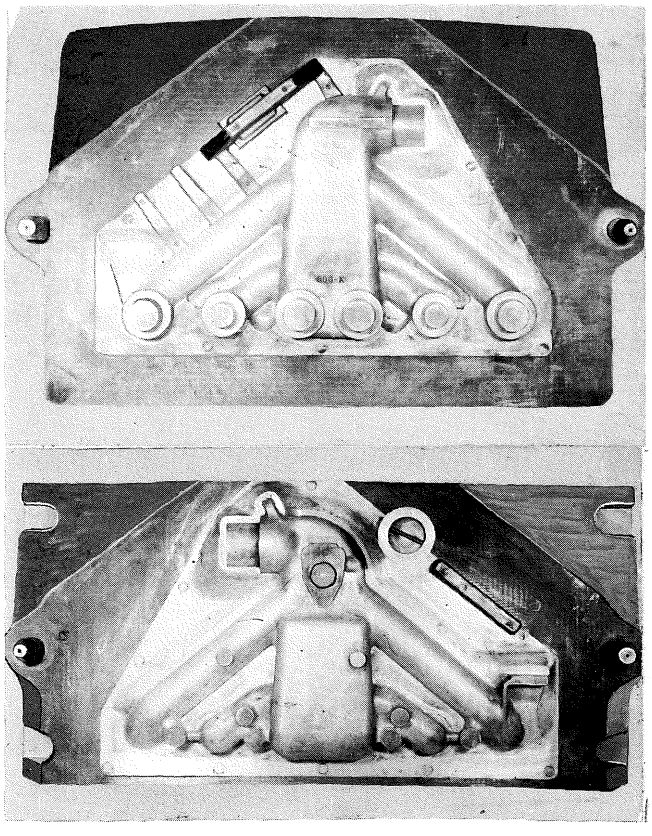


Fig. 7.4 — (Top) drag and cope (bottom) for an intricate manifold casting, showing core prints to support the core in center of casting.

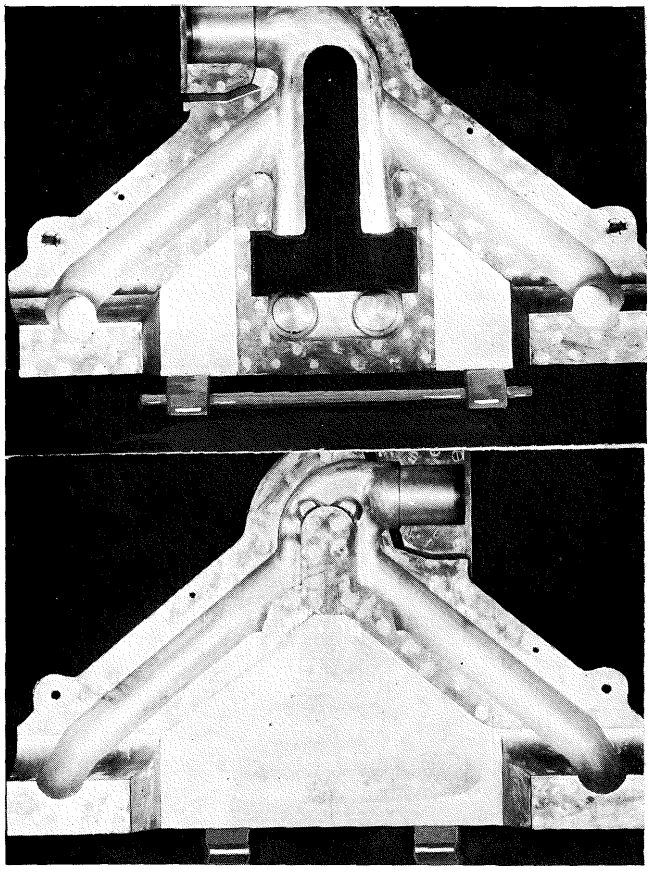


Fig. 7.5 — (Top) core box and core drier (bottom) equipped with hinge to facilitate booking the two halves together. Cores are used with pattern equipment shown in Fig. 7.4.

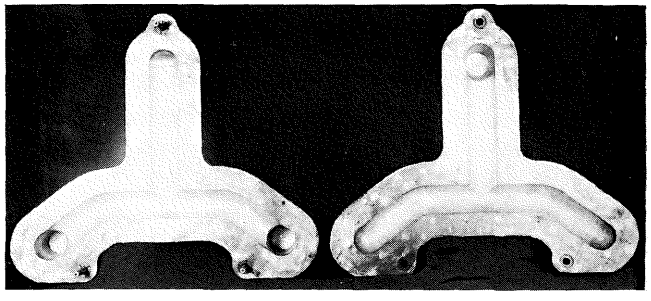


Fig. 7.6 — Additional core box and drier used with pattern equipment shown in Fig. 7.4.

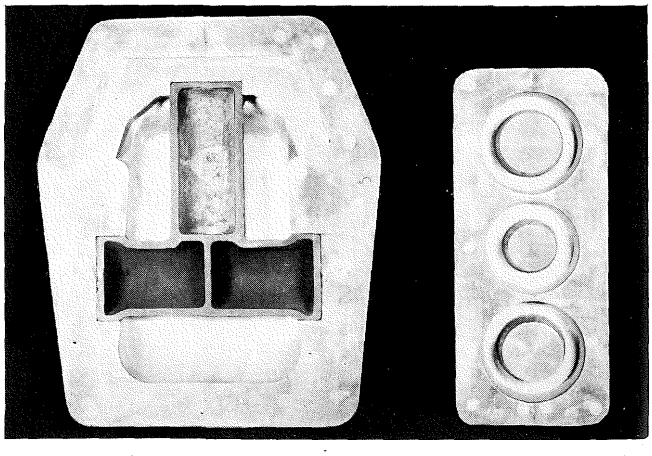


Fig. 7.7 — Core made in core box with ram up drier is pasted to core made with equipment shown in Fig. 7.5.

shown on the drag pattern. Figure 7.6 shows the core box for the core that fits into the core prints the second from each end (Fig. 7.4 — Top). The single end of this core fits into the core print shown on the cope side of the pattern (Fig. 7.4 — Bottom). Figure 7.7 is a piece of core that is pasted to the core made in the core box shown in Fig. 7.5. A drier is shown in the middle of one half of core box, Fig. 7.5, and also in the core box, Fig. 7.7 — Left, which is left in place during ramming and supports the center of the core during transportation and baking. When these cores are assembled, the core made in the core box, Fig. 7.6, passes between cores made in the core boxes shown in Figs. 7.4 and 7.7 — Left. The small core box, shown in Fig. 7.7 — Right, is for ring cores to fit around the six core prints shown on the drag pattern so the sand will not be broken away when the cores are placed in these prints. Figure 7.8 shows a large box being finished in a pattern shop.

Skeleton Core Boxes

To reduce the cost of the core boxes, where only one or a small number of cores are required, skeleton core boxes may be used. An example is a core for a straight cylindrical pipe. This core would be made in two semicylindrical pieces which are fastened together after the core is baked. The core is made in the following manner. Two semicircular boards are cut the desired diameter of the core. Two strips of wood, each being the desired length of the core, then are cut and the ends of each are fastened to the semicircular pieces, one on each side at the bottom. This is illustrated in Fig. 7.9.

This skeleton box is placed on a core plate and about an inch of sand is put on the plate. The cast iron arbor, shown in Fig. 7.9, then is placed in position. Sand is rammed into the core box to form a core that extends the length of the box and of a diameter at least as large as the ends of the box. A wooden strike, the shape of the cross-section of the core, is then pulled along the core from end to end to give the core the proper contour. This method of using skeleton core boxes and strikes may be used in many cases other than that shown.

CORE PLATES AND DRIERS

Cores usually are baked soon after they are made and must be supported in some manner prior to and during that operation. Where the support is a flat plate, it is called a core plate. Where extra supports or special shapes to fit individual cores are used, these special shapes are called driers.

If a plain, cylindrical core was made and placed on a flat plate, the weight of the core would press the core against the plate to make a flat surface on the bottom side of the core. If this core was placed in a form similar in shape to the contour of the core, the true shape could be maintained. This form or holder would be called a core drier. Driers usually are made to conform to the shape of the cores desired.

Materials

Core plates and driers must be made of material that will withstand the heat used to bake the cores. The most common material used for core plates and driers is cast iron. Due to the fact that aluminum alloys are lighter than cast iron, such core plates and driers are easier to handle. Therefore, where core plates and driers are lifted by hand, many are cast from aluminum alloys.

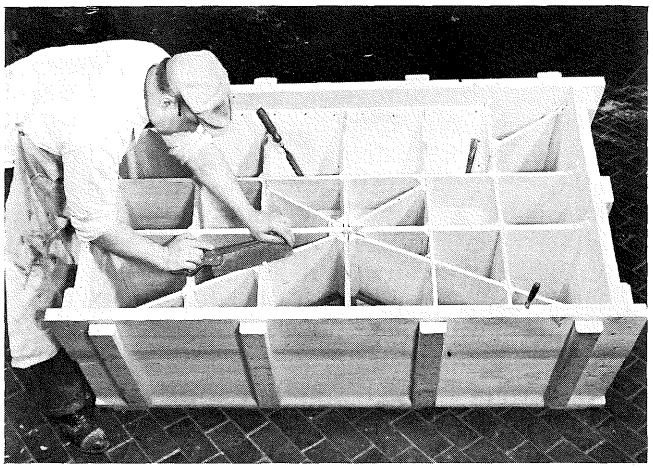


Fig. 7.8 — Large wooden core box.

Cast aluminum and magnesium core driers prove very economical because: (1) they machine easily; (2) they are light and easy to handle; and (3) the pounds of metal to heat up in the core baking oven is very low compared to the heavier cast iron plates.

The first essential of a core plate is that it have a plane surface. The second is that the plate be made of some material that transmits heat readily and is strong enough to resist warping, when subjected to alternate heating and cooling.

Small sized plates usually are made of steel or cast iron. A steel plate is lighter than one made of cast iron and can be easily peened to a level surface. Having a thinner section the steel plate allows the heat to penetrate more quickly, thus cutting down both baking and cooling time. Cast iron plates are thicker in section, heavier, must be planed to a level surface and, at times, require additional planing to maintain an even surface. Small steel plates often are reinforced by flanging opposite edges. Some coreroom foremen prefer perforations in small iron or steel core plates for a more even distribution of heat through the plate. Others prefer plain plates.

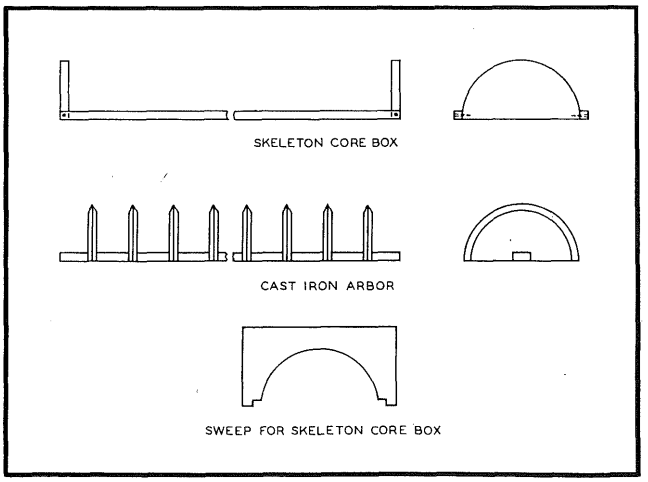


Fig. 7.9 — Skeleton core forming equipment and arbor for supporting core.

Another type of small size core plate is made of a mixture of cement and some heat resisting mineral. A mixture of these ingredients and water is squeezed under heavy pressure and, when dried, is waterproofed. This type of plate is rarely perforated, as holes through the plate break the waterproof coating and the plate is subject to disintegration by moisture.

Core plates of larger sizes require reinforcing to maintain a level surface. Ribs are cast underneath iron plates. Steel plates are reinforced by a framework of angles, bars, channels or a combination of these sections. The ribs or framework, by raising the plate, allow a better circulation of heat.

In the manufacture of steel core plates, the framework of the reinforcement is assembled and welded together. It then is machined to bring all members to a plane surface. The top plate is welded to the reinforcement and planed, usually to within 0.015 in. Cross and diagonal reinforcing members are not as deep as the longitudinal members so that the latter may be used as runners. Special hammered steel plates that remain flat in use also are employed in many core rooms.

When the size of plates increases to a point where they are too heavy to be handled by two men, trunnions or loops are required for movement by crane. Large size plates usually are perforated.

Plate Life

Properly designed steel or iron core plates of any size should last many years. Accidents may cause replacements or repairs, but such occasions would be rare. As an illustration of service given by core plates of correct dimensions, a quantity of approximately 80 steel core plates, varying in size from 33 x 44 in. to 50 x 59 in., were in use in a foundry making heater castings for more than nine years. An investigation showed that the plates had been used every working day since they were received and that no repairs of any kind had been necessary.

Bearing in mind that an installation of core plates is practically permanent, it is economy to equip originally with plates of proper design and strength.

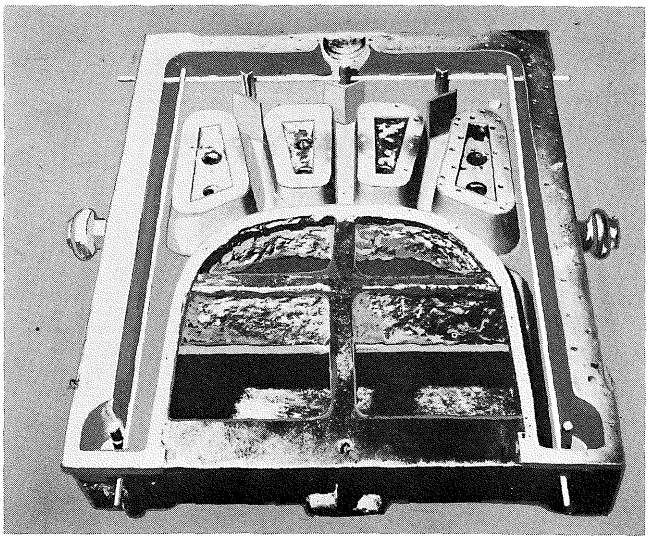


Fig. 7.10 — Core box with three rod vents in place. After the core is rammed, the rods are pulled out of the core box forming vents within the core.

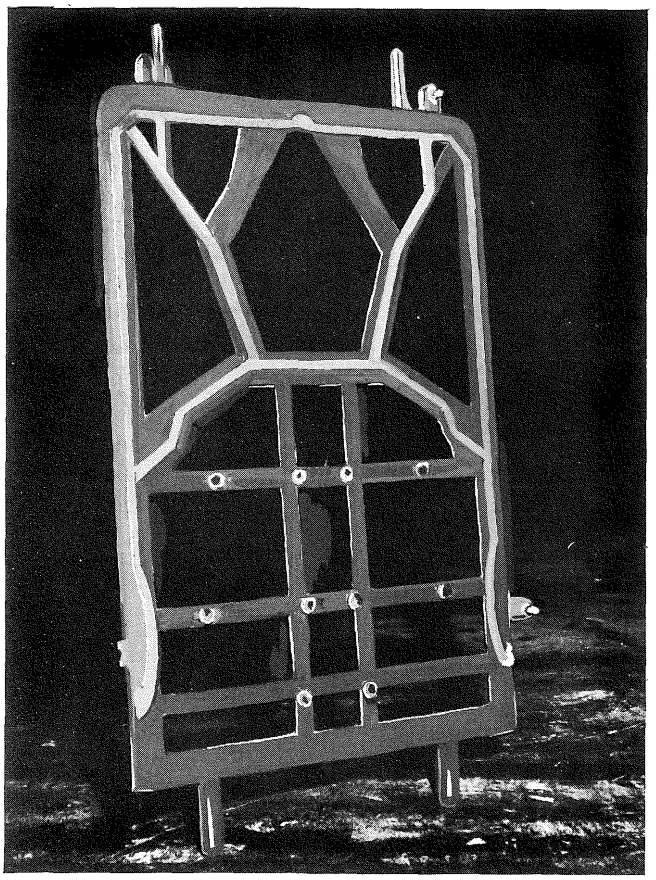


Fig. 7.11 — Vent plate with outline of V-shaped ridge which depresses the core sand to form a groove or vent at the parting line of a core.

A good way to remove scale from a core drier is to burn it off. The empty driers may be placed in a core oven for a few bakes. The scale can also be sandblasted off or dissolved in a bath of caustic soda.

VENTS AND VENTING

Due to the gases that are formed when metal comes in contact with a core, cores must be vented. Core sand is permeable and will allow the passage of gases through cores. Some cores may be of such a shape that the permeability of the core is the only ventilating required. The more of the core surface that is surrounded by metal, and the smaller the opening from the core to the outside of the casting, the more venting is required.

The details of venting vary greatly due to the size and shape of the core, type of core binder used, and available space to remove gases. The simplest and most common method of venting is to ram up a vent rod extending through the core print into or through the body of a core, as in the case of a straight cylindrical core similar to that made from the equipment shown in Fig. 7.1. In short cores, where a vent is needed, it may be simpler to push a vent rod or wire through the core after it has been rammed.

Wax Vents

Where a core is of such shape that a straight rod cannot be used to make a vent, irregular vents can be made by using vent wax. Vent wax is sold, wound on a spool like twine. It can be purchased in various sizes from $\frac{1}{32}$- to $\frac{5}{8}$-in. diameter. This wax is flexible and

can be placed in a core to form a vent opening. As the core is being baked, the wax melts and is distributed through the core, leaving an opening for the gas to escape.

Rope Venting

A core may be vented by ramming a smooth surfaced cotton rope in the core. The rope is pulled out of the core box through a hole through which the rope was threaded before filling the core box with sand. Rope vents may be used either for straight or circular vents.

Cross Vents

It is often necessary to vent cores in such a manner that while straight vent rods may be used, the vent is not brought out through a core print. Such type venting is illustrated in Fig. 7.10. This is possible by having cross vent rods touch a vent rod that is placed in a core print. The vent holes on the surface of the core are plugged where they would fill with metal.

Vent Plates

In production work, where two parts of a core are assembled either before or after baking, a vent plate may be used (Fig. 7.11). These vent plates have a raised section on the surface of the plate. By pressing the plate against the core, a depression is made in the core. When the halves of the core are assembled, the vent opening is between the two parts of the core.

In large cores, cinders or coke are used in the center portion instead of sand. These materials make the core more permeable; in other words, assist in venting the core. They also have other functions. Where a large body of sand would be required, it can be reduced by using cinders in the inside of the core. The cinders also make less core to bake, thus reducing baking time, and also act as a cushion so the casting may shrink without cracking.

CORE RODS AND ARBORS

Cores often must be reinforced to give the necessary strength for handling and for withstanding the lifting force on the core due to metal under the core in the mold. Cast iron weighs approximately four and one-third times as much as core sand. Therefore, it is more often necessary to reinforce a core against the previously mentioned lifting force of the metal than it is to withstand handling.

Small cores, where necessary, are reinforced by a rod or wires placed in the cores. In large cores, where large rods may not give sufficient strength, cast iron frames are used. These frames are of sufficient size to give the necessary strength to the core and are called core arbors. Figure 7.12 shows several core wires bent to desired shapes to be used in cores. Figure 7.13 shows a cross-sectional view of a core for a cast iron shell used in World War I. Note the wrought iron arbor, wrapped with burlap, on which the sand has been rammed to form the core. In this case, the arbor is used for supporting the core in an upright position and centering it exactly and rigidly in the mold, as shown. Figures 7.16, 7.17, 7.18 and 7.21 show other types of core arbors.

Arbors and Rods for Large Cores

Various methods are used to reinforce large cores, such as by the use of pipes, rods or arbors. Arbors may be made of iron or steel. Whenever practical, an arbor should be used, as it eliminates the use of rods and pipe. In a jobbing shop that has no facilities to make arbors and where the jobs change daily, it has proved more satisfactory to use pipes and rods.

Arbors not only simplify the making of the core, but often enable a core to be handled successfully under

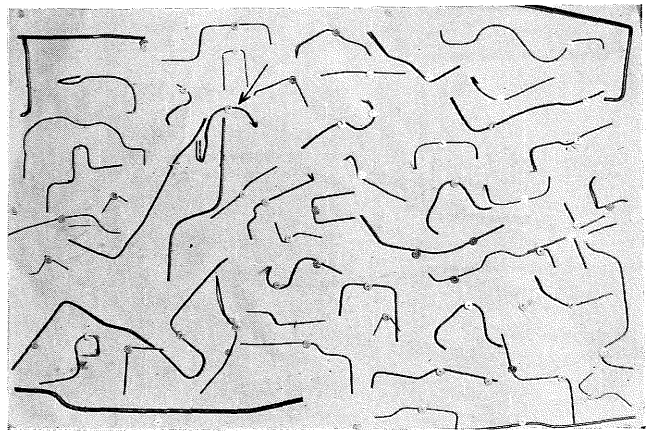


Fig. 7.12 — Various types of core wires bent to different shapes.

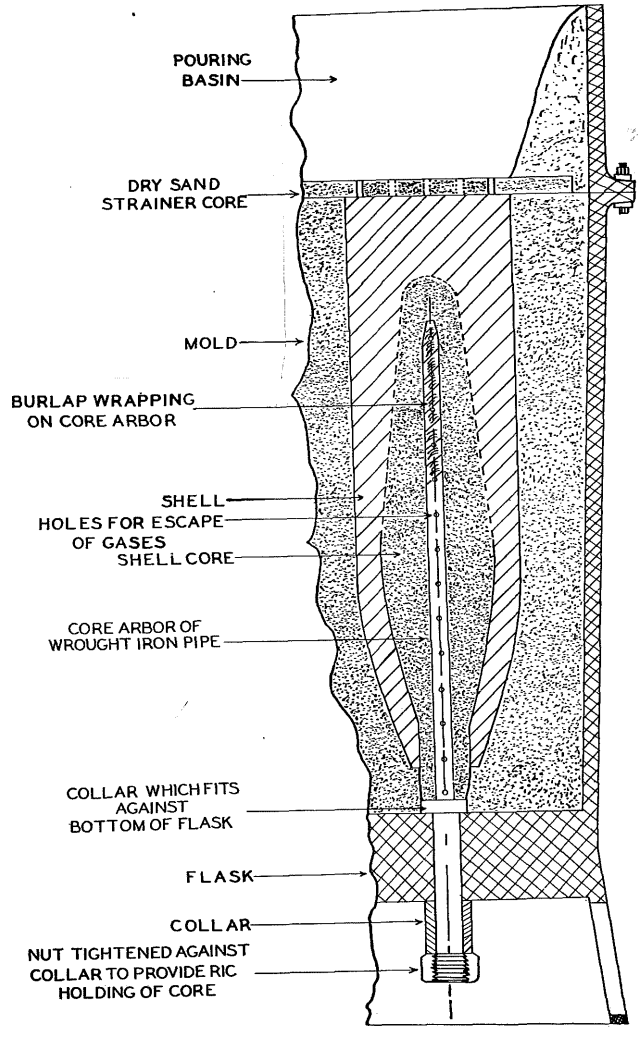


Fig. 7.13 — Cross-sectional view of core for cast iron shell.

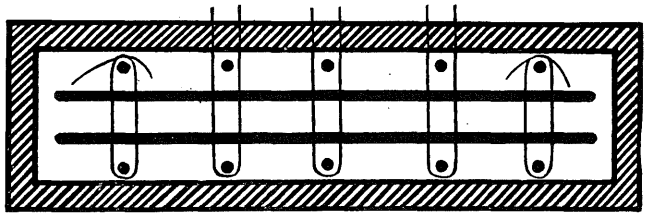


Fig. 7.14 — Side view of large core showing method of tying core rods together with wire to secure same effect as an arbor.

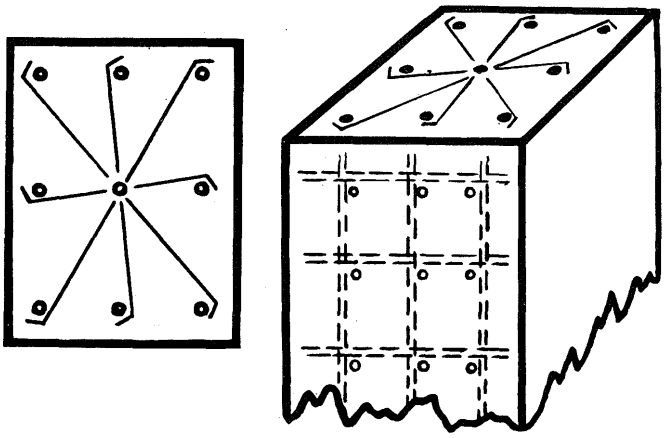


Fig. 7.15 — (Left) bottom view of large upright core showing method of tying upright rods together with gaggers. (Right) side view of same core showing upright and cross rods and gagger tie rods.

circumstances where, if only rods were used, it would be impossible to do so. Arbors are slightly more difficult to remove in the cleaning room, but whenever used, insure the best practice.

Arbors of all descriptions can be cast or welded. Wherever overhang is not safe with rods only, an arbor should be used and the rods eliminated.

There are a number of ways in which rods can be used to secure almost the same effect as an arbor. A layer of rods on top and bottom of a slab core, tied together with wire, will secure the core better and prevent splitting if the core must stand on end. An example is shown in Fig. 7.14, which shows a side view of a core with two layers of rods tied together with wire.

Rods are used in cores not only for handling, but so that the core can withstand the exerted pressure and hold its shape. In a core that stands from 4 to 5 ft high and in which an arbor is not practical, and the sagging allowance is not more than ⅛-in., rodding presents a different problem. In such a core, upright rods are set all around the outside of the core, 2 to 3 in. away from surface, about 12 in. apart and a gagger rod is used to tie in the bottom of the upright rod. As the core is built a gagger rod is used in the same capacity about every foot vertically until core is completed. This does not eliminate cross rods that must be used to hold core together.

As an illustration, a core 30 x 30 x 60 in. high would be rodded as shown in Fig. 7.15. On the left is shown a bottom view of the core with upright and gagger tie rods. On the right is a side view showing upright and cross rods and gagger tie rods.

LARGE SAND CORE PRACTICE

A good practice to follow on large cores is to use a good facing sand that will not allow the metal to penetrate, and back this with a soft backing sand. Hollow out the center of the core as much as possible with coke breeze, or other materials such as sawdust and cinders. This not only makes a soft core, but allows it to be cleaned out much more easily than when an all sand core is used.

Care must be taken to judge just how much of the core can be hollowed out. Where heavy metal sections surround the core and the possibility of cracking is not involved, coke can be left out of the core completely and small ditches can be cut to the core and mold vents. If a full sand core is used, a number of small vents is recommended so that gases can escape readily. If gases cannot escape readily, the core may blow.

Large cores for light sections 1 to 1½-in. offer a different problem. The core must be collapsible, due to the metal section, and the sand face must peel readily. A soft backing sand must be used and the core hollowed in the center so that it will deteriorate rapidly and allow the casting to shrink. Some such cores are 2 x 4 x 10 ft long while others are as large as 4 x 5 x 5 ft long and weigh from 3500 to 10,000 lb and are surrounded with 1¼-in. metal sections.

The use of cast and welded steel arbors is illustrated in the following: A cylinder center core weighing 22,500 lb, when set in the mold, was made with a large steel arbor in each half of the core. The core was 5 ft 2 in. in diameter and 10 ft 5 in. in length. It was hung from the cope by the arbor. Metal sections of this casting were extremely heavy, ranging from 17 to 27 in. in thickness; cylinder walls were included in this range. The casting weighed 100 tons when finished and it required 140 tons of metal to pour it. The core was faced with high silica content sand and coke breeze was used in center of the core for venting purposes and also allowed core to be cleaned out more readily.

A sketch of the cast steel arbor is shown in Fig. 7.16. It had 1¼-in. metal sections, was 5 ft wide, 10 ft long, with a 1¼-in. arched rib every 2 ft. The holes in the

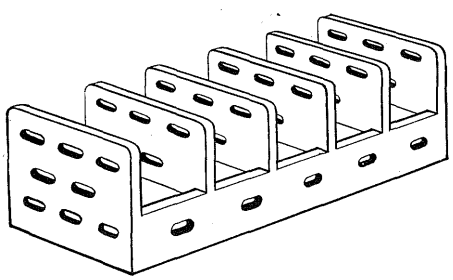


Fig. 7.16 — Cast steel arbor for large core weighing 22,500 lb.

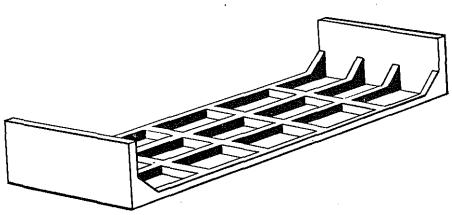


Fig. 7.17 — Welded steel arbor used in sand core for runner casting. Weight of core was about 14,000 lb.

ribs were for pipes to be inserted and gaggers were used for uprights to further anchor sand in position.

An example of a welded steel arbor is shown in Fig. 7.17. This arbor was used in a sand core for a runner casting and was made of pieces of ¾ x 1½-in. flat steel which were welded together as indicated. This arbor was 36 in. wide and 63 in. long. There were four upright rods and four cross rods to strengthen the assembly. This arbor balanced the weight of the large core which was about 7 tons when ready for use in the mold for which it was prepared.

ARBORED PIPE AND FITTING CORES

In making sand cast, cast iron pipe and similar cast parts that require cylindrically-shaped cores and in pipe fittings, such as T's, bends and Y's, cores may be made from molding sand supported by arbors. The cores may be green sand, dry sand or loam. In making pipe fittings, green molding sand cores are used. The core is strengthened so it may be handled and retain its shape in a mold by use of an arbor. The core is made in a core box and the two halves are hinged so they may be booked. Figures 7.18, 7.19 and 7.20 show the several stages in making green sand pipe elbow cores. Figure 7.18 shows the core box with the arbor in place before the core is rammed. Figure 7.19 shows the core completed. The two parts of the core box were rammed full of sand, struck off, and closed on the hinges like a book. The top part of the core box then was removed to leave the core as shown. An opening is shown in the center of the core. This is to allow a crane hook to be inserted and connected with the arbor for lifting the core by crane. The arbor projects at the ends of the core so that a man may balance the core on the crane by hand. Figure 7.20 shows a mold with cores in place.

In making soil pipe, the common method consists in having a cast iron core arbor which is smaller than the core desired and which is drilled with small vent holes. The core arbor is supported in bearings so it may be turned on its axis. A handle is fastened to one end for this purpose, or the arbor is rotated by friction drive from a motor driven pulley. A box of molding sand, the length of the core desired, is supported about 5 ft above the core. A small amount of sand at a time is allowed to rain down on the core arbor from this height, which is sufficient to ram the core. The core arbor is turned as the sand falls and, by use of a strike, the excess sand is struck off to produce the proper sized core. These cores sometimes are dried before use.

There are three general methods of making cast iron water pipe. Two are centrifugal methods. The pipe is cast horizontal and no core is used. The pipe is made by revolving a mold at a carefully regulated speed and pouring a weighed amount of metal into the mold. Centrifugal force thrusts the metal to the inside surface of the rotating mold where it solidifies, thus forming the pipe without a core.

The old method of making cast iron water pipe consists in pouring sand molds in a vertical position and coring out the inside of the pipe with a loam core. A core arbor is used to support the core. In small cores, for example 4 in. pipe, a steel pipe is used for an arbor. Vent holes are drilled through the pipe. To allow for shrinkage, make it easier to remove the core, and to aid the venting of the core, hay rope first is wound around the arbor, then the loam is applied. The cores are formed horizontally, as outlined in the previous paragraphs. To allow for the hay rope and loam, the arbor is from 1½ to 3 in. less in diameter than the core; the thicker the casting, the more loam is required. A special type paper has been developed that may take the place of hay rope.

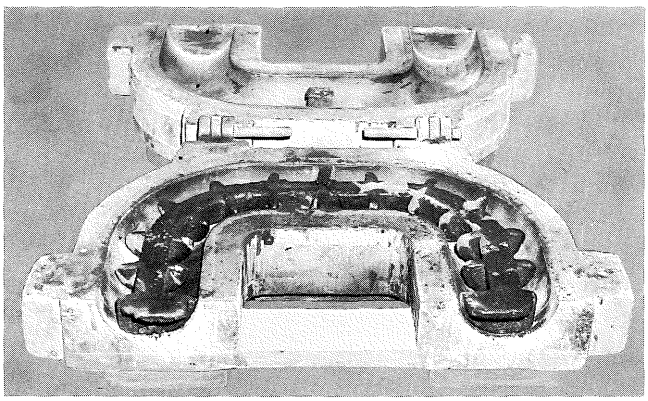


Fig. 7.18 — Cast iron arbor for pipe elbow core mounted in core box.

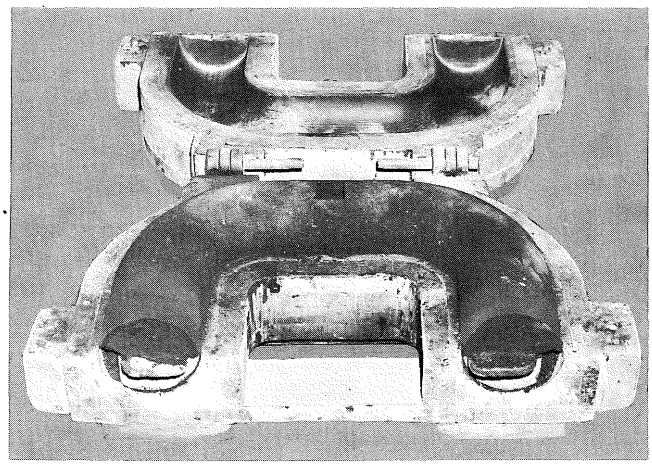


Fig. 7.19 — Rammed pipe elbow core with arbor located in center of core.

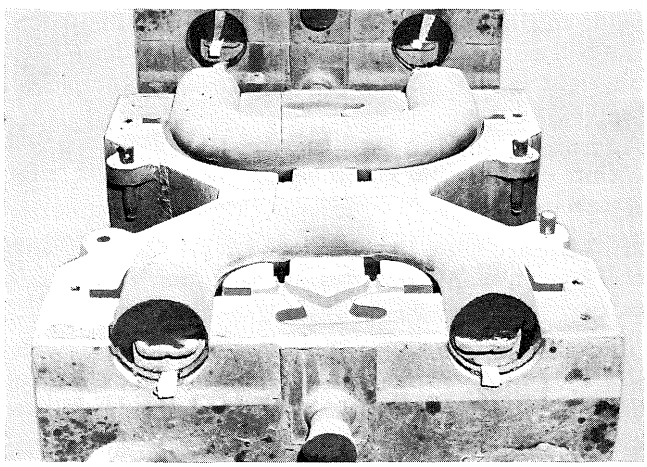


Fig. 7.20 — Pipe elbow core set in mold showing how core is supported by core prints.

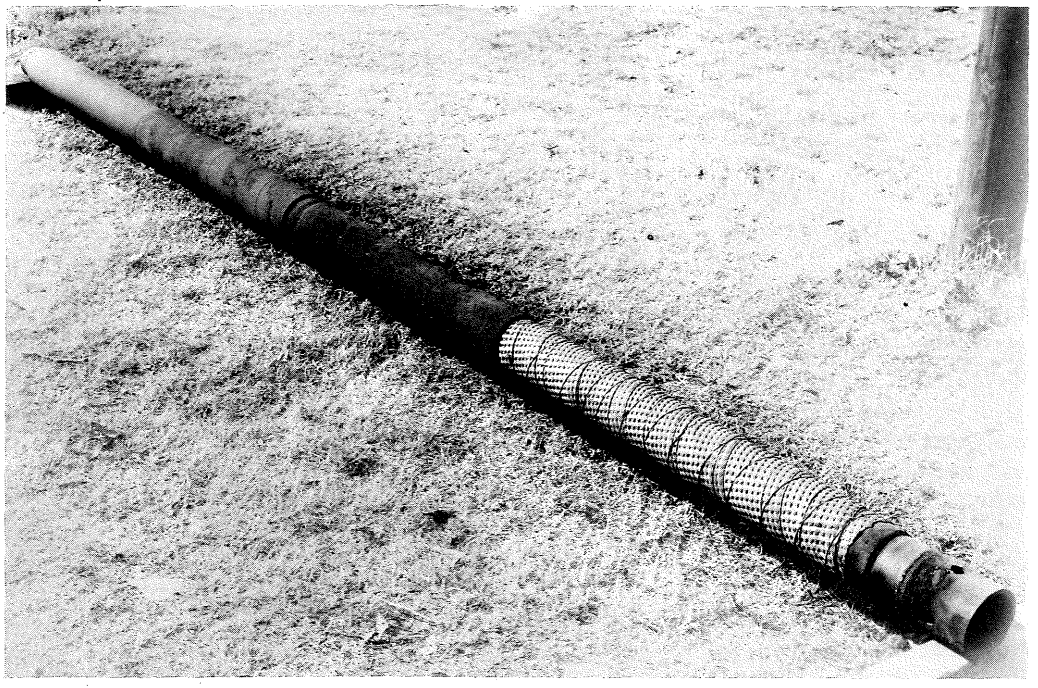


Fig. 7.21 — The photograph shows several stages in making loam core for cast iron water pipe.

Figure 7.21 shows, from right to left, the several stages in making a loam core for cast iron water pipe. As shown in Fig. 7.21, the holes in the end of the arbor are for lifting the core to place it in the mold. They also can be used for inserting a handle to rotate the arbor.

The first step consists of wrapping the full length of the arbor with a perforated paper and fastening it in place with cord. The second step is to apply the first coat of loam, which is allowed to dry before applying the second coat. The finished stage, with blacking coat, is shown at the left end. Due to the core being made to illustrate the several steps in its production, the bell of the pipe is not shown. It would have been on right end of core had the core been completed.

CORE CHILLS

Core chills should be avoided whenever possible for several reasons.

(1) They are more likely to cause defects than outside chills because any gas generated does not have as free exit without passing through metal.

(2) A greater number is required on long run jobs, due to the fact that cores must be made well ahead of casting time, while the mold is made only a few hours, and never more than one day, before being cast.

(3) They are more trouble to keep in production, especially in steel castings, for they often stay in castings until after heat treatment.

(4) In heat treated castings, due to excess heat and the fact they often go through heat treatment, core chills deteriorate more rapidly and must be replaced more often than outside chills.

A very satisfactory way of subtracting heat from an enlarged section of molten metal is by forming the chill of a molding material that possesses a high specific heat. Such a chill will be able to absorb quickly a large quantity of heat from the molten metal during solidification.

An excellent example is found in the nonferrous foundry, where a chill is formed within a core by making that section of the core, adjacent to the heavy section of a magnesium or aluminum casting, of a mixture consisting of iron grit and sand.

In this mixture, substantially equal parts of core sand and iron grit of suitable fineness are bonded with a core oil. Applying a one to two inch layer of this mixture on the face of a core will provide a suitable chill. This type chill is found useful for small run patterns requiring chills at irregular shaped sections.

Materials other than iron grit may be employed, for example, zirconium oxide and ilmenite. These two materials may be used in ferrous castings where only a limited chill is desired.

Size and Shape of Chills

The size of chills to be used on the job is determined by metal sections of the castings; in other words, use a large enough chill. The chill shape is as important as chill size. A chill should never be designed so as to form reentrant angles of sand at their sides or ends, except where it is desired to retard or control the chilling effect. The placing of chills is very important and should receive careful study for each

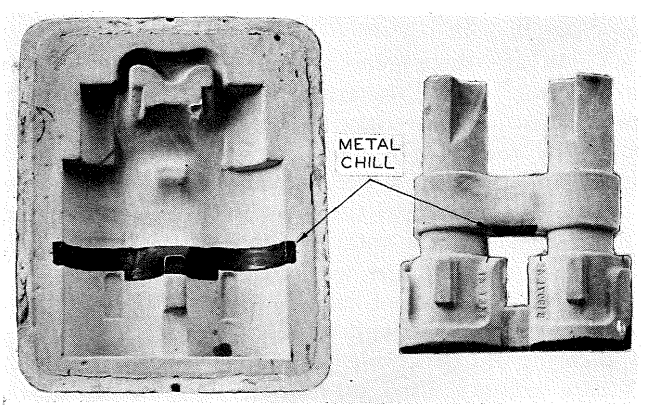


Fig. 7.22 — Use of metal chills in cores.

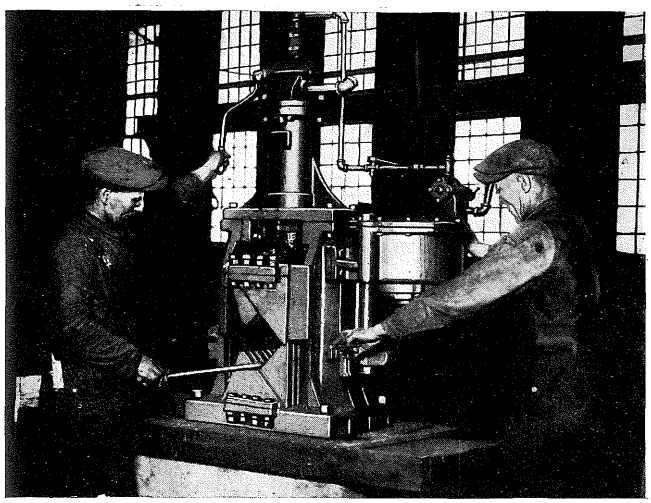


Fig. 7.23 — Rod-straightening machine in operation, straightening core rods and wires.

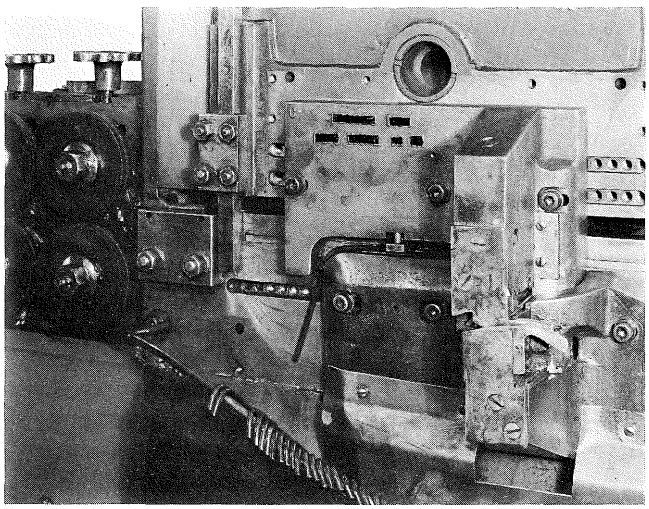


Fig. 7.24 — Another type of rod-straightening and bending machine.

application. Where chills are to be used on section junctions, it is desirable to have the radii at least one-third as great as the section thickness, but never more than one-half as great.

Chill Coatings

To prevent metal inserts and chills from blowing, the following coatings are recommended.

(1) A solution of alcohol and resin.

(2) Shellac.

(3) Dip in emulsion of water and red lead and dry thoroughly.

(4) A light coat of lard oil may also be applied to prevent collection of moisture by condensation.

Inserts also may be sandblasted to remove all rust, dirt, and foreign matter and then dipped in kerosene before setting in the mold. To make inserts hold tight they should be roughened, nicked, or threaded to provide an anchorage of the chill in the core.

Figure 7.22 shows a core assembly for a steel casting in which chills are used.

CORE ROD STRAIGHTENERS

Every foundry has occasion to use wire and rods for strengthening and supporting cores. In the final shakeout and cleaning of castings, these rods become bent and unfit for further use, unless straightened. To do this by hand often is more costly than to use new rods and results in waste.

Bent core rods and wires can be salvaged and used many times by use of a power operated rod straightener. Such a machine will quickly straighten any rod within its capacity. These machines are made to handle wire and up to 2½-in. diameter rods.

These machines also are equipped with shears for cutting rods to the desired length and bending dies to form gaggers. Skilled labor is not required. Fig. 7.23 shows the construction of an air-operated rod straightening machine and illustrates how the operations are performed.

Another type rod straightener is shown in Fig. 7.24. This machine, in addition to being a rod straightener, is equipped with a shearing and bending attachment. The machine is designed to cut and straighten wires from 1/16 to ½-in. diameter. The rollers at the left of Fig. 7.24 straighten the wire rod and feed it into the dies which may be set in practically any desired manner to produce the necessary wire shape.

VIBRATING STRIPPING MACHINE

Many core rooms use simple vertical guide plates, caused to vibrate by air or electric vibrators, to aid in stripping the core from the core box. After the core has been made, the core box is rolled over by hand onto a core plate. One side of the core box is pushed against a vertical guide on the vibrating guide plate, as shown in Fig. 7.25, and the operator raises the core box, holding the box against the guide. The guide vibrates the core box and enables the coremaker to strip the box from the core easily.

STOCK CORES

Stock cores may be considered as any cores which are made in quantities and stored for future use. More particularly, the term applies to those cores having a uniform cross-section. The most common stock cores are round, in sizes from 3/8 to 3 in. in diameter.

Stock Core Shapes

Figure 7.26 shows other shapes and sizes which can be made and classed as stock cores. These usually are

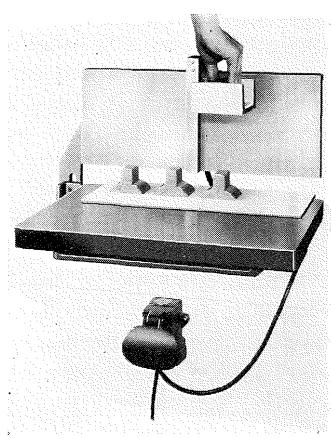


Fig. 7.25 — Vibrating stripping machine for cores.

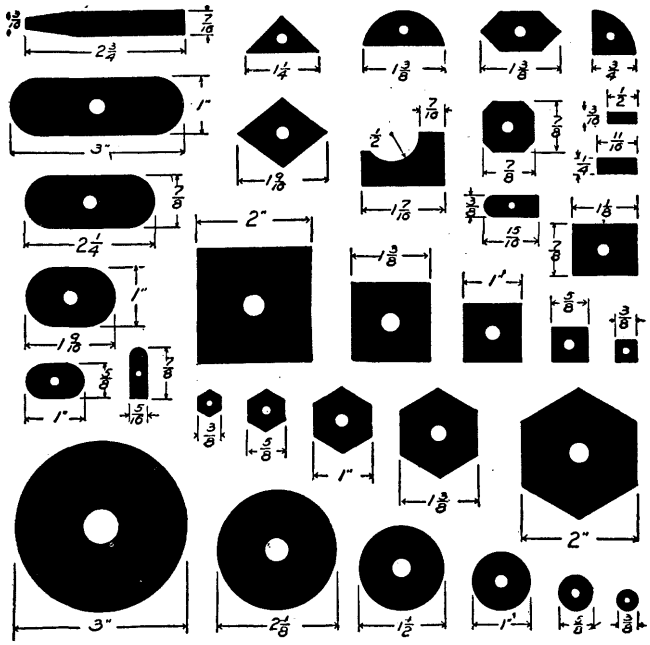


Fig. 7.26 — Specially shaped cores that can be made on a continuous core machine.

made and stocked in lengths of 20 or 24 in. and cut to length as required. Almost any shape, of a size within a 3 in. diameter circle, can be produced by stock core machines now on the market. Such cores are vented automatically through the center in the making.

Many of the shapes shown in Fig. 7.26 are made to fixed lengths in multiple core boxes on molding machines, but the most uniform cores are obtained by the continuous molding process, where the core is formed by forcing sand through a die of the exact shape and size wanted.

Continuous Machine for Stock Cores

Figure 7.27 shows a machine for molding stock cores continuously. These machines consist of a storage hopper for sand; a vertical shaft, having a stirring arm and paddles to push the sand downward into the conveyor chamber; a tapered spiral conveyor, which forces the sand through the die and tube; the adjustable length of tube, which controls the density of the core; a tray and tray support for catching and holding the cores preparatory to baking; and a motor and drive connections for operating. The speed of the conveyor on the machine shown in Fig. 7.27 is about 275 rpm and one-half horsepower motor is required. The machine may be mounted on a separate stand, or on a bench, as shown in Fig. 7.28. Grooved trays are provided to hold the cores as they come from the machine and to support them in the baking oven.

Cut Off and Tapering Machine for Stock Cores

When this type of machine was used, it was advisable to have a cut off saw and wheel for grinding tapers on cores. The machine shown in Fig. 7.29, but now rarely used, permitted fast cutting to exact lengths, and taper grinding to any angle.

Uses of Stock Cores

There are a number of ways in which stock cores can be used to advantage. Patterns and core boxes often can be made with loose pieces, permitting baked stock cores of proper length to be inserted and rammed up in the main core. This eliminates setting these cores separately, with the possibility of inaccuracy and misalignment. Such a procedure also avoids fins, which must be chipped. In this manner, the setting of one large core automatically sets all stock cores included with it.

Multiple openings in castings often can be secured by setting the required number of short pieces of stock core in the core box before ramming up the main core. This simplifies core box making and tends to produce more accurate spacing and smoother castings.

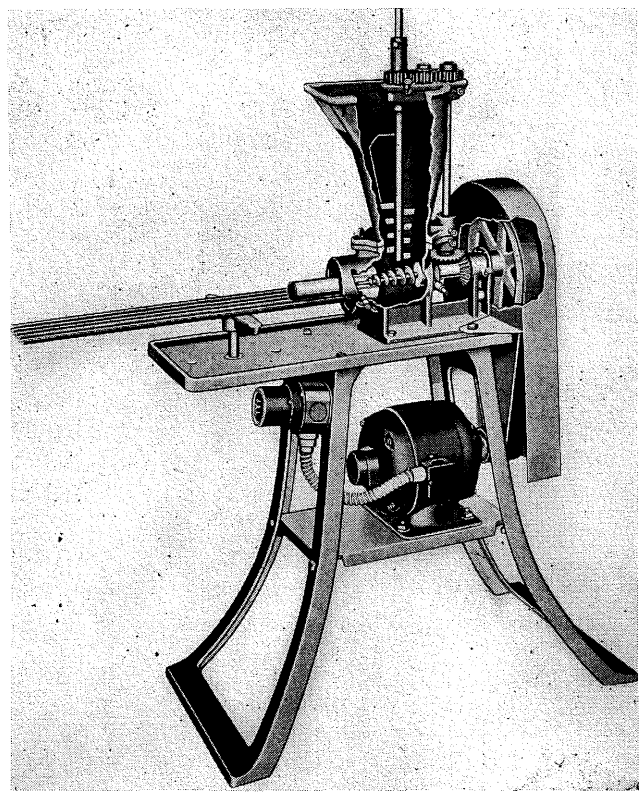


Fig. 7.27 — Continuous core machine for making stock cores.

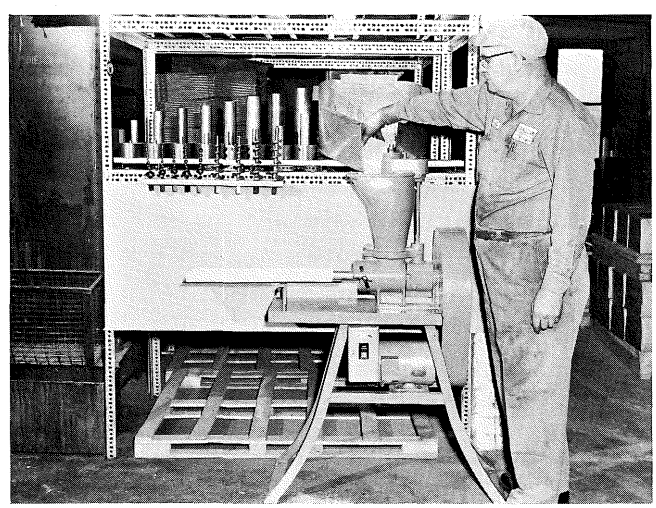


Fig. 7.28 — Continuous core machine mounted on bench.

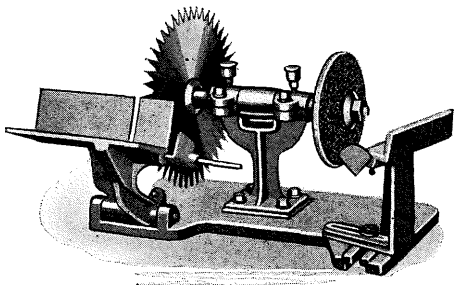


Fig. 7.29 — Cut-off and tapering machine formerly used.

Sand Mixtures for Stock Cores

Sand mixtures for use in continuous coremaking machines will vary somewhat, depending on materials available in the particular locality and conditions prevailing in the foundry, such as kind of castings or type of core oven used. See Table 7.1. The base sand should be clean and free from clay, which will absorb oil.

When liquid binders, such as sulfite liquor, or when flour or starch are used, a small amount of clay will not weaken the core but may reduce the natural venting capacity of the core by reducing permeability.

Storage

Finished cores should be stored in a heated, or at least dry, room and not exposed to undue moisture. Under such conditions, stock cores will maintain their strength and a saving can be effected in the amount of binder required. Core materials should be mixed thoroughly to secure uniform distribution of the binding elements so that maximum properties with least binder will be obtained.

A number of core mixtures which have been used successfully in continuous coremaking machines is given in Table 7.1. Slight changes in proportions to meet local conditions are to be expected.

CORE RAMMING

The degree of compactness necessary to produce a satisfactory core depends upon the type of binder used and on the size and shape of the core. Certain binders require different degrees of ramming. For example, core sands bonded with air drying binders, such as sodium silicate or portland cement, must be rammed well to bring the sand grains into proper contact. Oil sand core mixtures do not require hard ramming, as is evidenced by the fact that cores are made from such mixtures by jarring, blowing or pressing.

The size and shape of a core will dictate to a large extent the firmness to which the sand must be rammed. For example, a low height core need not be rammed as carefully as a tall core. Cores with restricted parts need careful ramming to avoid spongy areas.

The methods used to ram a core may be classified as hand, air rammer, jolt, squeeze, slinger, blowing and pneumatic throwing. Each of these methods of ramming a core will be discussed separately.

TABLE 7.1 — CORE MIXTURES FOR CONTINUOUS COREMAKING MACHINES

No.	Type Castings	Core Diameter in.	Silica Sand Parts	Silica Sand Qt	Molding Sand Qt	Cereal Parts	Cereal Qt	Core Oil Parts	Core Oil Qt	Fire Clay Qt	Sulfite Liquor Binder, Parts	Moisture	Remarks
1	.....	3/8, 1/2 5/8		5[1]	1/2[2]		1/2		6 oz.[3]			Add water if cores do not run full length of tray. Avoid excess water as this increases friction on dies.	[1]Dry Lake Sand. [2]Fine Molding Sand. [3]Raw Linseed.
2	Gray Iron ..	1/2 to 2 1/4	100[1]			10		1[2]				As little as possible.	[1]Clean Lake Sand. [2]Raw Linseed.
3	Gray Iron ..	1/2 to 2 1/4		12[1]			2		1/4[2]			As little as possible.	[1]Clean Lake Sand. [2]Raw Linseed.
4	Gray Iron ..	2 1/2 to 7		15[1]	3[2]		1 1/2		1/4[3]				[1]Clean Lake Sand. [2]Loam Sand. [3]Raw Linseed.
5	Steel	1/2 to 2 1/4		6			1		1/8[1]				[1]Raw Linseed. Mix well. Change quantity of fire clay to increase or decrease core hardness.
6	Steel	2 1/2 and larger		18			1 1/4		1/4[1]	3			[1]Raw Linseed. Mix well. Change quantity of fire clay to increase or decrease core hardness.
7	Steel	1/2 to 2 1/4		6			3/4		1/8[1]				[1]Raw Linseed. Mix thoroughly.
8	Steel	2 1/2 and larger		6			1 1/2		1/8[1]				[1]Raw Linseed. Mix thoroughly.
9	Brass	Small		4[1]	2[2]				1/8[3]			The more water this mixture will carry, the harder and stronger the cores.	[1]Silica or Clean Lake. [2]Brass Molding Sand. [3]Raw Linseed.
10	Bronze or Brass		50[1] + 20[2]					1				Moisten.	[1]Lake Sand. [2]Silica.
11	Aluminum ..	Small	50[1] + 10[2]								1 1/2	Moisten.	[1]Clean Lake. [2]Silica or 5 parts Molding Sand.

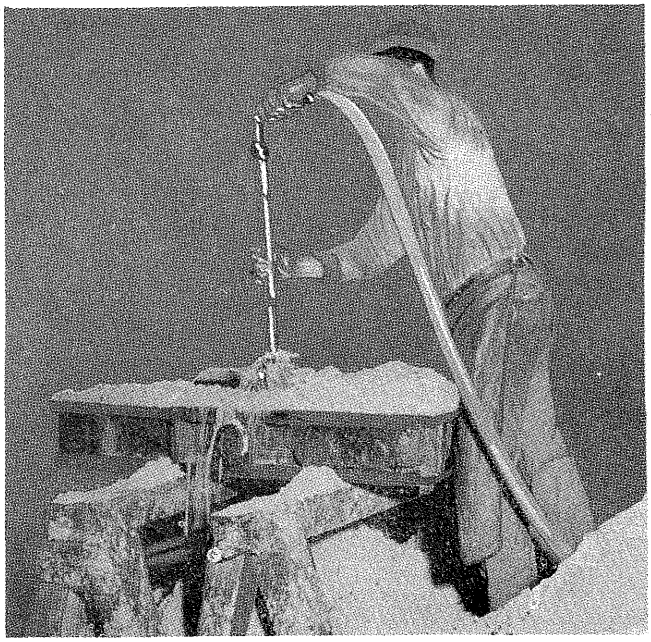


Fig. 7.30 — Ramming a core box with the aid of an air rammer.

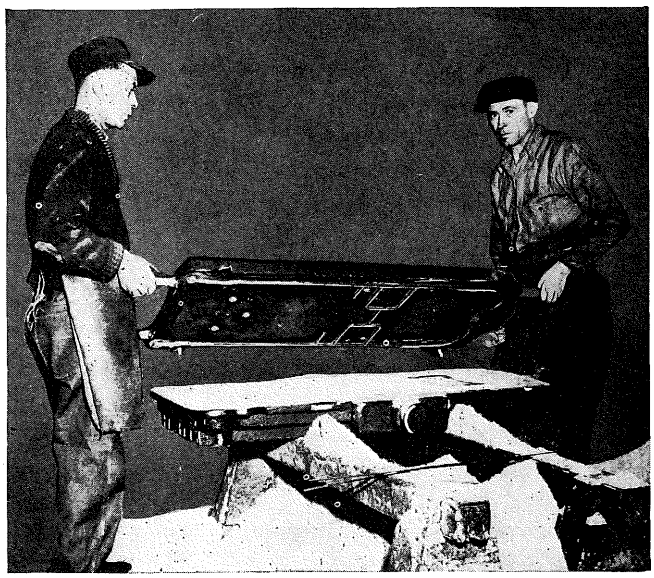


Fig. 7.31 — Venting a half-section core by pressing a vent plate on the parting.

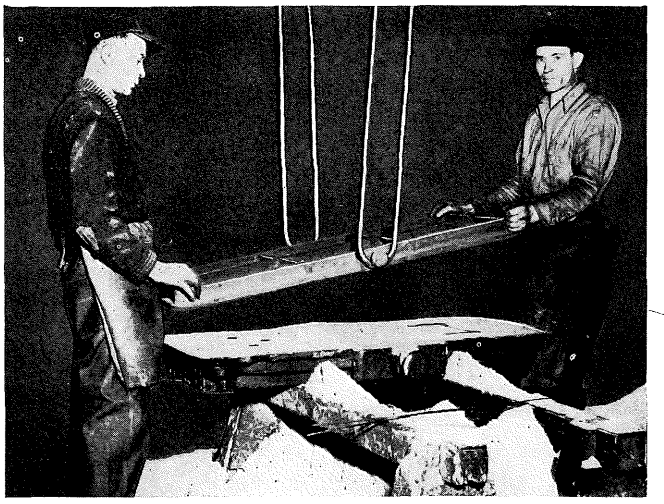


Fig. 7.32 — Placing core plate on face of core box prior to turning over core box.

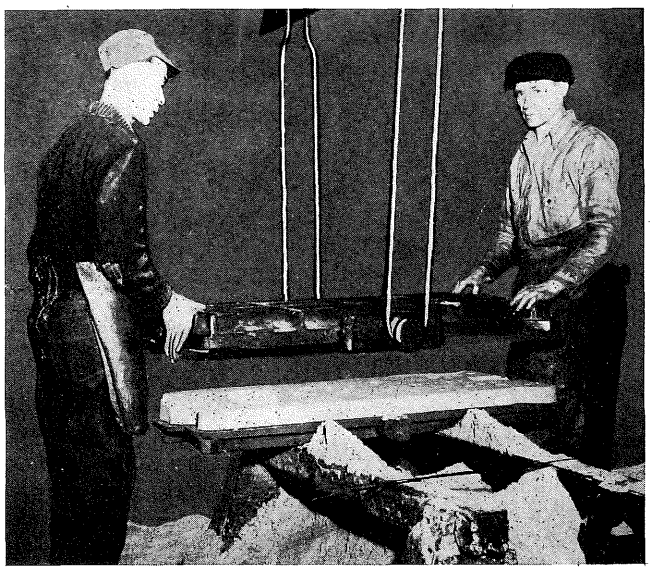


Fig. 7.33 — Stripping core box from core with aid of an overhead crane.

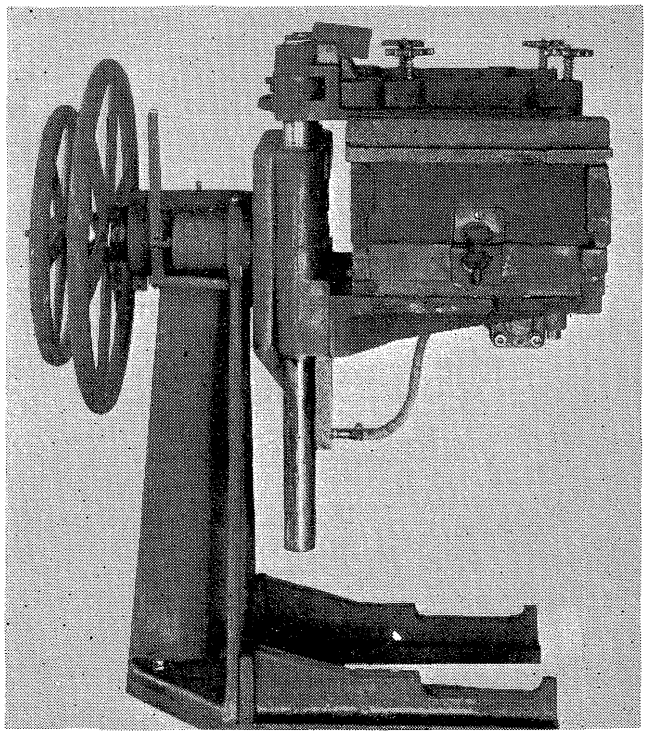


Fig. 7.34 — Hand roll-over coremaking machine.

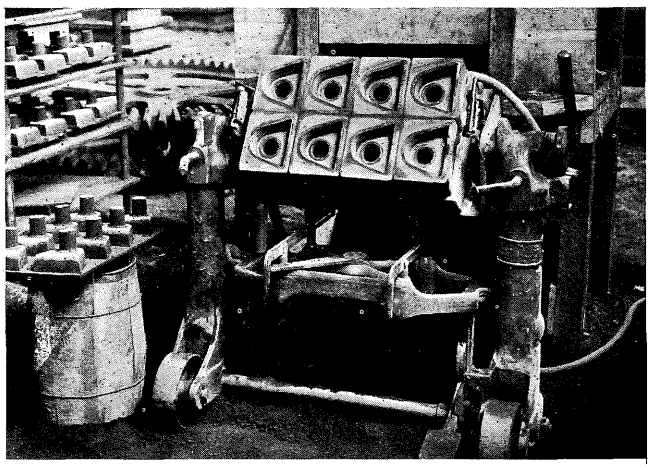


Fig. 7.35 — Another hand roll-over coremaking machine.

Hand Ramming

Small shallow cores frequently are rammed by patting the core sand with the palm of the hand. Where the core box is of an appreciable depth, for example, 4 in. or greater, or area of core is large, a bench rammer or peening stick is employed to an advantage.

Air Ramming

Ramming of large shallow core boxes is facilitated by using an air rammer to ram the sand. Figure 7.30 illustrates this method of ramming. After the core sand is rammed, the face of the core is struck off with a sharp-edged core strike. The next operation is to provide a vent for the core by pressing a vent plate on the core parting, as shown in Fig. 7.31. The third operation is to place a core plate on the face of the core box (Fig. 7.32). The core box and core plate then are clamped together with "C" clamps and rolled over. The "C" clamps are removed and the core box stripped from the rammed core with the aid of an overhead crane (Fig. 7.33). The core plate, with core, then is picked up by the crane and placed on a core rack ready for baking.

HAND ROLL-OVER COREMAKING MACHINES

Considerable skill and care are required to strip core boxes with a deep draw. Two distinct types of core stripping equipment are available; the trunnion roll-over, and the hinged. Two of the trunnion roll-over machines are illustrated in Figs. 7.34 and 7.35. In the roll-over machine shown in Fig. 7.36, the core box sets in a cradle, while in the machine shown in Fig. 7.34, the core box is gripped between two extended arms. With this type of equipment, the core box is rammed by hand and is stripped by machine. Figure 7.37 illustrates hinged roll-over machine for stripping core box from the hand rammed core.

Hand roll-over coremaking machines are especially suitable where production is limited and mechanical aid is required in rolling over and stripping the core box from the core after the core has been rammed.

SQUEEZING MACHINE

A core may be made by applying a squeezing load to the top of the sand. The possibilities of this method in production are shown in the following illustration. A coremaker making cores for a differential case by hand method is illustrated in Fig. 7.38. An ingenious power squeezer, shown in Fig. 7.39, was constructed, using an air cylinder to press the top-formed plunger into the core box. This method of making the cores doubled the production.

HAND JOLT, HAND ROLL-OVER MACHINES

Many medium size and small cores, which are made in gang core boxes and which require careful stripping from the boxes, are made advantageously on hand jolt, hand roll-over machines. A variety of work may be made on this type equipment and both wood and metal core boxes may be used. However, the latter is preferable for mounting on a machine. Two sizes of hand jolt, hand roll-over coremaking machines are illustrated in Fig. 7.40. The two small machines shown at the right are used for rolling over and strip-

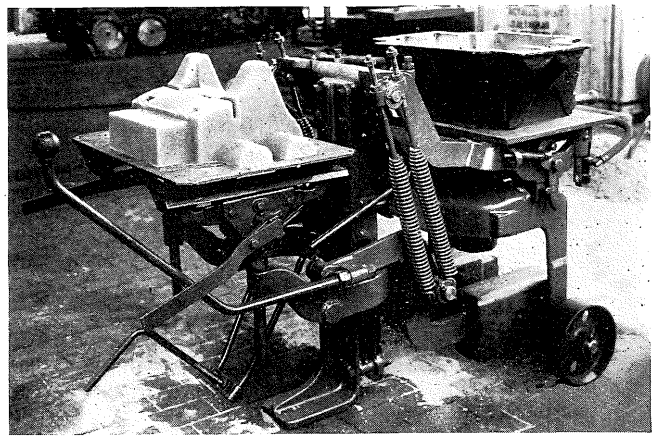


Fig. 7.36 — Hand roll-over coremaking machine in use.



Fig. 7.37 — Another view of a hand roll-over coremaking machine in use.

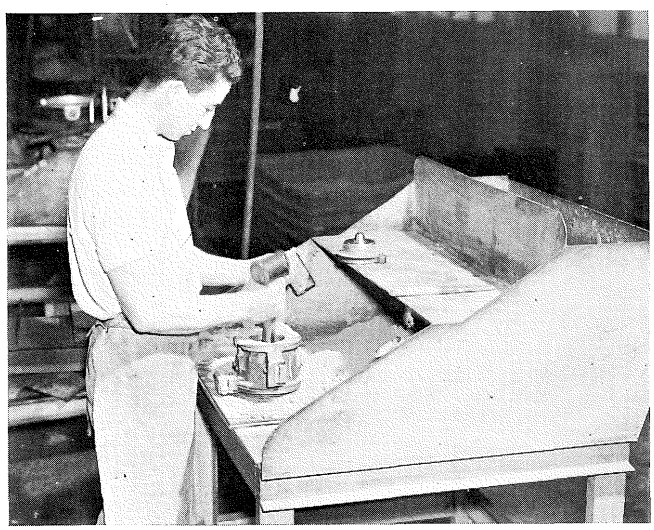


Fig. 7.38 — Hand method of making a one piece differential case core.



Fig. 7.39 — Air squeeze method of making differential cores.

ping small cores which require accurate stripping from their boxes. The core box may be rammed by hand after first being jolted by hand bumping.

The coremaking machines shown on the left of Fig. 7.40 are of a larger size. Note the aluminum raising blocks on which the core boxes are mounted. The coremaking machines are also placed on blocks to raise the work to a convenient height for the coremaker. The well arranged coremaker's bench, with core sand hopper and overhead core sand delivery trolley, does much toward obtaining efficiency in a core room.

CORE BLOWING

Historical

In 1903, A. M. Hewlett, works manager, Western Tube Co., Kewanee, Ill., began experimenting with the blowing of cores by filling a hopper with sand and admitting air above the sand. He received basic patents for the method. The Western Tube Company built a number of machines with six hoppers and six chucks, rotated and indexed automatically. At the first station, the core box was placed in the machine; at the second station the hopper was filled with sand; while at the third station, the core was blown. The remaining stations were used to take the core boxes out of the machine and prepare the machine for the next cycle. At the bottom of the hoppers was a plate with holes to direct the sand into the core box at the point which experience showed would give the best results.

Wm. Demler & Bros., Kewanee, Ill., were licensed to build machines under the basic Hewlett patents and did a great deal of pioneer and introductory work, demonstrating the value of blowing cores. They also developed the single hopper machine as they found that it was adapted to a greater variety of work than the multiple chuck, automatic machine. It consisted of an air chamber and valve, a reciprocating hopper, which is filled with sand in one position, and in another is under the air chamber ready to fill the core box. A chuck or vise holds the core box and an air cylinder is provided to clamp the core box and hopper in line with the air chamber while blowing the core.

When the basic Hewlett patents expired, other manufacturers began making machines for blowing cores. One company made the machine shown in Fig. 7.41 and another company that shown in Fig. 7.42. A bench type core blower is shown in Fig. 7.43.

Scope and Operation of the Core Blowing Machine

Importance of the core blowing machine as a modern means for rapid production of uniform and high quality cores is well recognized in the foundry indus-

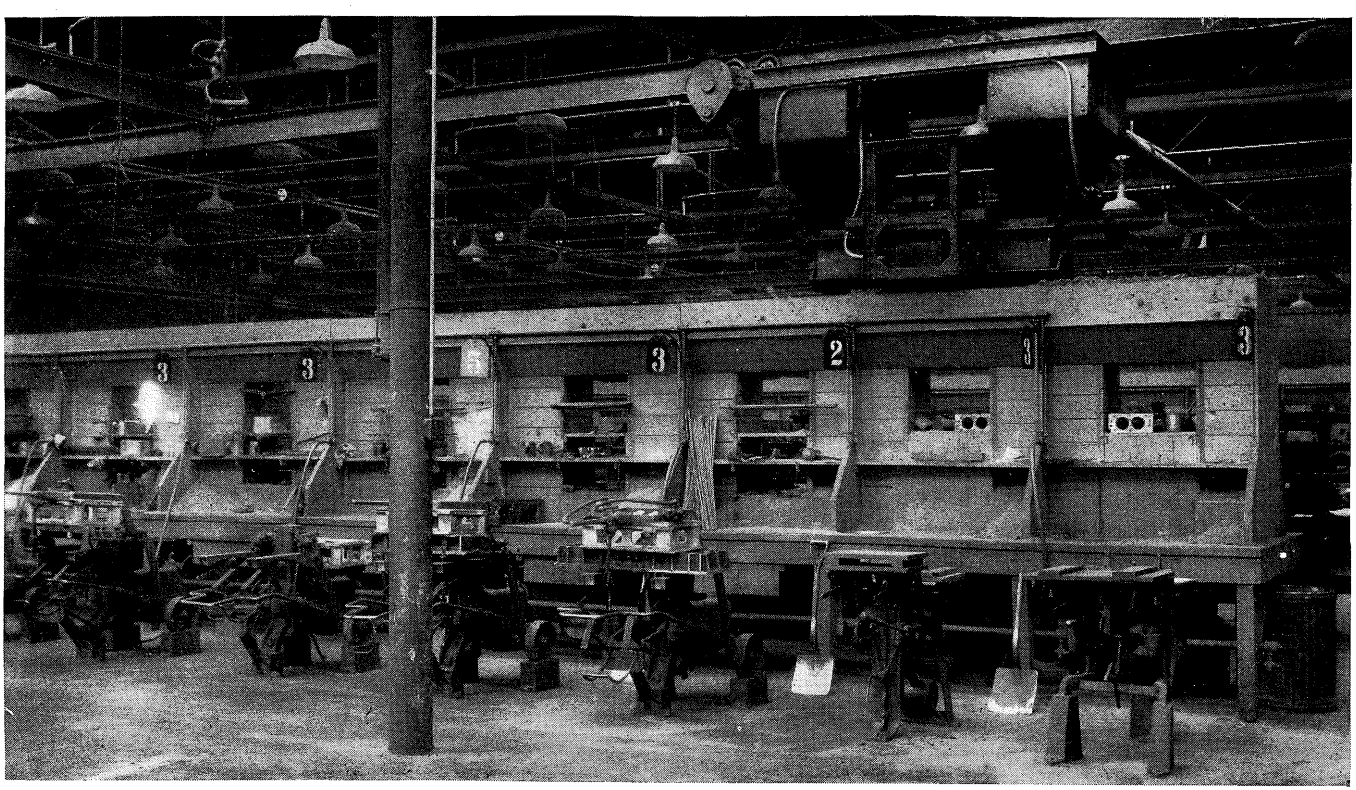


Fig. 7.40 — A view of a battery of hand jolt, hand roll-over coremaking machines.

try. It is characteristic of cores produced by the blowing method that the finer sand grains tend to arrange themselves at the outer surfaces of the core with the larger sand grains in the center. This results in a core having a skin of maximum smoothness and, due to the central location of the larger sand grains, the core will have a maximum permeability for the exhaust of gases.

The function of the core blowing machine is to fill and ram the sand in the cavity of the core box. All other related operations pertaining to handling and drying of the cores are fundamentally the same as required under conditions where the core box cavity is filled and the sand rammed by hand.

In the core blowing machine, filling and ramming the sand in the core box is done under predetermined mechanical control, with all factors constant. Thus, the human element is eliminated, insofar as the ramming of the core is concerned. This condition contributes to a uniformity of operation which is advantageous, particularly where cores have small intricate sections and difficult contours. The entire core box cavity is filled with sand in an extremely uniform manner which is difficult to equal by hand tucking and ramming methods. The elimination of potential hard and soft spots, which are the result of uneven ramming, greatly increases the strength of the core. Cores produced by the blowing method are said to have smoother skins, are lighter weight, more uniform in structure, and have higher permeability and greater strength.

Factors Governing Installation

The question is often asked, "Under what conditions can a core blowing machine be operated to advantage?" The obvious answer is that it is practical to operate such a machine under any condition where a saving in ultimate cost of production can be accomplished. Operating conditions, type of work, and production requirements are the governing factors. As these factors vary widely with different jobs, there can be no fixed set of limitations. The following should prove helpful in analyzing any individual situation.

The pneumatic core blowing machine is intended for producing small and medium sized cores in commercial quantities and is primarily a production machine. Satisfactory operation requires first-class metal core box equipment and should be confined to conditions where the cost of such equipment is justified and where the required sand mixture is free from heavy bond and of sufficient flowability to work freely in the machine.

Each individual core job must have, in addition to a suitable metal core box, its complement of metal driers (when not suitable to stand on a drying plate), and a blow plate with the blowing holes arranged to conform to the core box. When changing from one job to another, it is necessary to change the blow plate, readjust the machine so that the core box height, clamps, etc., will conform to the new job. In cases where a different sand mixture is required, the reservoir and sand hopper must be cleaned before receiving the new mixture.

How far these basic production characteristics can be modified and applied to miscellaneous and short



Fig. 7.41 — Core blowing machine.

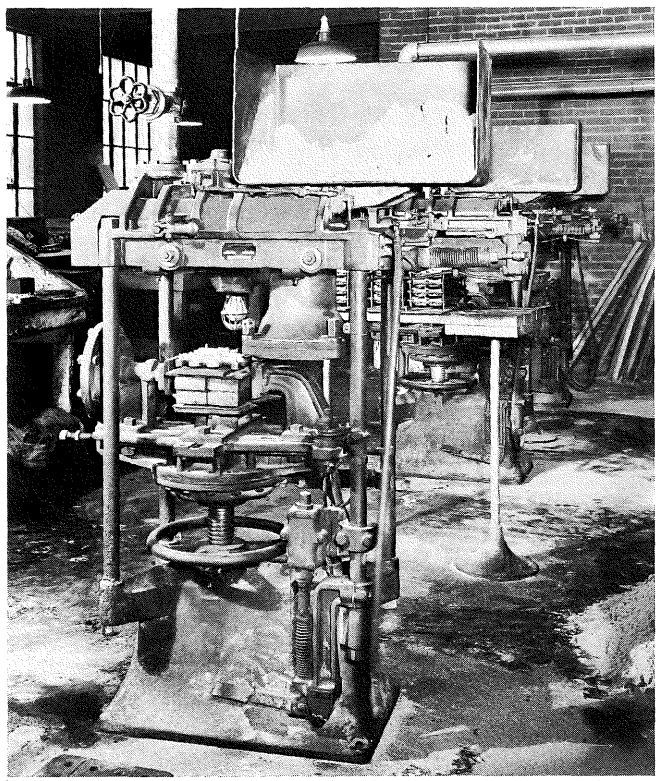


Fig. 7.42 — Another type of core blowing machine.

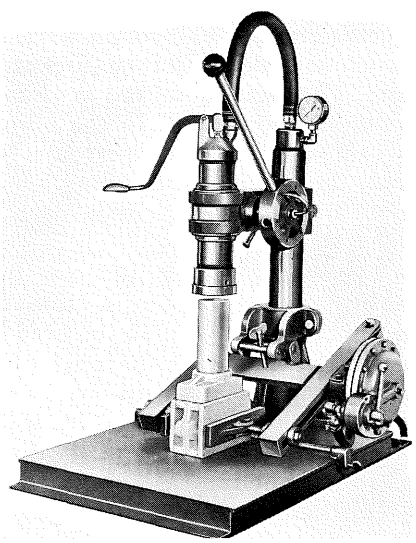


Fig. 7.43 — Bench type core blowing machine.

run jobs is dependent entirely upon individual conditions. The major consideration is whether or not the job will justify the cost of the equipment and the time required to change blow plates and readjust the machine. In a number of cases, where several different jobs are run with the same sand mixture, considerable ingenuity has been shown in developing methods for changing blow plates quickly without dropping the sand from the reservoir.

In other cases, a careful study of the jobs may show that it is possible to arrange the blowing holes so that several different core boxes may be blown from the same blow plate. This is accomplished by locating the blow holes so that certain core boxes will seal off certain holes while utilizing others. In the case of an unusually difficult core having small and intricate passages and contours which cannot be rammed satisfactorily by hand, it may be economical to provide core box equipment and change the sand, blow plate, and machine set up for even a comparatively short run of cores.

Theory of Core Blowing

In blowing a core, the core box cavity is filled by introducing sand, suspended in a stream of air which enters the cavity, at high velocity through the blowing holes. The core is rammed by abruptly arresting the travel of the sand grains themselves while the air stream is allowed to continue on to the atmosphere. The air is exhausted to the atmosphere through vents in the core box which are arranged so that the sand grains will be trapped in the core box cavity while the air stream is permitted to pass on out of the box.

In applying this theory to practical operation, there are five important factors involved, namely: the machine; the sand mixture; the core box equipment; arrangement of the blowing holes; and arrangement of the vents. For the purpose of clearer understanding, each of these factors will be discussed individually.

The Core Blowing Machine

Description

The pneumatic core blowing machine is a self-contained unit, consisting principally of a sand reservoir and blow plate arranged to travel back and forth from the filling position to the blowing position. That mechanism is mounted on a carriage in the upper structure, which is in turn supported by a frame and a base. The base houses the machine table and vertical clamping mechanism. In the filling position, the upper throat of the sand reservoir is open to receive sand from the hopper. After filling, the reservoir and blow plate are moved to the blowing position directly over the core box.

The machine table and core box are raised by a vertical clamp diaphragm, thus forming a seal between the sealing ring in the head of the machine and the upper throat of the reservoir, and between the blow plate and the core box itself. A working clearance of approximately $\frac{1}{64}$-in. usually is allowed between the blow plate and the core box in adjusting machine. Compressed air is applied in this position.

Horizontal clamps, when used, function in unison with the vertical clamp. After the blow has taken place, the clamps are released, the table is dropped and the reservoir is returned to the filling position. That sequence of operation usually is controlled by a combination of hand and foot operating valves. It also is quite common to use a fully automatic operating valve which requires only a single motion from the operator to start the machine through its sequence of operations.

Operation

The core box is filled by introducing air at high pressure on the sand in the reservoir. The pressure customarily is from 90 to 120 psi, depending on the size of the machine and the nature of the core. The pressure forces a stream of sand and air, at high velocity, through the holes in the blow plate and into the cavity of the core box. Vents are provided in the core box equipment, and occasionally in the blow plate or horizontal clamp plates, which will permit the air stream to pass through, but which resist the passage of the sand grains, thus trapping the sand and causing the core box cavity to fill. As will be explained later, the nature and location of these vents are of extreme importance.

Sizes

Core blowing machines are available in a range of sizes. Principal limiting factors in each size are given.

(1) Physical proportions of the core box which can be accommodated with relation to the size of the machine table.

(2) Distance available between the table and the blow plate.

(3) Distance between horizontal clamp jaws when using vertically parted boxes.

(4) Relationship of the clamp diaphragm areas to the opposing area of the cavity in the core box.

(5) Volume of sand which the machine is capable of delivering to the core box at a single blow.

It is obvious that a machine must be selected which, within its range of adjustment, will have sufficient room to accommodate the box to be used. For good operation, width of the core box should not exceed a dimension which will be cleared by the blow plate so that the box readily will be accessible for handling purposes when the reservoir has returned to the filling position. Whether using horizontal clamps with a vertically parted box or the vertical clamp with a horizontally parted box, area of the clamp diaphragm must in all cases exceed the area of the cavity in the core box. If that condition is not maintained, the blowing pressure will tend to force the box apart at the parting line and the desired venting balance not only will be destroyed but the core box equipment will be damaged materially by the escaping stream of sand and air.

Reservoir Capacity

Experience has shown that a little over one-third of the reservoir volume of sand can be delivered satisfactorily to the core box cavity in a single blow. This varies with the shape of the reservoir and the nature of the core being blown. The limiting factor is the

depth of the sand remaining above the blow plate after blowing. That depth must be sufficient to prevent cratering of sand above the blow holes. With a cylindrical reservoir having a relatively small blow plate area, a larger percentage of the total volume can be expelled than is the case with a reservoir having a wide conical shape and a larger blow plate area.

Selection of Machine

In this connection, it also is common practice, when blowing very small jobs, to fill several boxes before returning the reservoir to the filling position. However, under most conditions, best results will be obtained by limiting the total expenditure of sand to slightly under half the reservoir volume before refilling. Therefore, a suitable machine for a particular job is one having the following characteristics.

(1) The required physical proportions to accommodate the desired core box with handling accessibility at all times.

(2) A sufficient factor of safety in clamp diaphragm area.

(3) The capacity to deliver the required volume of sand to the box in a satisfactory manner.

Other contributing factors also must be given due consideration.

Air Supply

Satisfactory operation of a core blowing machine requires that compressed air be supplied (1) in adequate volume, (2) at constant pressure and (3) free from excessive moisture. To meet those requirements, air lines should not be smaller than the intake pipe size on the machine and should be kept as free as possible from abrupt bends and turns. Pipelines should be pitched and provided with wells and vents for draining condensation. If these precautions are not observed, the air discharge orifices become clogged, resulting in poor cores and decreased production. By use of an air separator in the line, difficulties caused by water, oil and other foreign substances in the air can be eliminated. A mechanical air separator that is designed primarily for air lines supplying core blowing machines has been marketed for that purpose. It is claimed that this separator requires no attention and will not retard the air flow or pressure.

The most effective blowing pressure is from 100 to 120 psi at the machine. Many small cores, such as valve and fitting, and miscellaneous small cores for aluminum castings, are being blown successfully at pressures as low as 90 psi, but pressures below 100 psi are not recommended for general operation.

To obtain the required volume of air without loss of pressure during the instantaneous blow operation, an auxiliary storage reservoir should be placed in the air line immediately adjacent to the machine. Where several machines are installed, one large reservoir may serve the purpose, as shown in Fig. 7.44. It is recommended that gate valves and not globe valves be installed for shutting off the air supply to each machine.

Amount of air required to operate a core blowing machine will approximate from 2.3 to 11.5 or more cubic feet of free air at 120 psi pressure per blow,

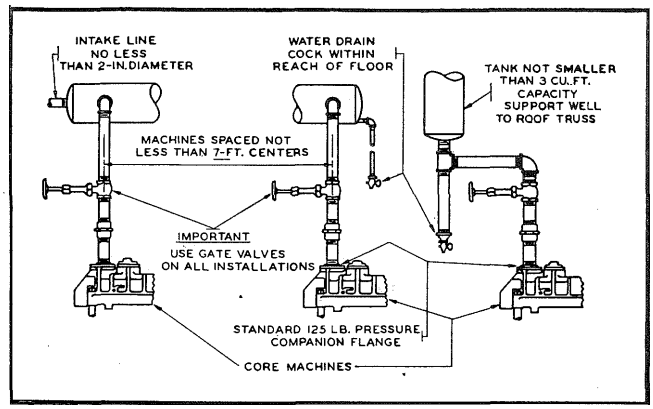


Fig. 7.44 — Diagram of installation of air storage reservoir. (Left) for three or more machines. (Right) for one or two machines.

depending on the size of the machine and the nature of the job. To provide the desired pressure for a blowing operation, it is common practice to install a booster compressor in the line to receive the air at the usual foundry pressure and step it up to the higher pressures required for the core room. It is recommended that manufacturers of compressed air equipment be consulted in providing the most suitable arrangement to meet any given condition.

The Sand Mixture

Production of good cores with a core blowing machine does not necessarily mean an abrupt departure from customary core room practice. In many cases, sand mixtures used on the bench will prove satisfactory for blowing. The major requirement in any sand mixture for use in a core blower is that it be free working and one which will flow readily in the machine. Moisture content should be kept low to prevent sticking in the box and the texture must be such as to provide the desired finish on the casting.

Ingredients

The base of any good sand mixture for core blowing purposes is a clean sharp silica sand, preferably one which has been dried artificially to facilitate accurate moisture control. Other ingredients may include a percentage of bank sand to provide a smoother skin on the core; a small percentage of dry binder, such as a cereal binder, to impart added green strength for handling purposes; a good grade of core oil; and sufficient water to provide the desired moisture content.

Mixing

It is customary to prepare the sand in a batch type mixer. Usually the sand is placed in the mill first, the dry binder added and the mixer allowed to operate dry a short time so that the dry binder may be distributed and the sand grains evenly coated with it. The core oil then is added slowly, while the mixer is in operation, and the batch allowed to mix for several minutes. Water then is added to bring the mixture to the desired moisture content and the mixer is allowed to run several minutes after all the ingredients have been added. In some foundries, the water is added ahead of the core oil. A few of the larger shops, where very accurate control is maintained, emulsify a constant proportion of oil and water and make the liquid addition in that manner.

Caution should be used not to over mix the batch after the ingredients have been combined. Good practice limits the usual mixing time to 8 or 10 min.

Precautions to Be Observed in Mixing Sand

The following precautions should be observed in mixing core sand to be used in core blowers.

(1) The sand should be low in green strength, that is, have high flowability.

(2) Moisture must be controlled closely, with 1½ per cent being the maximum for best blowing conditions on most cores.

(3) The sand must be thoroughly mixed but not over mixed. Mixing time will vary from plant to plant, depending on equipment.

(4) Avoid the use of core oils that have a sticky feel.

(5) With certain core sand mixtures, it will be necessary to add some light mineral oil (paraffine or kerosene) to the core oil used, about 1 part light mineral oil to 20 parts core oil.

Distribution

As the average core room will require a number of different sand mixtures for various jobs in production, provision must be made to mix and deliver each batch separately to the proper blowing station. Many methods are used to convey the prepared sand to such stations. In some of the larger foundries, the sand preparation equipment is located on a floor above the core room and the sand is conveyed to the machine by overhead spouts supplemented by automatic sand feeders at the machines. In other foundries, elevated runways are located back of the core blowers so that a batch of sand may be brought in, either by an overhead dump bucket or in a wheelbarrow, and deposited in the machine hopper at the proper station. Where few machines are operated, sand is brought in from the mixing department at floor level and elevated by hand to the machine hopper.

Sand Mixtures

For economic reasons, foundries take advantage, as far as possible, of local sand deposits. Since these natural formations vary widely in size and shape of grain, natural clay content, and other inclusions, it would be confusing to attempt to discuss the many different sand mixtures which are being used successfully in blowing cores. However, Table 7.2 gives three typical core sand mixtures used successfully in core blowers.

TABLE 7.2 — TYPICAL SAND MIXTURES FOR CORE BLOWERS

	Sand						
No.	Sharp, Qt	Bank, Qt	Dune, Qt	Core Oil, Qt	Cereal Binder, Qt	Moisture, Per Cent	Remarks
1.	150	—	—	3	3-4½	*	For cores baked in driers
2.	115	35	—	2½	3-5	*	Good general purpose mix
3.†	200	—	300	8½	12½	2	Manifold and jacket cores

*Not given. †Melting time 8 min.

Core Box Equipment

Of the utmost importance is the matter of the core box equipment and the rigging and venting of the boxes. Here again it is extremely difficult to suggest a

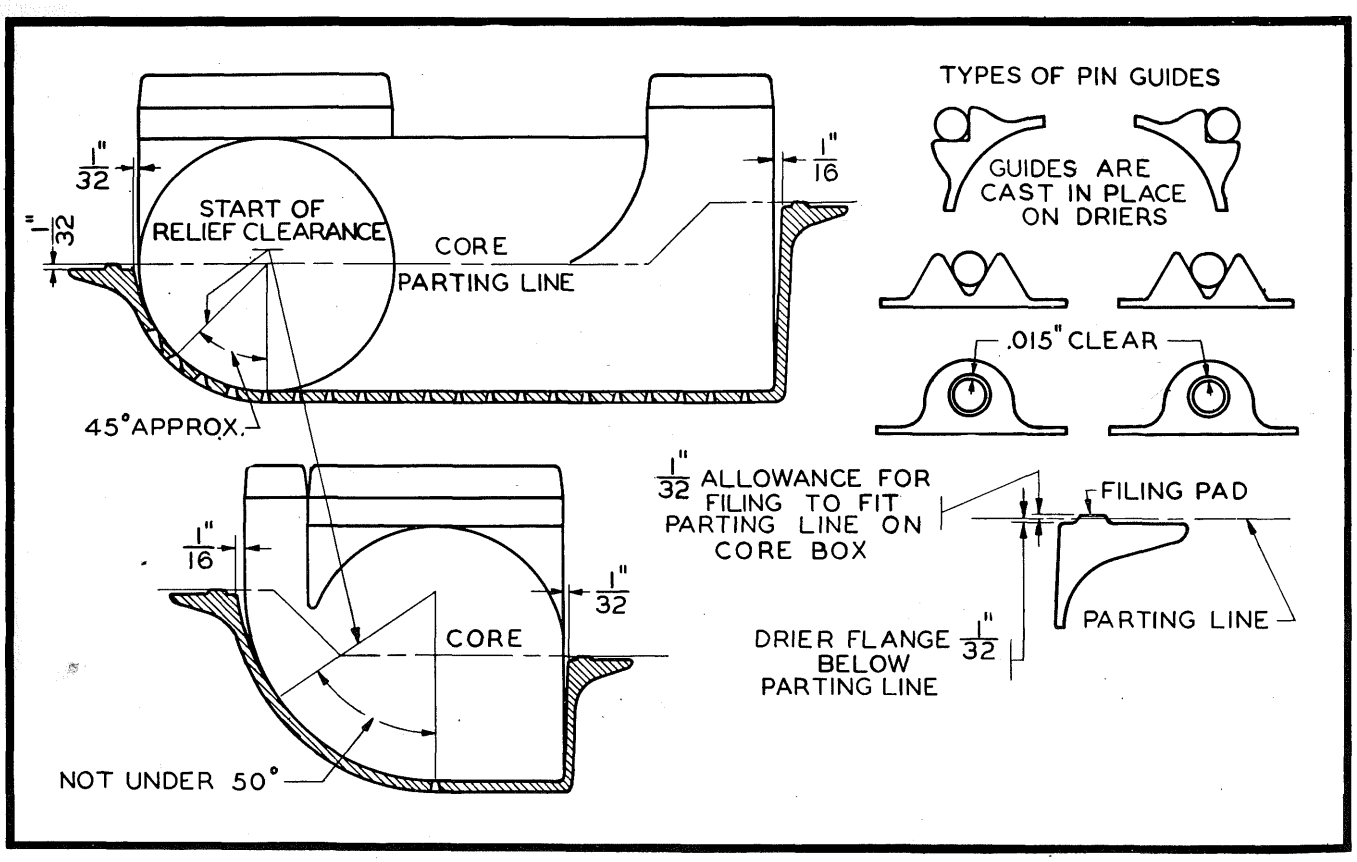


Fig. 7.45 — Typical design for core drier.

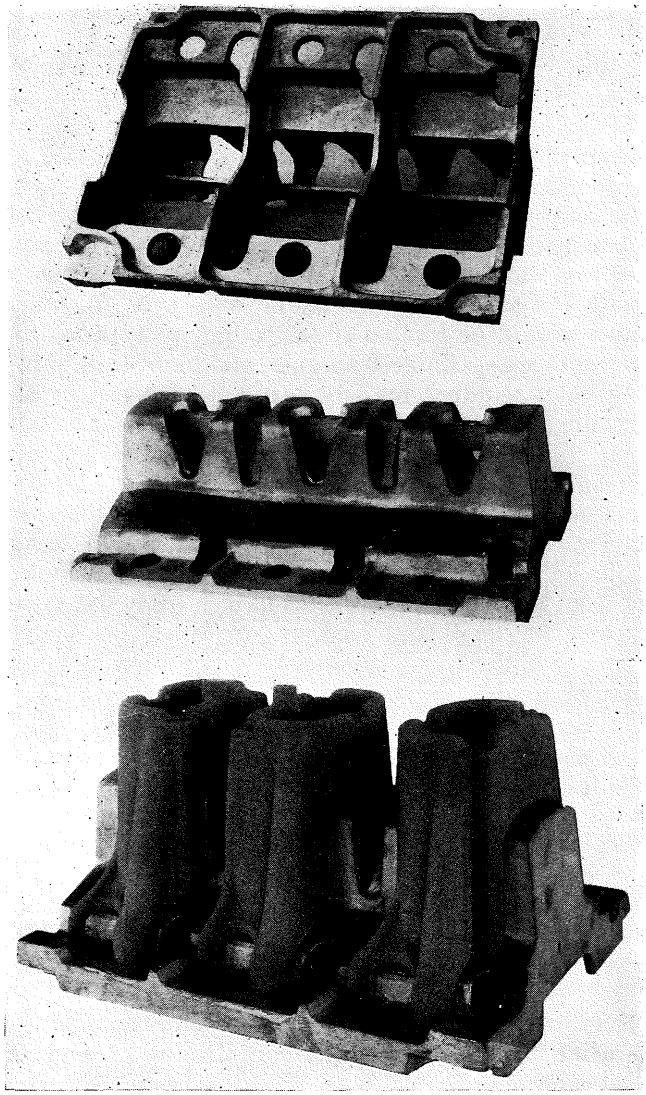


Fig. 7.46 — Typical core drier for blown cores.

code of hard and fast rules, as each job will require individual consideration. However, experience has established certain general principles which will prove helpful in guiding procedure in the preparation and rigging of jobs for production on core blowers.

Satisfactory operation of a core blowing machine requires first class metal core boxes having well-fitted joints throughout, and sufficient land at the parting joint and around the blowing holes to insure a tight seal. Outside surfaces of the box should be squared and all opposite clamping surfaces machined parallel, so that the box will clamp squarely in the machine.

Materials

Core boxes usually are constructed of cast iron, aluminum, magnesium, or a combination of those metals. Each material has certain characteristics which should be given consideration. Cast iron is high in resistance to wear, relatively costly to construct, is comparatively heavy to handle, but is more permanent and generally desirable where the box will not be too heavy to handle and the cost of manufacture not too high. In cases where the core box runs to larger proportions and the nature of the core requires intricate and extensive machine work, aluminum is the material usually selected.

Aluminum is light, works easily, but is subject to more rapid wear. Therefore, it is common practice, when making aluminum core boxes, to protect the wearing surfaces with steel bushings in the blowing holes, steel wearing plates on clamping surfaces, and replaceable steel inserts at points most subject to wear.

From the manufacturing standpoint, magnesium alloys are about equal to aluminum as a material for core boxes. The higher cost of magnesium is offset by the saving in weight. Usually its use is confined to large boxes where the saving in weight will offset the higher initial cost.

Driers

Metal core driers, as illustrated in Figs. 7.45 and 7.46, are necessary except in cases where the cores are of a nature which will permit standing on drying plates. These metal core driers usually are constructed of cast iron or aluminum and are heat treated to resist distortion in the ovens.

Rigging

A comprehensive example of core box rigging for blowing purposes is shown in Figs. 7.47, 7.48 and 7.49. Figure 7.47 shows a motor end bearing core, a relatively simple core to blow. It is blown through a single blowing hole located in the upper print. The core box has a vertical parting line, horizontal clamps being used on the machine. Box vents required are of the groove type, strategically located around the parting joint of the box. The core box cavity fills readily and the cores are transferred to the driers by placing the drier on the bottom half of the core box, rolling the half box and drier over, and drawing the inverted half box up off the drier, leaving the core deposited on the drier in the usual manner.

In the case of the automotive manifold core, shown in Fig. 7.48, the core box construction is somewhat more elaborate, and a carefully worked out arrangement of the blowing holes and screen vents was necessary. This illustration shows the upper and lower halves of the core box and also a view of the core resting in the core drier. This particular core is approximately 31 in. long and weighs about 7 lb. It is interesting to note that, due to the characteristics of a blown core as already described, no reinforcing wires or provision for gas vents in the core are required.

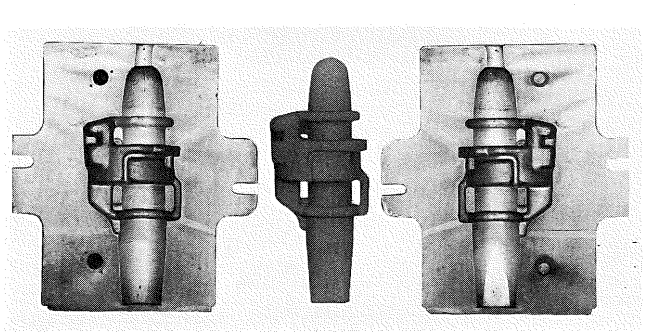


Fig. 7.47 — Motor end bearing core and core box. This is one of the simpler types of core box rigging for blowing purposes.

Figure 7.49 shows an automotive barrel and crank case core, which is of the more complicated type requiring a series of blowing holes. A carefully balanced venting arrangement has been worked out, involving several types of vents to influence the blowing stream in such a manner that the core box cavity will fill properly and the core come full and hard on the shoulders. Reinforcing rods must be blown in position in the body of the core, and removable vent rods are used to provide additional passage for gases generated during pouring. This core is dried on a drying plate with a loose support piece under the barrel end.

The cores illustrated are production jobs and representative of the diversified requirements which must be met in rigging different types of cores for blowing purposes.

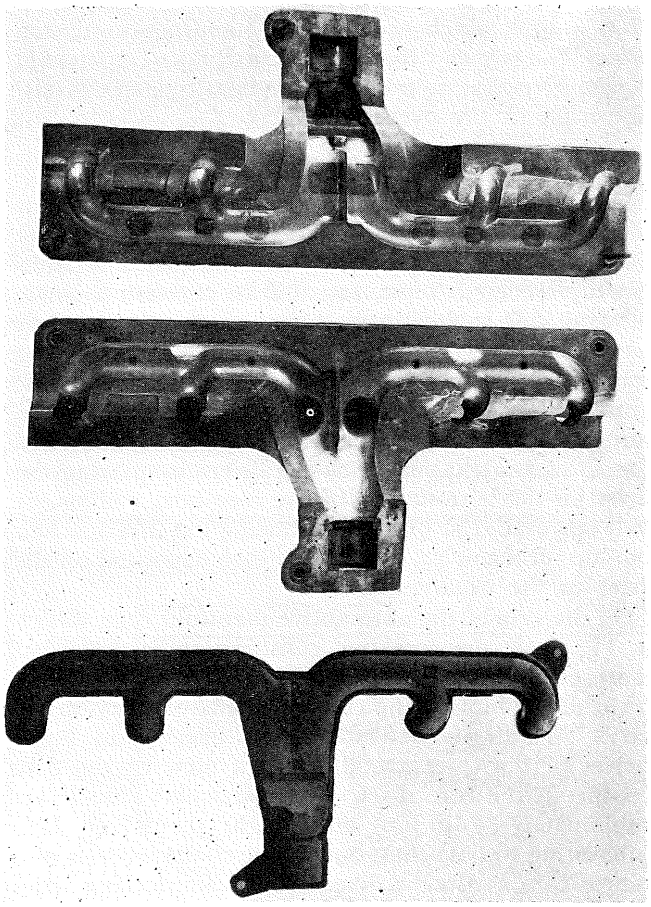


Fig. 7.48 — Core box used for production of automotive manifold cores. The core, resting in the drier, is also shown.

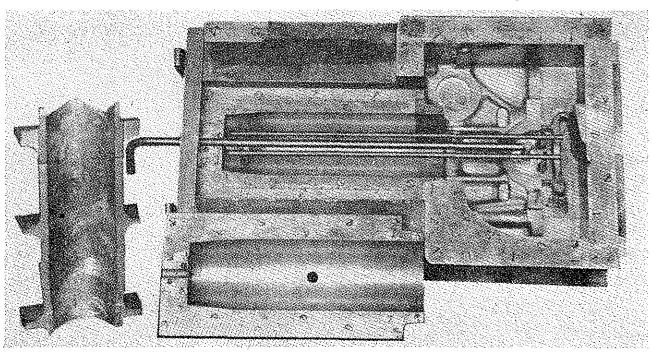


Fig. 7.49 — Core box for blowing automotive barrel and crankcase cores. This type rigging requires a more intricate arrangement of blowing holes and vents and includes support and vent rods.

Blowing Holes

With regard to blowing holes and their arrangement, it should be noted that in setting the job up on the machine, care should be taken to locate the box as near as possible to the center line of the blow plate. A center line, marked on the box, should coincide with the locating center notch, usually placed on the blow plate by the manufacturer. Using that center line as a register, holes should be drilled through the blow plate and top of core box to the core cavity. Blowing holes should be located strategically and kept as low in number as possible. Exact size and number of blowing holes required for any particular job can be ascertained only by actual trial.

It should be kept in mind that the sand and air stream should be introduced into the box at high velocity so that the sand will whip up and fill the core cavity. Therefore, it is desirable that the blowing holes be not too large in diameter. In most cases, holes of from $\frac{3}{16}$ to $\frac{1}{2}$-in. diameter have been found satisfactory for small and medium size cores. For larger cores, or under special conditions, larger blowing holes may be used.

When first starting to rig a new job of average size, it is advisable to place $\frac{5}{16}$-in. diameter holes opposite the larger portions of the core and somewhat smaller holes opposite pockets or narrow passages in the box that would not tend to fill from the natural whip of the sand from the other holes. Since sand does not flow readily around corners, that condition should be avoided in locating blowing holes. Figure 7.50 shows several typical arrangements for blowing holes. Attention is directed to the desirability of relieving the reservoir side of the blow plate by countersinking the blowing hole entrance to facilitate the flow of sand. It also is quite desirable to bush blow holes in both the blow plate and core box with replaceable steel bushings to take care of the abrasive wearing action of the sand. After the blowing holes have been arranged in accordance with the best judgment, the job should be tried, and the holes enlarged or additional holes added as the results may indicate.

Various schemes have been adopted in jobbing shops to adapt the core blowing machine to miscellaneous and short run jobs, such as standardizing the spacing of blow holes in the core boxes as far as possible, or arranging them so that a core box blanks off unwanted blow holes while utilizing others. Where this cannot be arranged, the unwanted holes can be plugged. This plugging should be done so as to form an air-tight seal, because air leaking through can cause a lot of trouble if it gets into the core box; it will carry no sand with it, and will merely add to the volume of air to be exhausted through the venting system of the box.

An effective idea for jobbing work is to cut a slot in the blow plate, probably a shorter slot crossing it at right angles. Adaptor plates of $\frac{3}{16}$-in. steel plate, with suitable holes drilled in them, are then placed on top of the core box at each blow. By this means, blow holes are made available in any part of the slot area. The addition of a couple of extra blow holes, strategically located and plugged when not in use, can almost eliminate the need for changing the blow plate.

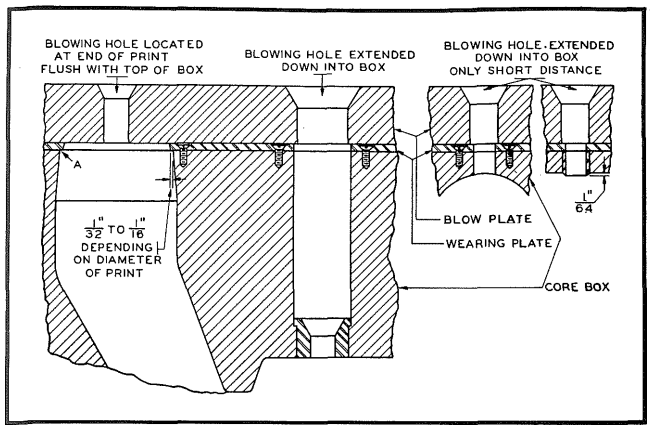


Fig. 7.50 — Diagram of typical blowing hole arrangements.

Many variations of such schemes can be worked out to suit local conditions. For instance, the adaptor plates just mentioned can be attached to the machine blow plate, with countersunk screws or by sliding into fittings, etc. The whole question is one of reaching compromise that will give the best all-round results in saving time and money.

Core Box Vents

Probably the most important factor in blower core box rigging is the size, type and location of the vents.

In venting a core box for blowing purposes, it should be kept in mind that in principle and theory the core box cavity is filled by introducing sand into the core box, suspended in a stream of air under pressure. The purpose of the vents is to provide passage for the air back to atmosphere and at the same time prevent the passage of the sand grains, thus trapping the sand in the core box cavity and uniformly filling the cavity.

Action of Air Stream

Since the sand and air are introduced into the box through relatively small apertures (blowing holes being from 3/16 to 3/4-in. in diameter on the average), and under a blowing pressure of from 90 to 120 psi, the stream of sand and air will enter the box at a high velocity. Upon passing through the restricted openings of the blowing holes, there is an immediate expansion of the stream to fill the space made available by the cavity in the core box.

This action approaches an explosive condition, causing the sand grains to rebound from the point of contact with the inside walls of the core box and to exert a general whipping action. Upon being released to the low pressure of the core box cavity, it is assumed that there is an initial drop in the velocity of the air stream with the result that the sand grains find permanent rest. The core cavity fills first directly under the blow holes through which the sand is introduced. Then, as the core box fills and the available room for the passage of air becomes progressively less, the velocity of the blow stream increases in the attempt to return to the ultimate, with the sand grains tending to follow the direction of the air stream in which they are partially suspended. As the natural flow of the air stream is toward atmosphere through the vents, it is further assumed that those portions of the core farthest from the blow holes and immediately adjacent to the vents, fill last.

Venting Area

As the air itself is introduced into the core box cavity solely as a vehicle for conveying the sand, it is necessary that adequate provision be made for the air to escape as the box is filled by the trapped sand grains. Therefore, the combined venting area in the core box plus leakage should balance the combined area of the blow holes. Quite contrary to an otherwise perfectly natural conclusion, when cores come soft, or with soft spots on the shoulders or corners, it is due to lack of proper and sufficient vents rather than to lack of blowing pressure.

In venting any given job, advantage should be taken of the degree to which the core box will fill, due to the natural flow of sand from the blow holes. Also, to properly fill the entire core box cavity, it may be necessary that the natural flow of sand in the box be influenced by diverting the air stream to the desired parts of the core. This is accomplished by introducing vents in the core box at these points. As previously stated under the subject of blowing holes, the sand flow resists abrupt changes in direction or around corners. This also has a direct bearing on the location of vents.

Venting Arrangements

Insofar as actual vents are concerned, there are many different sizes, types, and combinations used to accomplish the desired results. The ultimate purpose of a vent being to provide an outlet for the air and at the same time resist the passage of the sand, it sometimes is possible to blow small, simple cores satisfactorily with no vents other than the natural leakage at the parting line of the core box or by a series of slight grooves cut into the box at the parting line. On the other hand, where the core is complicated and it is necessary to influence the flow of sand into pockets or toward shoulders and corners, a more elaborate venting arrangement is required. Various types of vents, commonly used in combination to accomplish the desired results, are shown in Fig. 7.51.

Vent Plugs

Vent plugs, for use in venting core boxes for blowing purposes, are available commercially, and are manufactured in a wide range of plug diameters from 3/16 to 3/4-in. and in several different sizes of surface openings. The two best known types, shown at the right in Fig. 7.51, are the screen mesh construction and the slotted construction, each of which has individual merit under certain conditions. On intricate or difficult jobs, where these commercial vents are not adequate, special treatment is required in the way of blow plate venting, combination blowing and vent holes, etc. In all cases, it is important that vents are provided with free exit to atmosphere and that the core box is protected as far as possible from the cutting action of the sand particles suspended in the air stream. This can be improved by the use of steel wearing plates where possible.

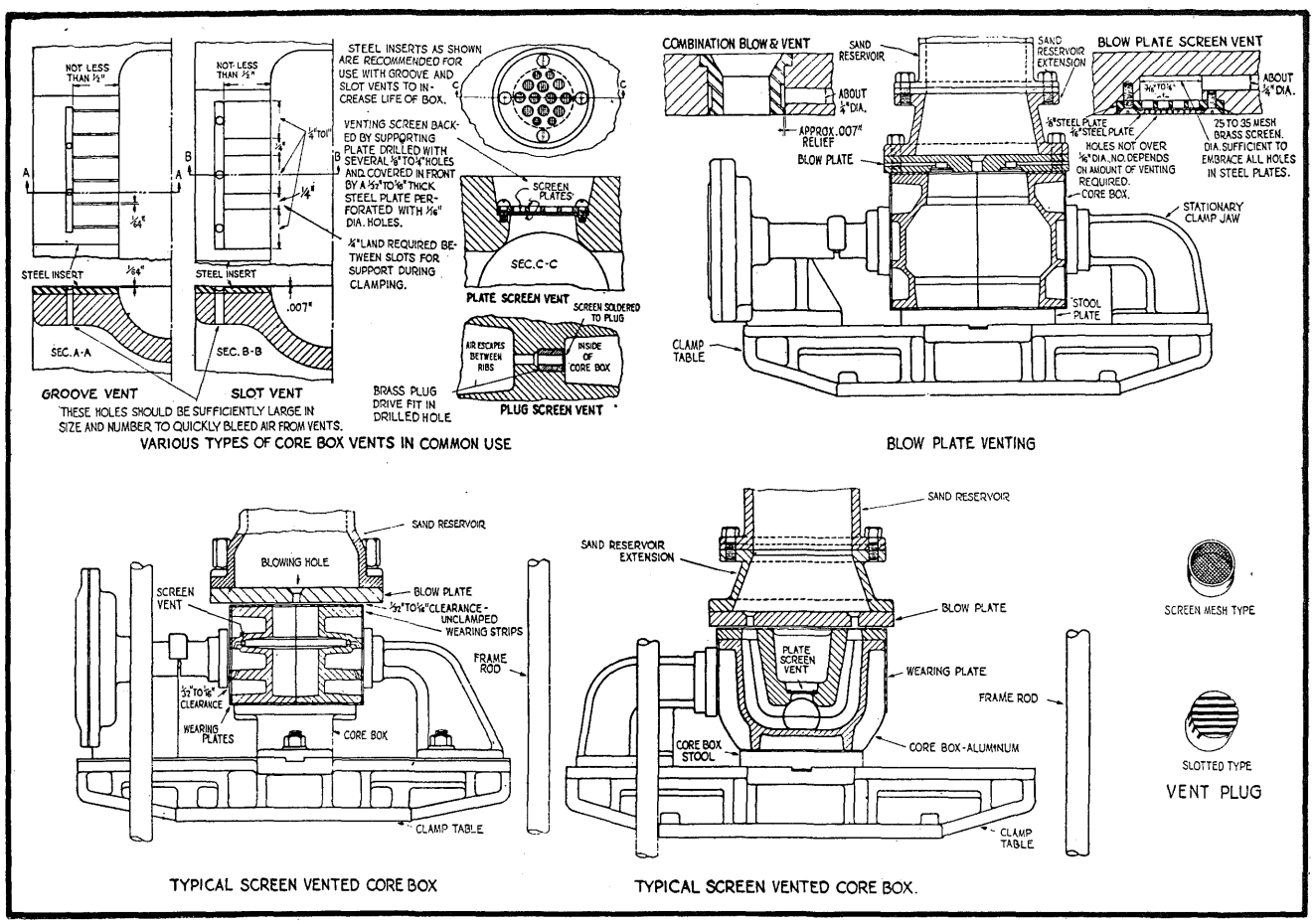


Fig. 7.51 — Diagram of types and typical arrangements of core box vents.

Groove or Slot Vents

Where groove or slot vents are used on a parting line, these vents should be converged into a common outlet and not extended over the entire width of the core box land at the parting line, as shown at the left in Fig. 7.51. Direct outlets from the core box cavity to atmosphere should be discouraged, since the cutting action of the venting stream on the core box is reduced materially by at least one short and abrupt change in direction. This retards the velocity of the sand particles which blow through the vents, without materially affecting the passage of the air, and consequently reduces the cutting action on the box.

Precautions

Although there are no definite rules that can be prescribed governing the location of blow plate holes and vents, each individual core should be made a study in itself. The following precautions should be taken into consideration in any core blowing job.

(1) Sand does not flow well around sharp corners or winding passages.

(2) The combined venting area in the core box plus leakage should equal the combined area of the blow holes.

(3) Blow holes should be small, $\frac{3}{16}$ to $\frac{3}{4}$-in. in diameter, depending upon size of core, so that the stream of air and sand will enter the box at relatively high velocity, thereby causing a general whipping action in the box.

(4) When cores come soft or with soft spots on corners or when pockets fail to fill out perfectly, it is probably due to lack of proper and sufficient vents.

(5) Each individual core job must have its blow plate with the blowing holes arranged to suit the core box. In some cases, one blow plate may be used on several different cores when arrangements are made for the box to seal off the undesirable blowing holes.

Use of Nails, Wires, and Rods

Since a blown core is of maximum strength, it will not require reinforcing wires and rods to the extent necessary in a hand rammed core. However, these reinforcing mediums may be used where necessary. Usually it is possible to design core boxes so that either they can be blown through a core print or so that the core prints will extend through the core box wall to permit nails or rods to be inserted through the prints after the core has been blown and before removal from the core box. In cases where the core is blown through the print, the blow plate seals off the opening through the core box walls. Where this is not the case, the core box must be arranged so that these openings are sealed off by the clamp jaws, table wearing plate, or some similar means.

In using wires on small or simple cores, it is possible to place the formed wire in the core box cavity, and the whipping action of the sand will pick up and embed the wire in the body of the core. On more difficult jobs it is quite common practice to bed the wire with a handful of sand in the lower half of the

core box before the box is closed preparatory to placing it in the machine. When rods are to be blown in the body of the core, they may be bedded in the lower half of the box with a handful of sand, as just described, or in extreme cases, supporting posts are built in the lower half of the box to support the rods. When these posts are used, there will be a corresponding opening in the finished core which will have to be filled and patched after the core has been baked. Whenever possible, an attempt should be made to place these posts on core prints, which will eliminate the necessity of patching.

Serving and Handling of Core Blowing Equipment

A core blowing machine, under proper conditions, will complete the full operating cycle and deliver a blown core in the core box on the machine in from 3.5 sec for the smaller machines, up to approximately 6.5 sec on the larger machines. The additional time required to remove the core to the drier and get a box back into the core blower for the next blow, completes the production cycle and is dependent upon the facilities available, the operator's skill, etc. As is the case with any piece of production equipment, it is desirable that the production cycle approach as closely as possible the machine cycle, or in other words, that the machine be kept operating as continuously as possible.

To accomplish this, it is quite common practice to serve a core blowing machine with sufficient duplicate core boxes and such additional man power as is required to balance the production cycle so that full advantage can be taken of the operating cycle of the machine. Sometimes this may mean one operator with two duplicate core boxes; sometimes it may mean several men and several duplicate core boxes, depending upon the amount of time and work involved in (1) removing the blown core box from the machine, (2) drawing the upper half of the core box, (3) handling loose pieces, (4) applying the drier or drying plate, (5) rolling over the low half of the core box, (6) transferring the core to the drier or drying plate, (7) cleaning and closing the box, and (8) getting an empty core box back into the machine for the next blow.

In addition, certain jobs may require special treatment, such as placing oil on the prints, or other hand work pertinent to that particular core. Last, the loaded driers must be placed on the drying racks.

The normal function of the core blowing machine is to fill the core box. When it is realized that a machine, even for the larger sizes, will complete the machine cycle and fill a core box in not exceeding a maximum of approximately 6.5 sec, it is an important part of the total operation that adequate means be provided to serve the machine with empty core boxes at a speed commensurate with the ability of the machine to produce the cores.

Use of Drawing Machines

To accomplish the related handling operations in the shortest possible time and maintain a smooth and constant flow of the core boxes back to the machine, many mechanical means are employed to facilitate the work. Core box drawing machines of the stripper type, or of the roll-over and draw type, may be used, as the case may require, for removing the blown core from the core box. The machine table may be equipped with rollers to facilitate handling large or heavy boxes.

Conveyors and Turntables

Conveyor loops or turntables provide a series of progressive individual operating stations with the auxiliary handling equipment always adjacent. Figure 7.52 illustrates a large size core blower installed with a conveyor loop. A core box drawing machine is situated in the conveyor loop for removing the core from the core box, and ample room and accessibility are available around the loop for such other working stations as may be required.

Figure 7.53 shows a similar machine installed in connection with a special turntable. This turntable provides individual working stations, including a roll-over and draw mechanism. The sequence of work is arranged and so timed that a fresh core box is delivered to the machine operator in step with the machine cycle. To further assist the operator, rollers are provided on the machine table. These rollers not only facilitate the handling of the core box, but also materially reduce frictional wear on both the core box and the machine table parts.

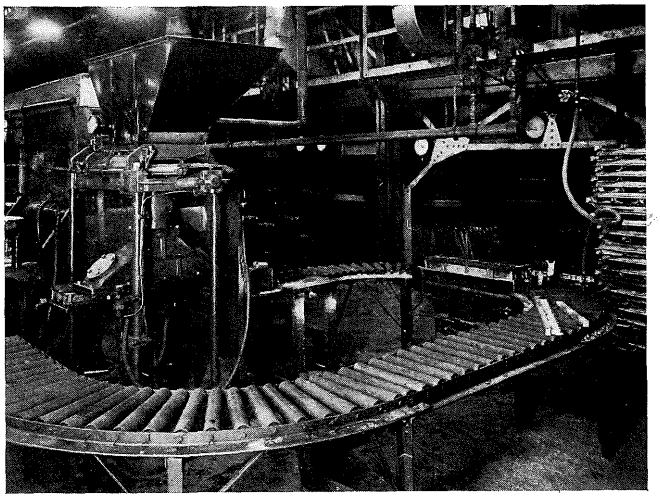


Fig. 7.52 — Core blowing machine served with gravity conveyor loop.

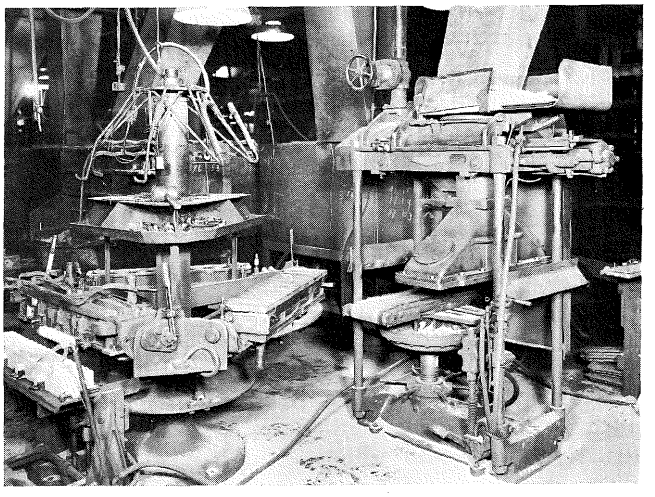


Fig. 7.53 — Core blowing machine installation with special turntable for handling and drawing the core boxes.

Mechanical Draw Feature

Another important mechanical help in connection with the operation of a core blowing machine is the mechanical draw feature which is built in. Machines having that feature are provided with a draw cylinder built into the base, and the machine table is supported by the corresponding draw piston. In lieu of the usual vertical clamp diaphragm, the vertical clamp action is accomplished by introducing air into the draw cylinder, thus raising the machine table and core box against the blow plate to obtain the necessary seal. The purpose of this arrangement is to provide automatic means of drawing the core on the return stroke of the draw piston and table.

It readily will be seen that, operating in this manner with an open face core requiring only a half box, it is possible to attach the half core box to the reservoir unit permanently and deliver the blown core directly on the core plate by the downward travel of the draw piston. Also, when using a two part core box, the upper half may be attached permanently to the reservoir and automatically drawn on the down stroke, leaving the core on the lower half of the box and thus saving one operation, that of removing the upper half to the box.

However, use of the core blowing machines having that type of draw feature is not universally advantageous. Among other factors which should be considered is the loss of speed and the increased air consumption. As it is necessary to fill the draw cylinder each time the table is raised to clamp, and the draw piston and table must travel upward a distance at least equal to the return downward stroke, it is obvious that both speed and air displaced are affected materially as compared with a conventional machine using a vertical clamp diaphragm. On some designs, that additional volume of air is offset somewhat by the use of hydraulic mediums. On many jobs, the core box can be removed from the machine and drawn faster by other means and with greater economy. Use of core blowing machines with the draw feature should be confined to such jobs as lend themselves to that particular type of operation.

In view of the characteristics and general nature of a core blowing operation, it again is unnecessary to suggest that a core blowing machine is basically a piece of production equipment. Just how far these basic production characteristics can be modified and applied to miscellaneous and short-run jobs is dependent entirely upon individual conditions. The major consideration is whether or not the job will justify the cost of equipment and the time required to change blowing plates and readjust the machine.

It is emphasized that each individual core should be made a study in itself. While all jobs will respond to the principles which have been discussed, no two core jobs are exactly alike, and the wide variation in requirements and operating conditions preclude the adoption of a detailed procedure which may be universally applied. However, it is said that cores produced by the blowing method will be more uniform in structure, lighter in weight, and higher in strength than those produced by other methods. They also are said to be formed more perfectly, to have a higher degree of permeability, and due to the smoother skins, to impart a better finish to the castings. The core blowing machine itself is simple to operate, has few parts which are subject to wear, and within the scope of the equipment, has the ability to produce quality cores at a high rate of speed.

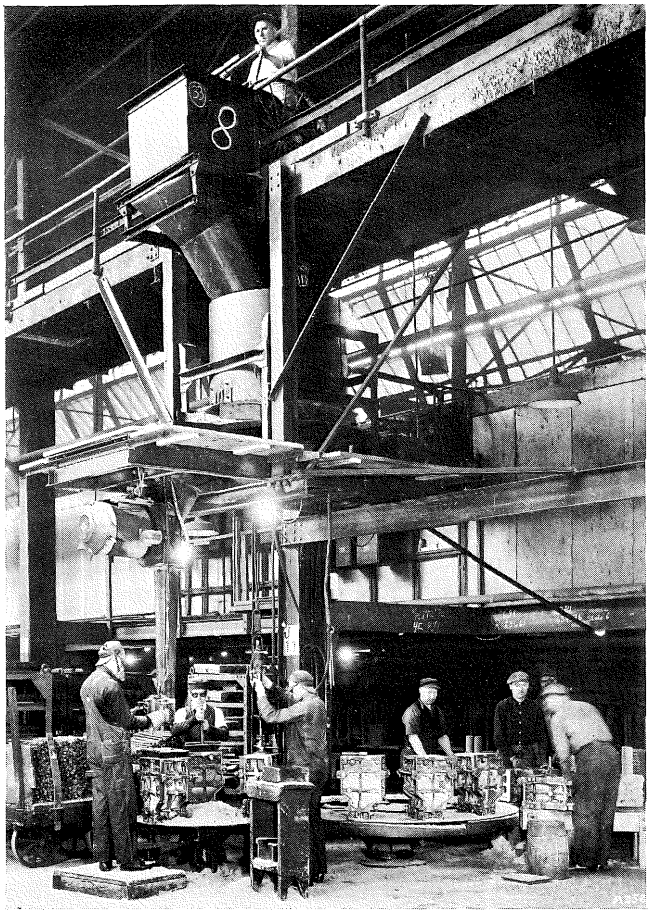


Fig. 7.54 — Sand throwing machine in operation in one of the large automotive foundries.

SAND THROWING MACHINES

A method of mechanically ramming cores that is used extensively both in production and jobbing foundries makes use of the centrifugal force generated when sand is thrown off a series of blades revolving at a rapid speed. The core sand is fed to the blades by different methods, depending on the particular arrangement desired by the individual foundry, such as revolving disc, apron or belt conveyor, chute, etc. The blades in the ramming head are directly connected to an electric motor. The type, shown in Fig. 7.54, used in a large automotive foundry, has a long spout directly connected to the discharge side of the ramming head. Handles at the end of the spout are for the purpose of directing the flow of sand into the core box. This unit swings freely in any direction.

Figure 7.55 shows a stationary machine used in a foundry making valves. This machine is designed to operate from a fixed position and is customarily served by sand preparation and sand handling equipment as well as conveyors for bringing the core boxes to the machine and removing the work after the cores are rammed.

The stationary machine usually is located at the

edge of a turntable so that the work is rammed as the core boxes or stripping plates come into position below the ramming head. Another arrangement permits the machine to operate in a circle above the core boxes or stripping plates, after which the cores are lifted onto conveyors. These machines are said to produce cores in which the ramming density is extremely even.

USE OF SHEET METAL FORMS TO SIMPLIFY COREMAKING

The use of tin forms, in reality tinned, sheet metal forms, in molding and coremaking operations, has been common in stove and furnace work since about 1880. Both designers and manufacturers of castings for other purposes have not taken the fullest advantage of the possibilities offered by such forms for simplifying molding and core room operations and reducing machine work. Recently, however, greater interest has been evidenced in these so-called tin forms and their application has been increased.

Hinge Tubes

Tin forms were developed for casting the holes for hinge pins in stove doors and door frames. They were so successful that their use has extended to other types of castings where it is required to produce holes crossways through sections above or below the parting line. The holes thus produced are smooth and of full size and accurately located.

A typical hinge tube for forming a round hole is shown at *"A"* in Fig. 7.56. It consists of two parts, a hood, *"B,"* and a tube, *"C,"* assembled and held together by heading or swaging out the ends of the tube. The tube is filled with a core sand mixture and dried similar to a regular foundry core.

The pattern is provided with a notch to locate the hinge tube in the required position, as shown at *"D,"* Fig. 7.56. This notch is of such shape and direction that the hinge tube fits freely in it and the pattern can be drawn away readily, leaving the hinge tube undisturbed in the mold. When the molten metal fills the mold, the hinge tube becomes virtually a part of the casting and the sand filling shakes out readily. The

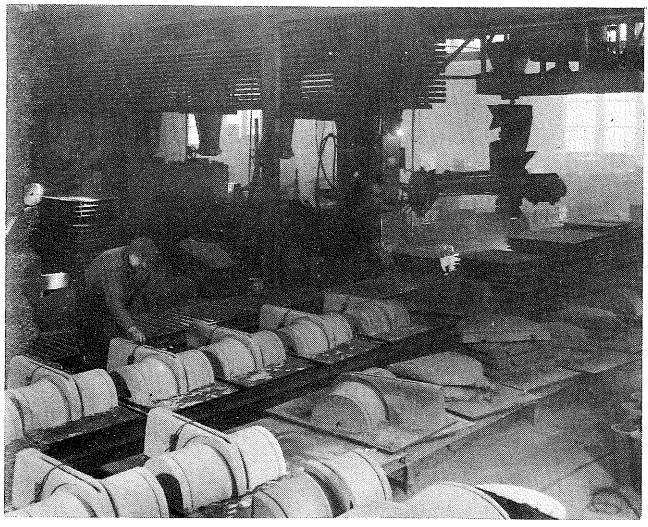


Fig. 7.55 — Stationary sand throwing machine in operation in foundry manufacturing valves.

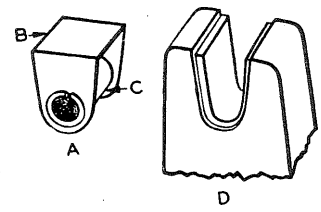


Fig. 7.56 — Typical hinge tube and method of locating it in pattern.

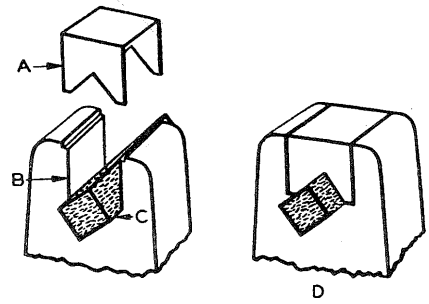


Fig. 7.57 — Typical half hood and method of using it.

sheet metal of the hinge tube, being protected by the sand on one side, does not melt, but welds to the casting, so that it forms a permanent union.

Hinge tubes are made for both round and oval holes in a large number of sizes. A great many of the sizes are denoted by numbers which have been adopted in common by all the manufacturers.

It is desirable to plan patterns so that regular stock hinge tubes can be used. Makers are glad to supply samples and all necessary information in regard to what they can furnish. Most hinges tubes are produced in automatic machines and the cost of tools for a special size is only justified when the quantity required is large.

A modification of the hinge tube, known as a half hood, is sometimes used whan a suitable hinge tube is not available. Such a tin is shown at *"A"* in Fig. 7.57 for use with a square core. The pattern is cut out as indicated at *"B"* and the core, *"C,"* is laid in place and covered by the tin, *"A,"* as shown at *"D."* The mold is then rammed as in usual practice. A little tucking probably will be necessary under the protruding ends of the core. When the mold is rolled over and the pattern is drawn, the core is left anchored in the sand at both ends with the half hood below it, its purpose of keeping the sand out of the opening in the pattern having been accomplished. This type of tin can be used for any shape of core, round, square or oval, or for a pin or bar which it is desired to anchor in the casting. These tins have to be made up specially for each job, but if the number of castings required is sufficient to warrant their use, they are said to cost less than making and setting stop-off cores.

Another type tin used for producing transverse holes through relatively thin ribs is shown in Fig. 7.58, where *"A"* is the tin, *"B"* the pattern recessed to receive it, and *"C"* the finished casting. The pattern here forms one side of the hole and the tin the other. These tins are not made in stock sizes. They have been developed for certain production jobs where the cost of the necessary tools for producing them has proved a profitable investment.

A tin quite similar in its manner of use to that shown in Fig. 7.58 is the square slot tin, shown in

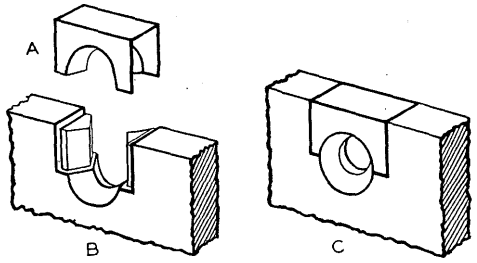


Fig. 7.58—Tin form for producing transverse holes through relatively thin ribs.

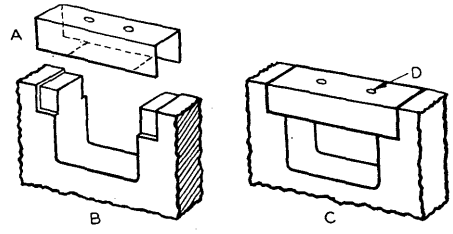


Fig. 7.59—Typical square slot tin form. It is used similarly to tin form shown in Fig. 7.58.

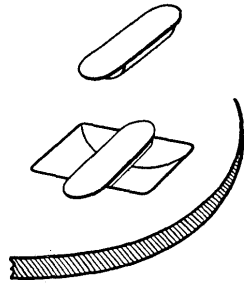


Fig. 7.60—Lifter bar tins for stove cover castings.

Fig. 7.59, where *"A"* is the tin, *"B"* the pattern, and *"C"* the finished casting. As the name implies, these tins are used to cast square holes or slots when it is desirable to avoid the use of cores. The tin is placed in the pattern and rammed up in the usual way, the molder giving the sand a pinch with his fingers to be sure that it fills the slot tightly. The metal enters the tin from both ends and fills it solidly. It is sometimes found advisable to provide small holes in the tins, *"D"* Fig. 7.59, to allow gas to escape. Except for a few stock sizes, these are special tins, made up as required when the quantity of castings justifies their use.

To cast the lifter bar in stove covers, tins resembling square slot tins, in their manner of use, have been developed. These are shown in Fig. 7.60. They are simply dropped into recesses in the pattern to assure their proper location and rammed up in the mold. They form a tunnel which fills up with the molten metal.

Tin Forms

So-called tin forms are used in the quantity production of castings having lugs, bosses, feet or other projecting parts which would interfere with the drawing of the pattern, without the use of cores or draw backs. The general principle of all these tins is the same. The required shape is formed out of thin tinplate by dies and is arranged so that it can be attached in its proper place on the pattern in such a way that it will not be moved or shifted during the ramming of the sand and that the pattern may be drawn away from it, leaving it in the mold to be filled with the molten metal. The thin metal remains on the casting, the adhesion being sufficient for all practical purposes.

Many of these tins forms are standard and have been given identifying numbers by the makers. A few of the most common applications of these tins are shown in Fig. 7.61 where *"A"* is a stove door catch, *"B"* a pair of dove tail lugs, *"C"* a lug on the cover of a pump for attaching it to the pump body, *"D"* a foot shaped projection and *"E"* the shaker lug on a grate bar. These are all made in several sizes.

Tins for special shapes have to be designed so that they can be economically produced in dies, but if the quantity warrants their use, they are worth while. Some special tins are shown in Fig. 7.62, in which *"A"* is a T-slot tin, *"B"* a lug for a bolt hole in a deep casting, and *"C"* is a turned in end on a malleable conveyor chain link.

Threaded holes, with threads sufficiently accurate for many purposes, are formed in castings by means of the tin shells shown in Fig. 7.63. These shells are dropped in the pattern and filled with green sand in some cases, and in others they are filled with core sand. One of the places where they are used is in hard iron castings to form the threaded holes to receive grease fittings. The shells are drawn from a flat blank and the threads are produced by rolling. Standard sizes of these shells are made for pipe threads, for some U.S. standard threads, and for a damper screw considerably used in the stove industry.

Threaded inserts, made and threaded on a screw machine as shown in Fig. 7.64, also are used for forming screw threads in castings. A patent was issued on a tapered wooden plug which screws into the insert and forms a shank which is gripped by the sand of the mold to hold the insert in place when the pattern is drawn.

A recess in a casting may sometimes be advantageously cored out by means of a tin form. Undercut holes to anchor babbitt metal in place where it is used

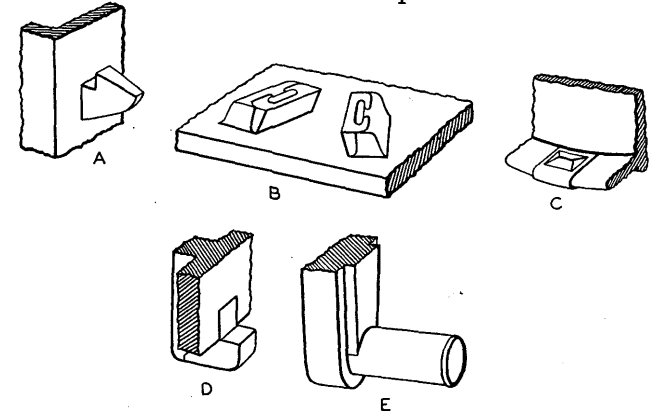


Fig. 7.61—Common applications for tin forms. A—Stove door catch. B—Dove tail lugs. C—Lug on cover of pump for attaching it to the pump body. D—Foot-shaped projection. E—Shaker lug on grate bar.

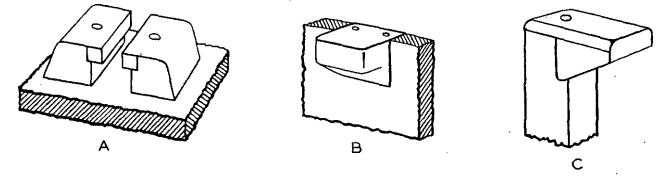


Fig. 7.62—Special tin form shapes. A—T-slot. B—Lug for bolt hole in deep casting. C—Turned in end on malleable conveyor chain.

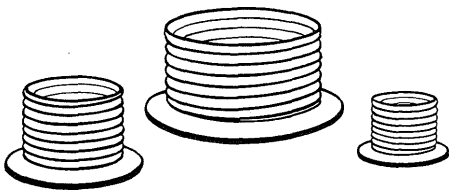


Fig. 7.63 — Forms for producing threaded holes in castings. They are made in standard sizes for pipe threads. U.S. standard threads and for a damper screw used in the stove industry.

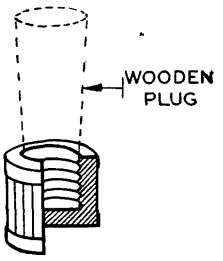


Fig. 7.64 — Illustrating use of tapered wooden plug to hold insert in position.

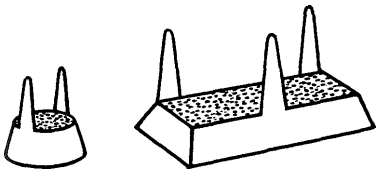


Fig. 7.65 — Forms for making bearing anchor holes in castings.

to form bearings, is a typical example. It is customary to form recesses of this kind by means of small cores secured to the mold or core by means of nails or tacks. Tins the shape of the required anchor hole, as shown in Fig. 7.65, filled with core sand and made with projecting prongs to attach them to the mold, are convenient and economical and can be kept in stock without deterioration or danger of breakage. Furthermore, the sand mixture in these tins, being protected from direct contact with the hot metal, does not vitrify and burn hard, but cleans out readily.

Tins can be used to form a hole or recess in a casting with sharper corners, smoother surface and greater

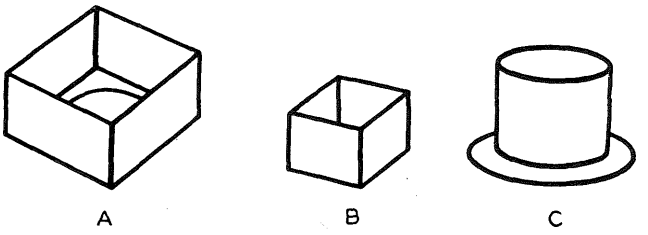


Fig. 7.66 — Forms used to produce accurate holes and recesses.

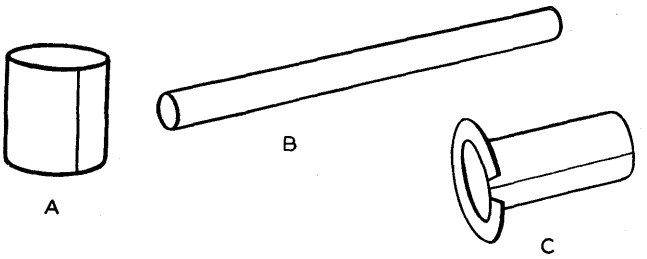


Fig. 7.67 — Tubes for forming various type round holes.

accuracy than can be obtained directly from the sand. Figure 7.66 shows at *"A"* a tin formed with sharp square corners which drops into a recess in the pattern to form a seat in the casting for an accurately fitting bolt head. *"B"* shows a tin used to secure a square accurate hole in a valve handle, and at *"C"* a tin shell used to produce a smooth round hole of accurate size in a similar manner.

Short tin tubes, as shown at *"A"* in Fig. 7.67, are used sometimes for reinforcing and venting cores, and side frames, to produce smooth, round holes for the connecting bolts. Longer tubes, shown at *"B,"* are used, filled with core sand, for coring long holes of relatively small diameter where an unprotected core would not withstand the heat. Perforated tin tubes are used sometimes for reinforcing and venting cores, and tubes with a flange on one or both ends, shown at *"C,"* are used for various purposes.

Chapter 8

CORE BAKING

INTRODUCTION

From the standpoint of economics at least, a green sand core is the most desirable type core, particularly so if it is left in the mold cavity by the pattern. Such a procedure eliminates the necessity of core boxes, driers, and handling. If it were possible to use green sand cores in all castings, it would be possible to eliminate core sand mixing equipment, baking equipment, certain types of binders, etc. The more green sand cores that can be used in any one foundry, the less baking equipment and handling are required. For these reasons and others, green sand cores are utilized wherever possible. However, there are innumerable core applications which render the use of green sand cores either impossible or impracticable. In such cases, dry sand cores are used, and it is safe to say that the majority of cores used in the foundry are of that type.

One of the primary reasons for baking cores is that in such condition they are stronger and harder than in the green state and, therefore, can be handled more easily, resulting in less breakage and core loss. The baking process itself has certain advantages. For example, it drives off the water and other volatile constituents, thus reducing the total gas-forming material in the mold. Futhermore, dry sand cores are more permeable than green sand cores made of the same core mixture and equally rammed. Higher permeability of dry sand cores allows easier egress of gases formed during the pouring operation. Oftentimes baking is required for cores because of their shape. Certain shaped cores must be baked to keep them from sagging when placed in the mold, or to eliminate the possibility of their floating when metal is introduced into the mold. Certain shaped cores could not be applied in the green state unless rods or arbors were used for supports and baking eliminates the necessity for them. In other instances, the molding operation can be simplified by the use of a dry sand core, thus, in turn, reducing molding time.

The production of cores depends not only on the equipment available and the production per coremaker, but also on the ingredients used in the core mixture. Such materials influence the baking rate of the cores which, in turn, may also affect the type and amount of baking equipment necessary. Assuming that the materials have been chosen to produce a core of the desired properties and good baking equipment is available, top efficiency in the baking operation has not necessarily been reached because, even under such conditions, there are many variables that influence the baking rate.

The rate at which a core bakes in a core oven depends on many factors, such as temperature, time, type of binder, size of core, humidity of the atmosphere both within and without the oven, fineness of the sand used, and ventilation within the oven. The manner in which each of these items affects core baking should be well understood by foundrymen.

In discussing core baking, it is well to remember the manner in which heat acts on the core. When the core is placed in the oven, the first action of the heat is to drive off the moisture. Next, if oils are used, the highly volatile fractions of the core oil are distilled off from the mixture. Finally, the actual baking of the binder, which causes the sand grains to adhere to each other, takes place.

As will be shown in this chapter, the actual baking of a core is a series of complicated reactions involving not only the addition of oxygen but the rearrangement of molecules to provide the proper bond. Consequently, to secure the best results, care should be the watchword in the core baking operation.

TYPES OF BINDERS

Sand mixtures used in the manufacture of cores are composed of one or more types of sand and one or more types of binders, plus water. When a particular sand or combination of sands is decided upon as the base material, the selection of the core binder or binders to be used to produce cores of the proper quality and physical properties must be decided. As previously stated in Chapter 3, core binders may be divided into four classes: (1) Binders that become firm on freezing, (2) binders that become firm at room temperature, (3) binders that become firm on heating, and (4) clays. The mechanism by which the binders in Classes 1 and 2 function to hold the grains of core sand together, are almost self-explanatory. In the discussion of core baking, the third class of binding materials is of specific interest.

Binders that become firm on heating may be subdivided further into: (1) Those that dry, that is bake, on heating, such as core oils, (2) those that harden on cooling after being heated, such as pitch or resin, and (3) those that adhere on heating, such as cereal, sulfite and protein binders.

There is a difference in the mechanism which produces the necessary bonding properties in these three subdivisions of binders. Those binders included in subdivisions 2 and 3 function through physical phenomena, while those included in subdivision 1 operate by chemical reaction.

Pitch and similar materials of subdivision 2 are solid at room temperature, but on heating become a viscous liquid which flows around the sand grains. When the mixture of sand and binder is cooled, the binder again assumes the solid state and thus binds the grains together into the required shape.

The binders falling into subdivision 3 are introduced into the core mixture in the dry state and thoroughly mixed with the sand grains. When water is added, they become gelatinous, thus imparting green strength to the mixture. When heated, these binders become dehydrated, harden, and adhere to the sand grains, thus holding them together.

CORE OILS

The baking of cores in which core oils are used, involves a series of both physical and chemical reactions. In the baking process, the first action of the heat is to drive off the moisture, and possibly at the same time or slightly later, to distill from the core oil the lighter oil fractions which are often present in such oils. The final steps in the baking process involve oxidation, polymerization and decomposition. Naturally, continuation of the baking process to the place where the core binding material decomposes must be avoided as in such a case the core is burned and loses strength.

In the baking process the various reactions, evaporation, oxidation, polymerization, and decomposition, may proceed in systematic order or, as is usually the case, overlap each other. However, the important factor is that each step takes place and produces a certain result in direct proportion to the heat applied, depending on the composition of the oil. For a concrete example take linseed oil.

It is well known that if linseed oil is baked slowly at a moderate temperature of 375 F (191 C), it will produce a very strong bond. On the other hand, if it is baked quickly at a temperature of 500 F (260 C) or more, the resulting bond will not be equal to that produced by the slow, moderate bake.

Wood oil, if baked at the above two temperatures and periods of time, does not show any material difference in the strength of the bond produced between the long, low temperature bake and the high temperature, fast bake.

The baking properties of linseed and wood oils illustrate the fact that a certain result is obtained in direct proportion to the heat applied in accordance with the composition of the oil. This rule holds true not only for one individual but also for any combination of oils.

Oxidation

To understand the process of oxidation which core oils undergo when they are baked, it is necessary to know something about the substances of which they are composed. Drying oils of the vegetable type, which form the basis for many core oils, are composed mainly of glycerides of fatty acids. These fatty acids are said to be unsaturated, which means that they are capable of taking up or uniting with other elements or compounds without the formation of any side product. The fatty acids of which the various vegetable drying oils are composed differ both as to type and degree of unsaturation, the latter depending on the type. Hence the difference in drying or baking properties of various core oils.

As an example, linseed oil is known to contain certain glycerides of oleic, linoleic and linolenic acids. It also is known that oleic acid is singly unsaturated, that is, can pick up or unite with one molecule of an element or compound; linoleic acid is double unsaturated and can unite with two molecules; and linolenic acid is trebly unsaturated and can unite with three molecules.

The baking or drying of core oils containing vegetable oils is primarily an oxidizing process. This means that oxygen is taken up by the unsaturated fatty acids in accordance with their degree of unsaturation. By so doing, the fatty acids become saturated and form larger and more complicated molecules which, in turn, are rearranged later through polymerization to form the hard films which hold the sand grains together. Thus it can be seen that the hardening ability of core oils containing vegetable drying oils as bases depends to a certain extent on the degree of unsaturation of the fatty acids of which the oils are composed, which, in turn, is related to their ability to unite with oxygen.

It may be stated that the vegetable drying oils, such as linseed, unite with oxygen at normal temperatures but the rate at which oxygen is taken up, and hence hardening, is relatively slow. By the application of heat, the rapidity with which oxygen is taken up is increased and the polymerization can begin sooner, thus forming the required solid film more rapidly. This is one of the reasons why cores are baked.

It should be pointed out that, as with any chemical reaction, there is a definite ratio between the time necessary to complete a reaction and the temperature at which the reaction takes place. This also is true of core baking. However, there also are other important points to be taken into consideration if proper and maximum baking efficiency in the core room is to be attained.

Polymerization

Polymerization is defined by Webster as follows: "To change (by union of two or more molecules of the same kind) into another compound having the same elements (for example, carbon, hydrogen, oxygen, etc.) in the same proportions, but having a higher molecular weight."

Many of the theories concerning the hardening mechanism of core oils are based upon the knowledge of film formation in paints and varnishes. It is interesting to note that Krumbhaar[1] makes the following statements with regard to film formation, some of which appear to be applicable to core oils and to explain the behavior of certain general types.

[1]Dr. Wm. Krumbhaar, from *Driers and Drying*, p. 9, by Bennett.

"Regarding the process of film formation from a more practical standpoint, it must be borne in mind that the drying of a surface coating film consists of two steps, the process of oxidation and the process of polymerization. Invariably, oxidation initiates and precedes polymerization, but the two processes overlap each other and the kind of film that is formed depends upon the respective parts played by the two processes.

"Types of film formation in which oxidation prevails are the drying processes going on at ordinary room temperature, particularly, when a large amount of drier or a strong catalyst . . . is present. Oxidation also predominated the drying of coatings composed of oils of the linseed type, etc.

"Films in the formation of which polymerization prevails are produced when drying is carried out at elevated temperatures by baking or stoving, particularly in the absence of driers or if only small amounts of weak oxidation catalysts . . . are present. Polymerization also predominates in the drying of coatings containing a major portion of oils of the tung type, etc."

From the above, it is evident that the process of polymerization is the final step in the baking of a core oil and that some heat is necessary for that reaction to begin. As there is only so much core oil in a core sand mixture and as this reaction must go to completion, and further, as there are no side products formed, the temperature of the baking process and the baking time are extremely important if complete efficiency is to be obtained in the baking operation. It also points to the necessity of using only the minimum of oil required to produce the desired results as a method of reducing baking time.

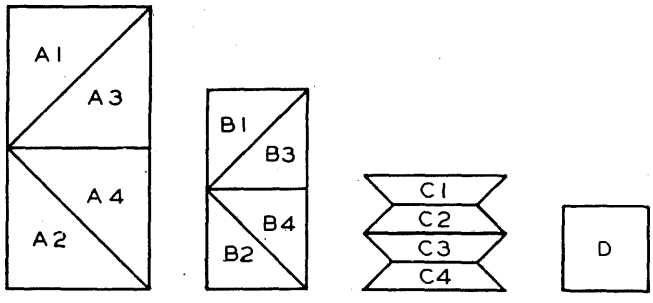


Fig. 8.1 — Blocks illustrating initial components of a core oil.

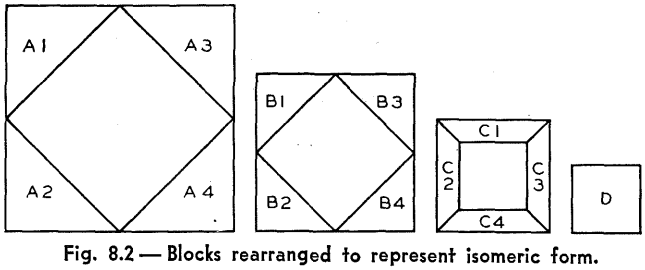


Fig. 8.2 — Blocks rearranged to represent isomeric form.

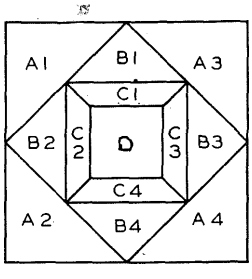


Fig. 8.3 — Blocks rearranged a second time to represent the core oil in its polymerizable form.

The above also explains the behavior of the so-called quick drying core oils. Such core oils require the use of a readily polymerizable oil as a base. Since a large portion of the oil already has been oxidized, and the time for oxidation is practically eliminated from the drying process, these core oils form the required hard film between the sand grains relatively rapidly. Many of the mineral base core oils are of the polymerizable type.

To convert a compound from its natural state into a polymerizable form, it is necessary to pass it through an intermediate or isomeric stage. Isomeric substances are those composed of the same number of the same atoms but differing in construction and properties. Such structures are found particularly among the hydrocarbons, of which vegetable and mineral oils are composed, and are said to give rise to the different physical and chemical properties that may be found in various samples of the same oil, as well as accounting for the changes that sometimes take place in these properties with the passage of time and exposure.

Isomers are divided into two classes: Those that retain the same molecular weight as the original form, which are known as metameric, and as such are often reversible; and those that increase in molecular weight, are described as "polymers," and as such progress only in one direction.

This change of structure, which takes place by the rearrangement of atoms within a molecule, is in the use of oils to produce a baked bond, superseded by the fact that whole molecules can be interchanged within a compound.

To illustrate the various stages of rearrangement of atoms and molecules that occur during the baking process, let us assume that the components of a certain oil are a series of differently shaped blocks, such as shown in Fig. 8.1, in which all the A's are grouped together to form one uniform compound, the B's to form another, and so on. If they are left in this form, they do not produce a balanced structure. Again to illustrate the desired balance, let us, for the purpose of simplicity, express chemical balance as a structural or visible balance. To bring about this balance, the component parts of each compound must be rearranged so that there is a definite structural relation between each of them. This is illustrated in Fig. 8.2, in which each still remains the same compound consisting of the same blocks but in a different form. In this new form, it will be immediately seen that the different arrangements can be fitted together to form one compact structure, as shown in Fig. 8.3.

Returning to the comparison of linseed and wood oils, in wood oil nature has produced a balanced structure which, upon the addition of heat, immediately begins to polymerize. On the other hand, linseed oil first must be carried through a low temperature stage to produce a rearrangement of its component parts before it will polymerize.

Carry this balance one step further. Suppose, for example, that linseed and wood oils are mixed and this combination heated. It would be necessary, not withstanding the fact that wood oil can be polymerized at elevated temperatures, to hold the mixture at a low temperature to first effect the rearrangement

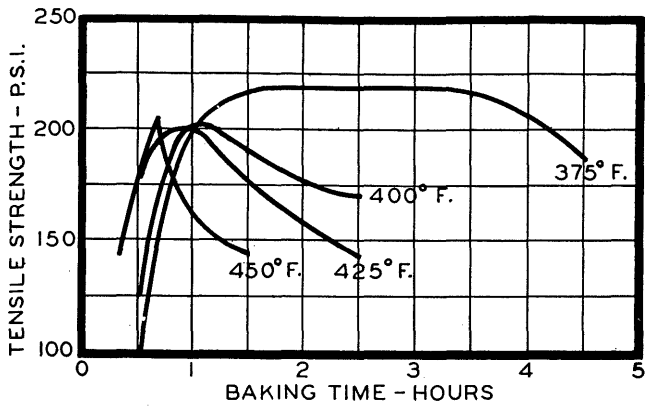


Fig. 8.4 — Effect of time and temperature on baking strength of raw linseed oil cores.

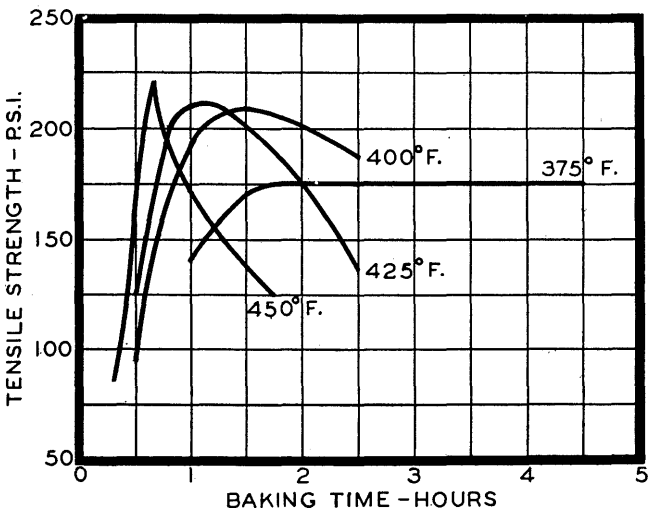


Fig. 8.5 — Effect of time and temperature on baking strength of raw soybean oil cores.

of the linseed oil components before the entire mixture could be polymerized. By way of comparison, however, suppose that an elevated temperature is immediately applied to the mixture. The resulting product will not be a balanced structure having one definite set of properties. On the contrary, there will be two resulting products, a polymerized wood oil and an oxidized linseed oil, having two distinct sets of properties.

From the foregoing it can be seen that, to save baking time and reduce to a minimum the chances of any undesirable reaction, it is advantageous to use a core oil which is properly balanced structurally so that, when the proper temperature is applied, each part of the oil will react in the same way.

Conversely, it is important that the rate of heat application for a given core oil should be such that the proper sequence of reactions take place to secure the maximum results.

As a further example of how the type of oil affects baking rate, linseed and soy bean oil may be selected for comparison. Baking characteristics of raw linseed oil and raw soy bean oil are shown respectively in Figs. 8.4 and 8.5. These charts show that for each temperature and type of binder there is a definite baking time that gives maximum strength.

From the preceding it is evident that the type or types of binders used in the core mixture exert an important influence on baking rate.

EFFECT OF CORE SIZE

Where such curves, as shown in Figs. 8.4 and 8.5, are used to predict the baking characteristics of large cores, the following results might be expected. The outer surface of a large core will reach the baking temperature first and therefore will be the first part to reach maximum strength. If the temperature is maintained, the inside will continue to bake until finally it reaches maximum strength. By that time the outer surface will be overbaked with a consequent loss in strength.

Therefore, in the baking of large cores, the baking rate must be adjusted to promote as uniform baking as possible.

For oils which dry by a process of oxidation, the problem not only is one of raising the center of large cores to a baking temperature, but of introducing oxygen to the center of the core. Therefore, the rate at which the center increases in strength depends upon the temperature and the permeability of the sand.

SIZE AND MOISTURE

To obtain a measure of the temperature gradients inside a large core during the baking period, a number of test cores were prepared as solid cylinders of 4 in. diameter and 4 in. high. Thermocouples were placed in the cores at three points, at a height of 2 in. above the core plate. The first rested in the center of the core. The second was placed half way between the center and the surface and the third was in contact with the surface. The cores were placed in a core oven conforming to AFS standards at 400 F (204 C) and temperature readings were taken on the three couples at regular time intervals. Cores were made with both linseed and soy bean oils mixed in the proportion of 100 parts sand to one part oil and with one and 6 per cent water.

TABLE 8.1 — EFFECT OF SIZE ON BAKING CHARACTERISTICS OF SOY BEAN OIL BONDED CORES

Baking Time, Hours	Type of Core Plate	Tensile Strength, psi		
		Top Section	Center Section	Adjacent to Core Plate
1½	solid	121.2	106.4	65.2
1½	drilled	147.2	142.0	107.2
2	solid	128.0	138.4	118.1
2	drilled	135.2	148.8	154.4
2½	solid	118.4	127.2	163.2
2½	drilled	144.4	134.0	169.6

Results for linseed oil bonded cores, shown in Figs. 8.6 and 8.7, are practically the same as those secured on the cores bonded with soy bean oil.

The curves show that during the heating period there is a very appreciable lag in the temperature of the inside of the core. This temperature lag is even more pronounced in the mixture containing the most water. The temperature remains constant at the boiling point of water for a period sufficient for evaporation. Naturally this feature increases the time necessary to raise the entire core to a uniform temperature.

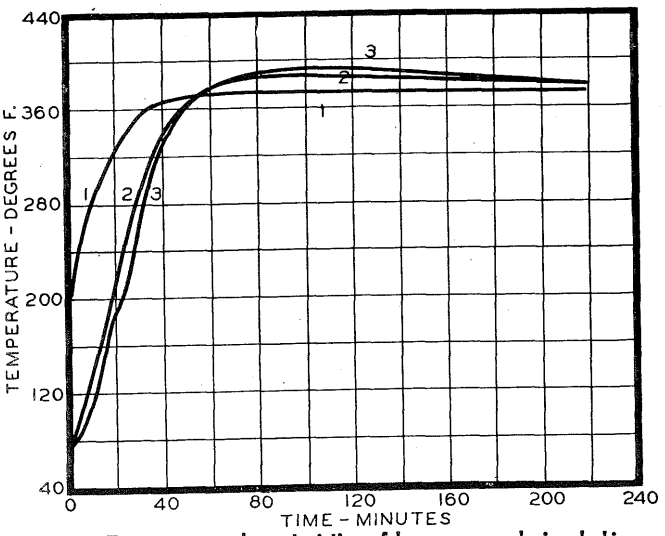


Fig. 8.6 — Temperature characteristics of larger cores during baking. Cores bonded with linseed oil contained one per cent moisture.

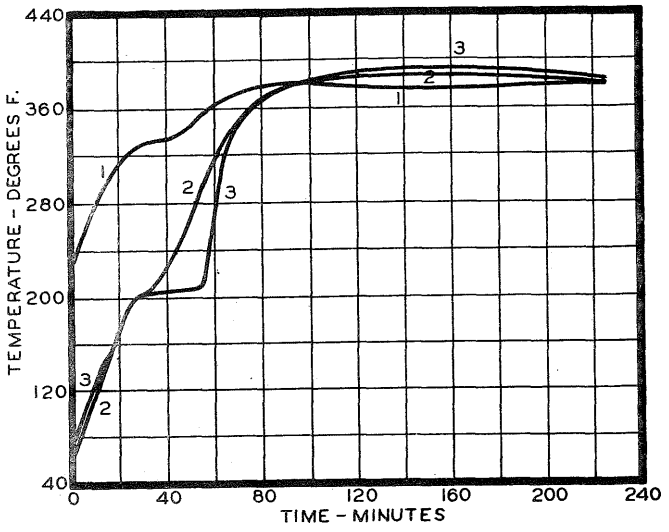


Fig. 8.7 — Same as Fig. 8.6 but cores contained 6 per cent moisture.

Effect of these various factors on core strength was measured. Additional cores of the size previously described were made up and baked for varying periods. The cores were cut into sections so that three AFS standard tension test cores could be made from each large core. One test specimen was taken from the top, one from the center section and one from the section adjacent to the core plate. Duplicate cores were dried upon solid and upon perforated core plates.

TABLE 8.2 — EFFECT OF SIZE ON BAKING CHARACTERISTICS OF LINSEED OIL BONDED CORES

Baking Time, Hours	Type of Core Plate	Tensile Strength, psi		
		Top Section	Center Section	Adjacent to Core Plate
1¼	solid	166	145	124.8
1¼	perforated	151.6	160.0	140.8
1½	solid	157.0	154.1	135.7
1½	perforated	184.4	166.4	198.8
2	solid	145.6	153.2	178.4
2	perforated	151.6	156.4	174.8

Results are shown in Tables 8.1 and 8.2. It may be noted that the strengths vary in a manner that might be expected. The maximum strength was attained first on the surface and then, as the baking time was continued, the strength moved toward the center. The outer part lost strength to a corresponding extent as the central part gained. Due probably to the better circulation of air, the variations in strength are not so pronounced in the cores dried upon the perforated plates.

Dierker[2] reported the results of similar tests in a commercial core oven. His results are shown in Fig. 8.8. The solid lines indicate the time necessary to dry the core completely while the dotted lines represent the time required to bring the center of the core to 350 F (177 C). Cores used in the test were 5 x 5 x 8 in.

Two things retard the heating rate of sand cores. One is the insulation properties of sand, the other is water. In order to obtain uniform cores, the moisture content of the core sand mixture should be maintained at a constant level. Core baking can be accelerated by keeping water content of core mixtures as low as possible and by keeping the air in the core oven dry.

MOISTURE ELIMINATION

Green core sand contains, on an average, about 6 per cent moisture. This is practically all in the form of vapor before the baking operation is half completed. At 6 per cent moisture, each 100 lb of sand contains 6 lb of moisture which, upon vaporization, expands to about 165 cu ft at 212 F (100 C) and to greater volumes at higher temperatures.

Grubb and Jamison[3] conducted tests by means of a thermocouple located in the center of a core which was being baked to show that the rise in temperature is retarded at about 212 F (100 C) thus indicating that the water was being evaporated.

Additional evidence that this is true is shown by Willsea[4] and others. In discussing Willsea's paper, Dierker[2] presented results he had obtained in a commercial core oven. He rammed thermocouples in the center, top and bottom of several various sized

[2]Dierker, A. H., Discussion of *"What Happens to a Core in a Core Oven,"* AFS TRANSACTIONS, vol. 46, pp. 751-753 (1938).

[3]Grubb, A. A., and Jamison, U. S., "Air Required in Baking Cores Made With Linseed Oil," *Chemical and Metallurgical Engineering*, pp. 793-5, (Oct. 26, 1921).

[4]Willsea, J., *"What Happens to a Core in a Core Oven,"* AFS TRANSACTIONS, vol. 46, p. 739 (1938).

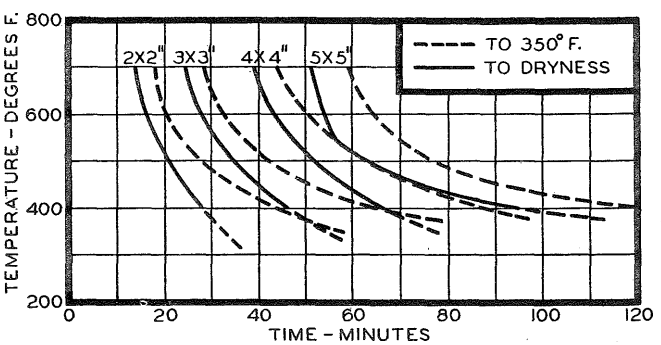


Fig. 8.8 — Effect of core size and temperature on drying rate. The solid lines indicate the time necessary to dry the cores completely while dotted lines represent the time required to bring the center of the cores to 350 F (177 C).

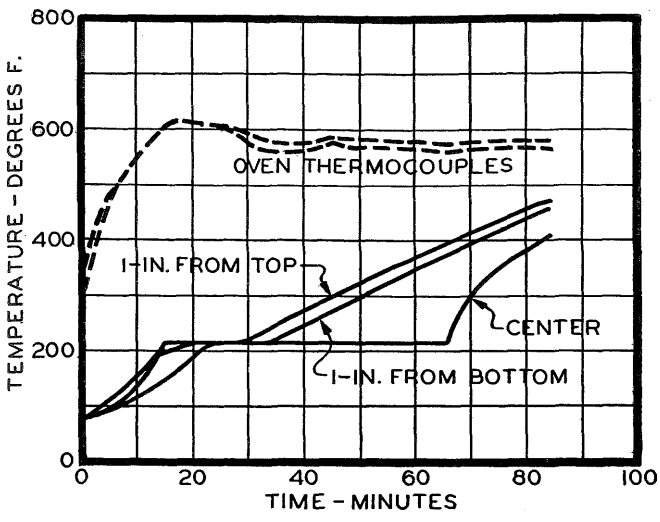


Fig. 8.9 — Readings of three thermocouples placed inside a 5 x 5 x 8 in. core resting on a solid cast steel plate. One thermocouple was placed one in. from top, one at the center and one at one in. from the bottom.

cores. The cores and couples then were placed on a plate in a commercial core oven and the temperatures at the various locations in the cores were recorded. Figure 8.9 shows the temperatures at various times within the cores. Note the difference in time necessary to expel the moisture from the center of the core as compared to the top and bottom sections.

From the above, it can be seen that the weight of cores and their moisture content exert an important influence on oven operation and design, particularly the amount, temperature and humidity of the air introduced into the oven and the baking time.

OXYGEN REQUIRED FOR DRYING

Since many core oils go through the oxidation process during the baking period, some investigations on the amount of oxygen required to dry linseed oil may be of interest. The first dry sand cores were made with linseed oil and this oil still serves as the base for many such oils now used for core purposes.

In the oxidation of linseed oil, A. Genthe[5] found that said oil absorbed 23 per cent oxygen. Cloez[6] determined the amounts of carbon, hydrogen and oxygen in linseed oil and Grubb and Jamison calculated from that analysis that 33.24 grams of oxygen were required to completely dry 100 grams of linseed oil. In experiments of their own, Grubb and Jamison found that linseed oil requires about 73 per cent of its weight of oxygen in the baking process. Their figures were higher than the investigators mentioned because, they pointed out, a properly baked core is more than dried. They stated that when the linseed oil in a core is merely dried the core has a greenish appearance, while if it is thoroughly baked it has a decidedly brownish color.

The amount of oxygen required to bake a core thoroughly has a direct relation to the amount of air that must be used in a core oven, which, in turn, has a decided influence on oven operation and design.

[5]Allen's Commercial Organic Analysis, vol. 2, p. 345.
[6]Allen's Commercial Organic Analysis, vol. 2, p. 348.

ATMOSPHERIC HUMIDITY

Extensive research has led to the conviction that atmospheric humidity plays a surprising part in successfully drying oil sand cores. Tests, running into the hundreds and extending over a long period of time, have brought out interesting and pertinent facts relative to core strength and speed of baking. Foundrymen know that on some days cores seem particularly good; that is, they are well baked and strong, and give off a minimum amount of smoke and gas. At other times, the cores are not satisfactory, some being underbaked, causing the foundry to be filled with disagreeable smoke and gas. At other times, the cores may be brittle from overbaking.

As an example of the important part played by moisture in the core baking process, Mayer[7] compiled some figures on the moisture carried into and produced in a gas-fired core oven and the heat required to eliminate it. The author assumed use of a typical gas, such as produced in the Ohio, Pennsylvania, or most any natural gas area, and which may be composed of nitrogen (N_2), 1.6 per cent by volume; methane (CH_4), 80.3 per cent by volume; and ethane (C_2H_6), 18.1 per cent by volume.

These gases combine with oxygen of the air provided for combustion as follows:

$$\text{(A)}\quad CH_4 + 2O_2 = 2H_2O + CO_2$$
$$\text{(B)}\quad 2C_2H_6 + 7O_2 = 6H_2O + 4CO_2$$

From the above, obviously 1 cu ft of CH_4 produces 2 cu ft of H_2O and 2 cu ft of C_2H_6 produces 6 cu ft of H_2O. In each cubic foot of gas, there is 0.803 cu ft of CH_4 and 0.181 cu ft of C_2H_6.

The natural gas considered has a specific gravity of 0.65 referred to air. Air at 70 F (21 C) weighs 0.075 lb per cu ft. Therefore, the weight of one cubic foot of this gas will be 0.0488 lb. Accordingly:

CH_4 produces $0.803 \times 2/1 \times 0.0488$
$= 0.078$ lb of H_2O.
C_2H_6 produces $0.181 \times 6/2 \times 0.0488$
$= 0.026$ lb of H_2O.
Total 0.104 lb of H_2O per cu ft of gas burned in complete combustion.

These figures represent theoretically complete combustion applied to the properties of a given natural gas in a given producing field, and may vary depending on the particular properties in the field.

In a typical rack type core oven baking around 2500 lb of sand in 2 to 3 hrs with an air heater handling about 3000 c.f.m. and burning, say, 750 cu ft of gas per hour, the moisture formed due to combustion would approximate:

750×0.104 or 78 lb per hr, or the equivalent of 546,000 grains.

Assuming the fairly humid condition of, say 75 F (24 C) and 75 per cent relative humidity:

(a) Air contains 7 grains of moisture per cu ft.
(b) Air saturated contains 9.5 grains per cu ft.

[7]Mayer, C. F., "Moisture Due to Combustion and Its Effect on Drying," *Industrial Heating* (June, 1939).

(c) The weight of air is 525 grains per cu ft.
(d) 7000 grains is equivalent to one pound.

Thus the initial air to heater contains 7/525, or 1.3 per cent moisture per cubic foot.

A typical core sand will contain about 6 per cent moisture, before baking. Thus 2500 lb of sand will contain about 150 lb of water, or the equivalent of 1,050,000 grains.

In heating the initial air from 70 to 400 F (21 to 204 C) (oven temperature), the moisture content remains constant, but the relative humidity drops rapidly and the moisture absorbing possibilities increase greatly. Theoretically oven air at 400 F (204 C) can absorb 600 grains per cu ft. Since initially the air held 7 grains it can theoretically, at the raised temperature, absorb 600 — 7 or 593 grains. In practice, only 60 per cent is considered, or about 355 grains.

From the preceding it was observed:

(a) 750 cu ft of gas per hr produces in combustion (bake of 2 hours) about 1,092,000 grains of water.
(b) The 2500 lb of sand contains 1,050,000 grains of water.

Total, 2,142,000 grains per bake.

Accordingly, 2,142,000 grains of water must be disposed of during a bake, or about 1,071,000 grains per hour. To do this requires that a suitable amount of air must be introduced with the ability to absorb this moisture and that means be provided to remove the proper proportion at all times to produce favorable drying and baking.

Research in the paint and varnish industries shows that the process of drying constitutes two major phases, irrespective of materials used and as to whether the oil is air dried or baked. These phases are:

(1) Oxidation of oil to form larger, more complicated, polar molecules.
(2) Orientation and association of these to form solid film.[8]

It is further concluded by the same authority that excessive moisture or humidity in the air inhibits drying, particularly in the first phase. It may then be logically concluded that the second phase or final formation of solid film would be incomplete.

In consideration of these data, a series of uniform core tests was started[9] in which core strengths at different baking periods were plotted. The method of test was to use the standard briquette of one square inch area. A standard commercial sand was used, mixed in a ratio of 75 parts of sand to one part of oil by volume. Moisture content, mixing and baking procedure were held as near constant as possible.

From each oil-sand mix, cores were baked at 1 hour, 1½ and 2 hours, respectively, to determine both the strength produced at different periods and effect of humidity variations on formation of film. Relative humidity values were tabulated both near the baking oven and as furnished by the U.S. weather bureau. It was found that inside humidity readings were modified somewhat and showed less abrupt changes and, since they represented the air passing through the oven, were used in the curves. However, Fig. 8.11 shows both inside and U.S. weather bureau readings.

Figure 8.10 shows the strength results of the 2 hour bake from each test plotted against relative humidity. While the 1 hour and 1½ hour bakes gave equally comparable results, the 2 hour results were selected and plotted because they should more nearly parallel

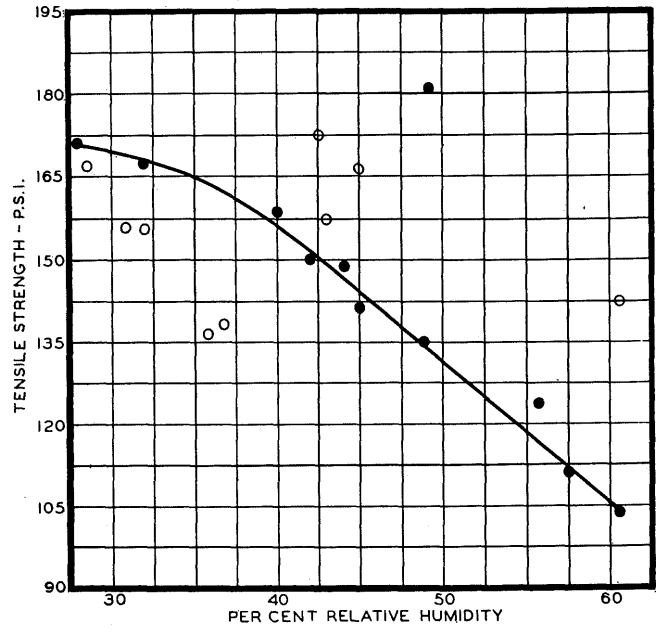


Fig. 8.10 — Strength results of a 2 hr bake from each test plotted against relative humidity, linseed oil-silica sand ratio, 1-75 by volume; water-sand ratio, 1-30 by volume; baking temperature, 400 F (204 C).

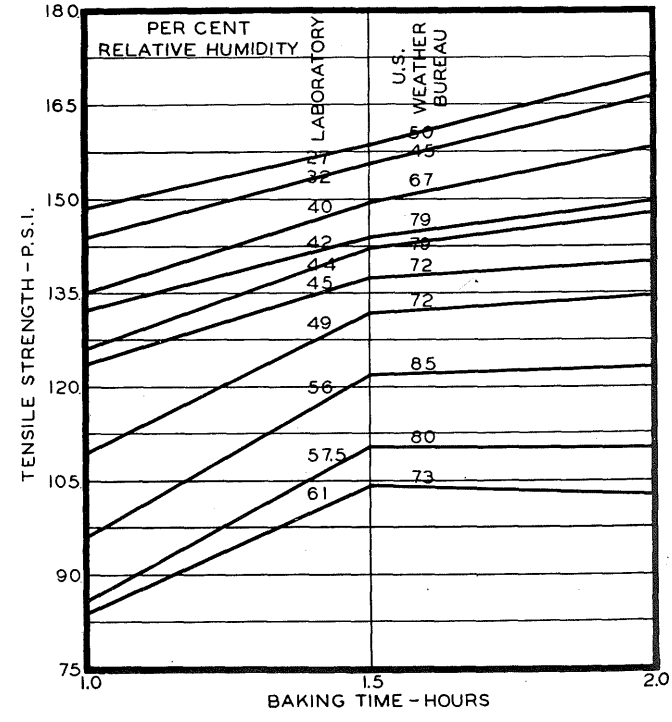


Fig. 8.11 — Complete strength curves of a group of selected tests. These curves show that low humidity produces greater strength. Same conditions as Fig. 8.10.

[8]Long, J. S., "The Mechanism of Drying and Aging of Oil Films."

[9]Coulter, A. S., "Humidity and Oil Sand Cores," *The Foundry*, vol. 61, pp. 13, 52 (Feb. 1933).

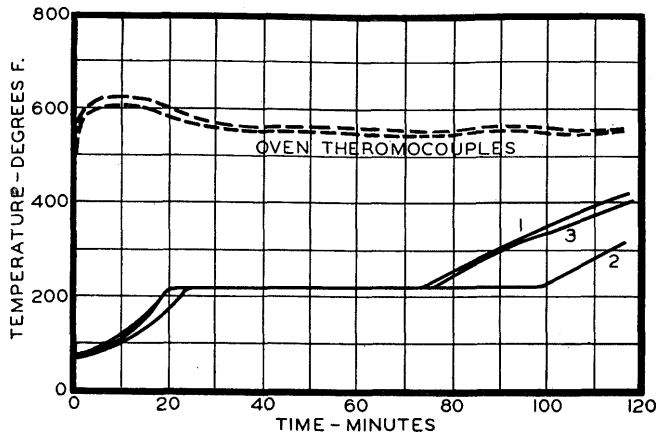


Fig. 8.12 — Effect of core position on drying rate. Cores one and 3 were at ends of row with core 2 in center.

actual foundry baking. Results leave no doubt but that greater strength is produced under conditions where the oven humidity is low.

Figure 8.11 shows complete strength curves of a group of selected tests as indicated in Fig. 8.10. Strength variations are apparent and particular attention is directed to character of the various curves. At high humidity the strength is not only low, but the oil starts to lose strength or burn out between 1½ and 2 hours. Low humidity produces greater strength at all baking periods and at 2 hour baking the maximum strength has not been reached.

From the above, perhaps excessive humidity does prevent proper initial oxidation or first phase action. It then will become apparent why low strength and burning out result from the forced completion by heat of the second phase.

It is apparent from results shown in this series of tests that proper conditioning of the air passing through core ovens not only permits the foundryman to carry the oil-sand ratio at the lowest point consistent in obtaining commercial cores, but also he would be assured of constant baking conditions. From Fig. 8.11, it will be observed that if cores are baked for the proper length of time to get maximum strength at low humidity, the binder will be burned out if baked the same length of time at high humidity.

ARRANGEMENT OF CORES

Dierker,[2] in his experiments on core baking, showed the value of proper spacing of cores on the core plate during the baking period. He placed three 5 x 5 x 16-in. cores on a core plate as close together as possible. The cores were marked 1, 2 and 3 with cores 1 and 3 at the ends and core 2 in the center. Figure 8.12 shows the results. The lines marked 1, 2 and 3 indicate the temperatures at the center of the cores. When the cores were spaced one inch apart, the drying rate was approximately the same for each core.

FINENESS OF SAND

The time required to bake cores is related definitely to the fineness of the core sand. Figure 8.13 shows the relation between baking time and fineness of sand for cores bonded with a linseed oil compound. The baking time to secure maximum strength for an open core sand with a 40 mesh average is 1½ hr. When a core sand fineness is increased to 60 mesh, 2¼ hours will be required to secure a maximum strength core. An increase of fineness above 60 mesh does not materially affect the baking time.

The baking time referred to above is for test specimens baked in a test oven conforming to AFS standards. In production ovens, cores frequently must be baked twice the length of time indicated.

TEMPERATURE WITHIN A CORE DURING BAKING

The temperature rise within a core during the baking cycle is much slower than one would generally assume. This is particularly so for cores of any appreciable size. For an illustration of the rate of heating of an oil-cereal bonded core, refer to Fig. 8.14. Temperature readings are shown at the surface of the core, 1 in. from the surface, 2½ in. from the surface

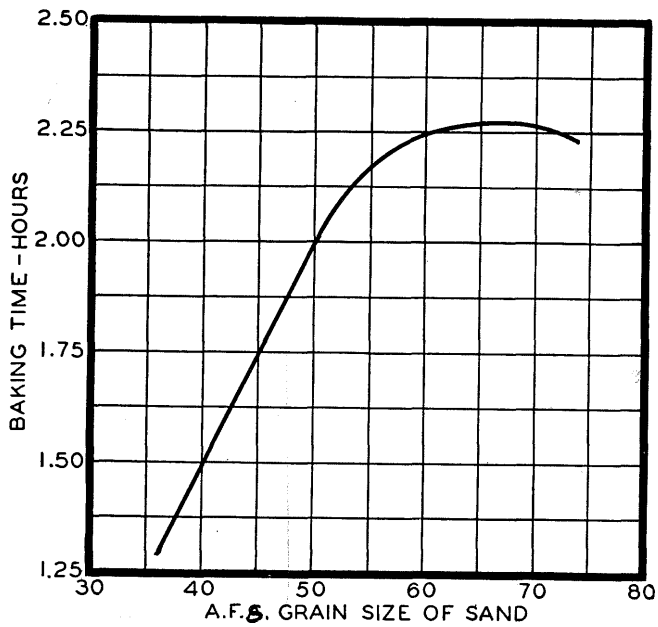


Fig. 8.13 — Core baking time for maximum strength as determined by grain size, baking temperature 400 F (204 C), oil to sand ratio, 1-62, water 5 per cent.

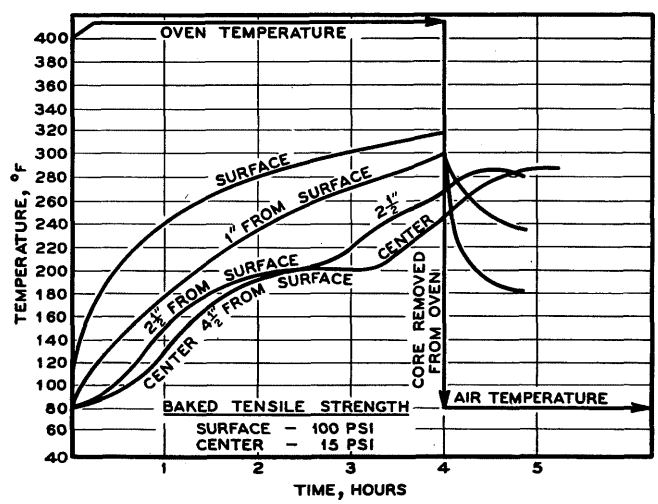


Fig. 8.14 — Rate of heating of an oil-cereal bonded core.

and at the center of core which was 4½ in. from the surface. The base of the core measured 10 x 10 in. and top measured 8 x 8 in.

The core mixture consisted of the following ingredients:

Michigan City lake sand, lb	1280
Michigan bank sand, lb	56
Cereal binder, lb	20
Western bentonite, lb	6
Linseed base core oil, lb	20
Moisture, per cent	1.6

The core was baked for 4 hr at an oven temperature of 418 F (214 C). Referring to Fig. 8.14 it may be noted that the surface of the core reached a temperature of 240 F (116 C) after 1 hr of baking. In the second hour of baking the temperature of the surface reached 280 F (138 C) and in the third hour a temperature of 303 F (151 C) was reached. At the end of the fourth hour baking period, the surface reached a temperature of 318 F(159 C) which is 100 degrees lower than the oven temperature. The steam from the center of the core cooled the surface of the core.

Noting the temperature rise curve for the section of core one in. below the surface (Fig. 8.14) it may be observed that this section of the core has a gradual temperature rise as the baking cycle progresses. The maximum temperature reached was 278 F (137 C) or 20 degrees lower than the surface temperature.

The 2½-in. and 4½-in. sections which represent the center section of the cores have a similar temperature rise. After 2½-hr of baking, these two temperature rise curves meet each other at a temperature just above 200 F (93 C) where steam was generated. As baking proceeded the temperature of the section of core, 2½-in. from surface, increased faster than the center section. It was becoming free of moisture while the center section did not free itself of moisture until 3¼-hr of baking. After 3¼-hr of baking, the temperature of the center section again increased; at the end of the 4 hr baking, the temperature of the center section was 247 F (119 C) or 171 degrees lower than the oven temperature.

The interesting point is that after the core was removed from the oven the center and 2½-in. from surface sections, continued to increase in temperature, indicating liberation of heat due to the chemical change of the oil as the interior section of the core continued to bake itself after it was removed from the oven.

This proves the point that interior sections of heavy cores do continue baking after the cores are removed from the oven as so often stated.

Chapter 9

CORE OVENS AND THEIR CONTROL

INTRODUCTION

Because of the fact that the drying of oil-sand cores is a baking process, the first core ovens were modeled after bread-baking ovens. They generally were built of brick with a fire box at one end or in one corner and the waste gases were exhausted near the floor at the opposite end or corner from the fire box. Even the first continuous ovens were of brick construction, and such ovens are a relatively recent development.

When we consider the materials available for oven construction 50 years ago, we can realize that there was very good justification for the materials used in the construction of ovens. For example, gas, oil, and electricity were not used widely for commercial heating purposes, and the standard fuels were coke and coal. All core ovens were hand fired and the use of insulating materials, as applied to core ovens, was not widely known. Steel constructed ovens were out of the question, as at that time there were no rust-resisting steels, as we have at present, and wrought iron was expensive. If metal ovens, made of material available at that time, were left over the weekend in a cold building, they rusted quickly causing high maintenance costs.

It was not until about 40 years ago that a New England company realized the value of rust resisting steels and insulating materials in core ovens and developed a practical sectional oven constructed of galvanized sheet steel with an insulated filling of corrugated asbestos.

HISTORICAL

According to H. M. Lane, the modern core oven manufacturing industry dates back to about 1903. In that year, he conducted an extensive series of tests on core ovens used in a large number of foundries. In his experiments, Lane drilled 18 holes in the side of the oven under test and arranged thermocouples to extend well into the oven. A typical arrangement was as shown in Fig. 9.1. The oven illustrated was about 20 ft long, 8 ft wide and 8 ft high. Heat from the fire box entered the oven through a flue at the back and the waste gases were exhausted at floor level near the front of the oven into flues in the walls that led to a flue across the top of the oven.

The core car was about 18 ft long. The cores always were loaded so the thermocouples could extend well into the car. In Fig. 9.1, the temperatures shown at different points are those found after the oven had been in operation for one hour. At the back of the oven, directly over the inlet flue, the temperature was 920 F (493 C). About 7 ft above, at the back, the temperature had dropped to 680 F (360 C), or a drop of 240 F (133 C) in a vertical rise of 7 ft. Near the roof at the front, the temperature was 500 F (260 C), which is too hot for oil sand cores. Near the outlet in the front, the temperature was 320 F (160 C). The coldest place was within 3 ft of the hottest area, near the floor under the back of the core car.

The explanation is simple. As the hot gases rose, some of them entered the back of the car and, coming in contact with the cold metal and cold damp cores, became cooler and heavier. This gas continued to cool and fall, until it reached the floor. The rapidly rising columns of hot gases, from the openings in the floor, caused such strong rising currents that they drew the cold gases along the floor to the back. Here the cold gases united with entering hot gases. This accounted for the 240 F (133 C) drop in temperature in a vertical rise of 7 ft.

The heat ran along the roof and tended to pocket at the front of the oven. As a consequence, the cores in the part of the car marked *A*, Fig. 9.1, at the back, and *B*, at the front, always were burned. Those in the area *C*, Fig. 9.1, were baked properly and those in the area *D* were underbaked or green.

It was thought that, if the gases in the oven could be mingled rapidly, the points at which the cores were burned could be eliminated. A disc fan, about 4 ft in diameter, was installed at the back of one oven, with a

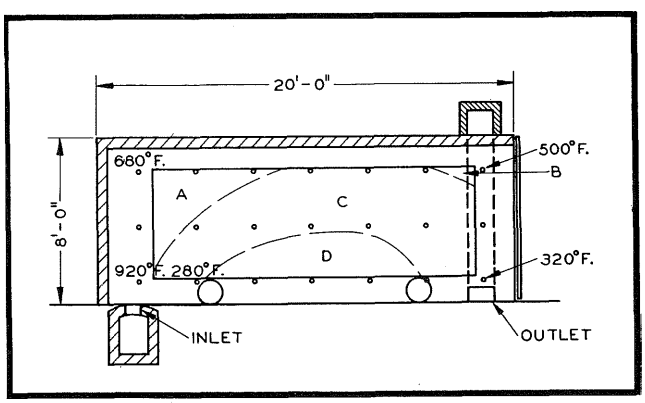


Fig. 9.1 — Diagram showing location of thermocouples used in test of core oven temperature conditions by Lane. Note the large temperature differences from one section of the oven to another.

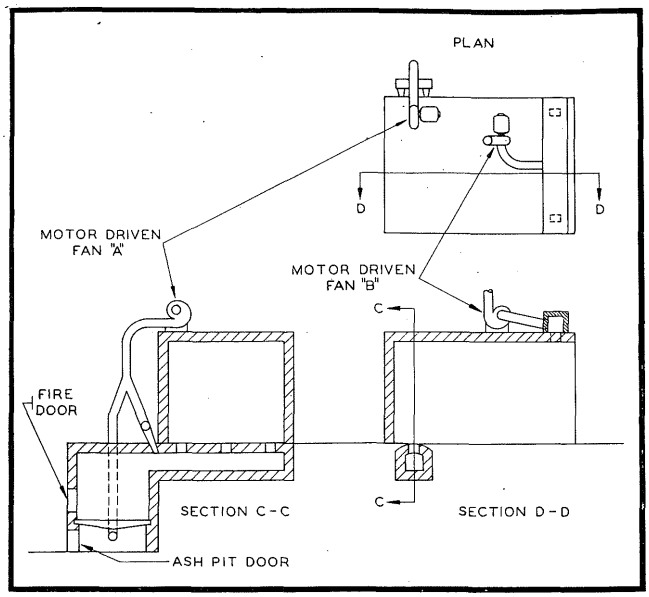


Fig. 9.2 — Layout of oven equipped with fans to control amount of air delivered to the core oven and to exhaust waste gases.

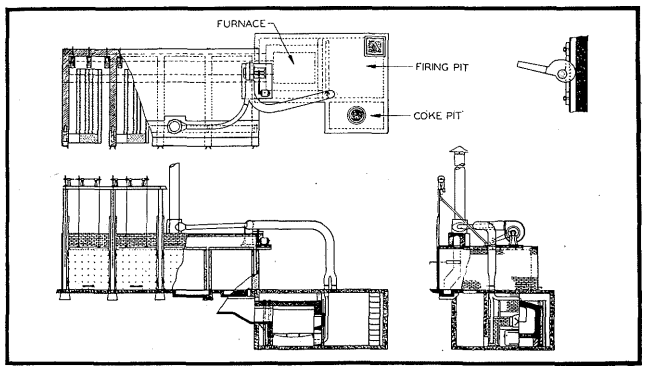


Fig. 9.3 — Diagram of core oven constructed to utilize heat in the fire box walls and arch to heat a portion of the air introduced to the oven.

drive shaft extending through the back wall. Through this arrangement, the benefits obtained from air circulation within a core oven were well illustrated.

Next it was proposed to use two fans. One was installed to drive a certain amount of air to the ash pit to control the amount of coke burned and, through a second pipe, to blow cold air through tuyeres into the flue between the fire box and the oven. This is shown in Fig. 9.2. The fan *A* blows air to the ash pit and also to the flue beyond the fire box. Dampers in both pipes controlled the amount of air delivered to each location. With this device a large volume of air, at a safe temperature for baking cores, could be delivered to the oven. A second fan, *B*, exhausted the gases from the oven and delivered them to the stack.

About that time, one of the automobile companies wanted to double the core capacity of its foundry. The plant was equipped with a battery of nine coke-fired ovens. Over 20 per cent of the cores were scrapped because they were either burned or underbaked. Lane obtained the cooperation of a blower manufacturer and built an oven using the plan illustrated in Fig. 9.2.

The result was that the output of the ovens was much more than doubled and both burned and green cores eliminated. The plan worked so well that it was patented. Within 4 months, nearly 50 ovens were changed over or newly built, and the core oven business started. These ovens were known as forced draft, auxiliary air ovens.

However, other difficulties occurred. First, installing forced draft in an ordinary core oven made such a hot fire that the side walls and arch of the fire box in many cases lasted less than 2 months. To increase refractory life and decrease maintenance costs, the fire boxes were constructed with air jackets around the walls and over the arch. The auxiliary air was circulated through this space and then introduced into the flue.

Another improvement consisted of putting the firing pit under a 2 to 4 oz blast pressure. With this arrangement, the amount of coke burned was controlled by the opening from the firing pit into the ash pit. The remainder of the air entered the jacket on each side of the oven near the floor, circulated upward outside the fire box, over the arch, and through openings into the flue to the oven. In this way, the heat passing through the fire box walls and arch was picked up by the air in the jacket and passed to the flue to help dry cores, as shown in Fig. 9.3.

In Fig. 9.3, a single fan is used both for blast and exhaust. A large pipe leads to the right and divides. One branch blew air directly into the fire pit and the amount of coke burned is determined by the amount the ash pit door is open. The other branch divided and air was forced into the jacket on each side of the ash pit, as shown.

Later, the branch entering the jacket was omitted and the amount of air introduced there was varied by controlling the openings from the firing pit to the jacket. There was a series of openings over the fire box arch, into the end of the flue, under the oven, through which the auxiliary air passed.

In the design shown, a single fan served to give blast under the grate, auxiliary air in the flue, and to exhaust the gases from the oven. This was accomplished by the arrangement shown at the base of the stack at the bottom left of Fig. 9.3. Air was blown into a chamber about the base of the stack. In this chamber, the inside wall was a cone section that left an angular space into the stack at the top of the chamber. This gave a blast around the inside of the stack that induced an exhaust current in the stack and drew the gases from the oven.

Later it was found that it was better to use a low pressure fan to supply air to the pit and a higher pressure fan to operate a venturi section in the stack.

The first forced draft, auxiliary air ovens all had a separate exhaust fan to take the gases from the oven and force them up the stack. Efforts to reduce the fire hazard from condensed combustible material within the flue of core ovens led first to the exhaust system shown in Fig. 9.3; and later to the venturi exhaust in the pipe as shown in Fig. 9.4.

The venturi consists of a short cone in the stack with a conical nozzle arranged below it. The relation between the stack diameter, the high pressure blower pipe with its nozzle in the pipe below, the throat, and

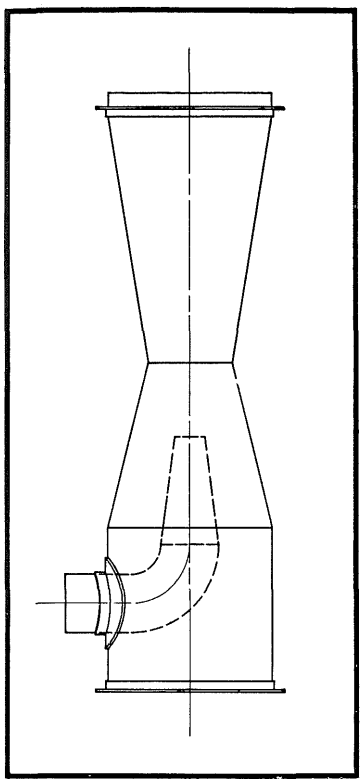


Fig. 9.4 — Venturi exhaust pipe for core ovens.

all the arrangements of parts must be carefully planned for good results. The arrangement, developed by a blower company nearly 45 years ago, had a short cone pipe below the throat and a longer one above. One is now made with the upper cone very long, extending to the top of the stack.

Stoker-Fired Core Ovens

The first stoker-fired core ovens were installed soon after 1900 and were fired by underfired or similar stokers. The stoker setting was introduced in place of the usual fire box and the products of combustion conducted to the oven by flues, such as those shown at the back of the oven in Fig. 9.1. Later stokers were introduced into settings similar to that shown in Figs. 9.2 or 9.3. In these cases, auxiliary air can be introduced into the flue beyond the fire.

An arrangement used to convert hand-fired ovens to stoker-fired, recirculating ovens is shown in Fig. 9.5. In this case, two ovens, 6 ft wide, 13 ft deep, by 7 ft high, were coke-fired from a fire box below the floor at *A*. Before taking out the old fire box, the stoker setting shown was constructed behind the ovens.

The stoker setting proper was surrounded by an air jacket. Fresh air entered at ground level at the front of the oven at *B*-*B*1 through damper-controlled openings. This air passed up the outside of the fire box and united with the products of combustion passing through openings in the fire box arch over the stoker fire. The gases then passed to the rear where they united with return gases from the oven and the blend was blown into the oven by the fan *C*.

The old inlet flue from the original fire box, *D*, became the oven outlet flue. Part of the gases passed through a damper controlled opening at *E* and upward behind the fire box to blend with the hot gases and enter the fan *C*. The remainder of the gases leaving the oven passed in the opposite direction in flue *D* to the base of a stack placed where the old fire box had been at *A*. A venturi section and small, high pressure fan (not shown) insured the proper exhaust up the stack and a damper controlled its volume.

A second stack, *F*, was placed over the stoker fire box to take off the smoke when the fire was first started. The damper in this stack was closed when the oven was in use. The stoker hopper is shown at *G*.

The hot gases from the fan *C* entered a metal flue across the back of the two ovens and were distributed along the sides of the ovens through four flues, *H*, the distribution of gases being controlled by dampered outlets in the flues. The doors for taking out the ashes are shown at *I*.

Gas-Fired Ovens

When gas first was used, burners extending the entire length of the oven were installed along the floor. However, such burners could not be regulated automatically. Then, too, the flame frequently damped off at the back of the oven and let raw gas accumulate, resulting in explosions and wrecked ovens.

As long as the temperature of the circulating gases was well above 212 F (100 C), the presence of water in the gases, in the form of steam, was of no detriment. Hence, to conserve heat and to give a more rapid circulation, several ovens were built in which a large volume of the gases were returned to the flue, entering the oven at a point beyond the fire box. As long as the laboratory personnel regulated the ovens they gave good results. When oven regulation was left to the oven tenders, they would not follow directions or got ideas of their own and tried to do still better. They would try circulating too much of the return gases and the lack of oxygen slowed down the drying of the oil cores.

In many cases, because of lack of proper control, the recirculation of gases was impractical until automatic control equipment was perfected for oil and gas. The innovation, where heat is obtained from outside heater units, meant further progress and required automatic control.

Drawer Ovens

Small drawer ovens for baking both cores and bread were being made by several firms over 45 years ago,

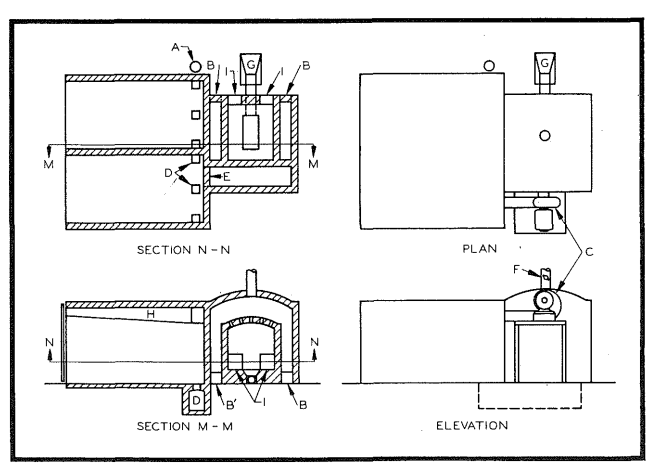


Fig. 9.5 — Arrangement for converting hand-fired to stoker-fired recirculating oven.

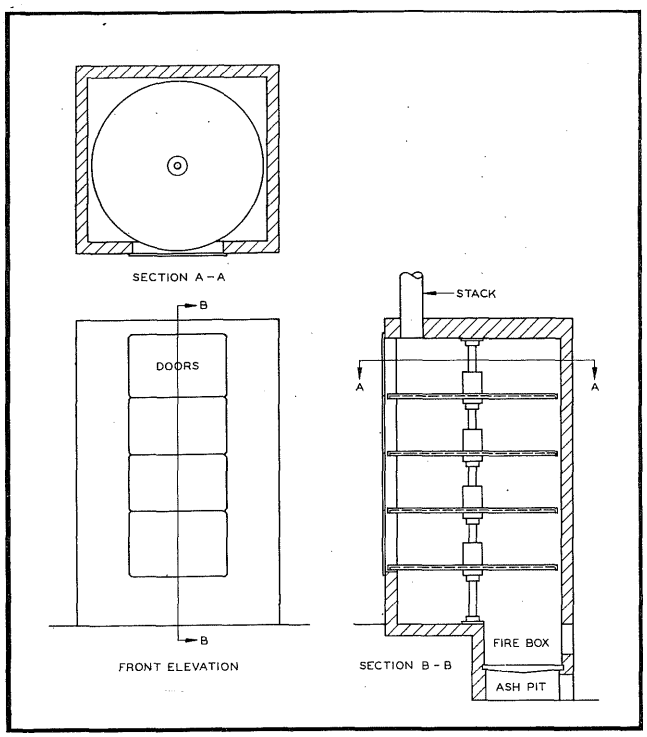


Fig. 9.6 — Design of early reel core oven.

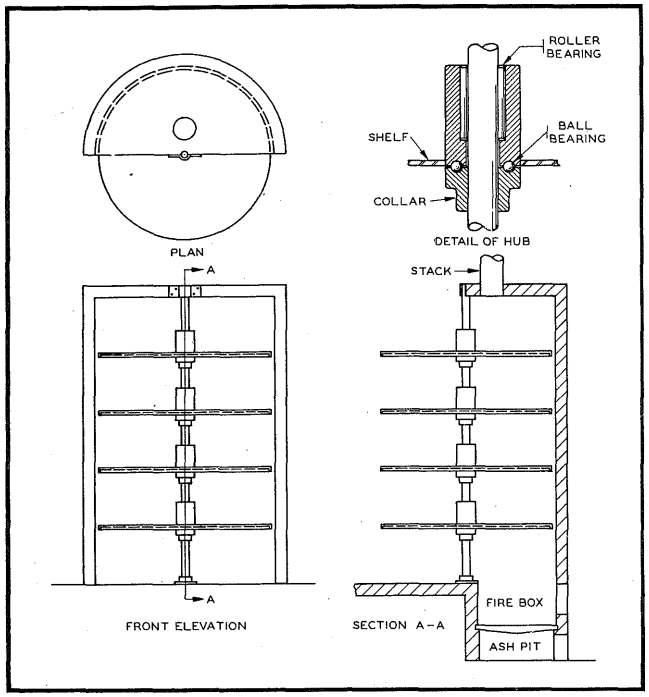


Fig. 9.7 — Improved reel core oven.

but the temperatures varied from 40 F (22 C) to over 100 F (55 C) between the top and bottom shelves. All of the original ovens were car ovens, carry in ovens with stationary shelves inside, or ovens with hinged metal doors to give access to shelves.

The drawer oven first appeared about 65 years ago, and about the same time, the quadrant swinging shelf came into use. Then came two types of reel ovens. The first were brick ovens with a vertical shaft in the center and a series of round shelves that could be turned (see Fig. 9.6). The reels were turned by a simple wrench that gripped the outer rim.

Next came the so-called improved reel oven as shown in Fig. 9.7. The back wall of the oven was of brick and followed the back half of the shelves so as to have no unused space in the oven. As in the type shown, the fire box was below the floor and the fuel was coke or anthracite coal. In the center was a tall shaft that carried a roller bearing and the shelves rested on ball bearings supported by collars, as shown in the detail. These ovens were rather efficient in comparison with the old carry in ovens.

Drawer, reel and carry in ovens necessitated a great deal of walking to get the cores into and out of the oven. In the early type car ovens, no baking was in progress when the cars were withdrawn for unloading. To overcome this difficulty, transfer cars or turntables and tracks were installed so a car of baked cores could be taken out and another car run into the oven. All of this required a fixed pattern of production and lacked flexibility.

Rack and Reel Ovens

To overcome this deficiency, an attempt was made about 1905 to use racks about 5 ft square with four casters so they could be run from the coremaker to the oven and from the oven to the cooling and stripping space. But at that time, no casters were on the market that would withstand such service.

The lift truck had just been invented and soon it was applied to handling core racks to and from all parts of the core department. In baking cores it is important to reduce individual handling of plates to a minimum to avoid unnecessary labor and the chance of core breakage.

In drawer ovens, the common practice was to have the coremaker put the cores on a plate, transfer the plate to a rack near the oven and from the rack take the plate to the oven. After baking, the plate was removed from the oven, on a cooling rack, taken to the core cleaning and inspection space, and finally, the empty plate was returned to the coremaker. This represented six individual plate handlings and a lot of walking. In one core room, it was found that 28 miles per day of walking could be eliminated by the lift truck, rack system. In some cases, the use of lift truck racks or mechanical carriers eliminated as much as 75 per cent of the handling labor in the department.

Figure 9.8 shows a battery of four lift truck rack

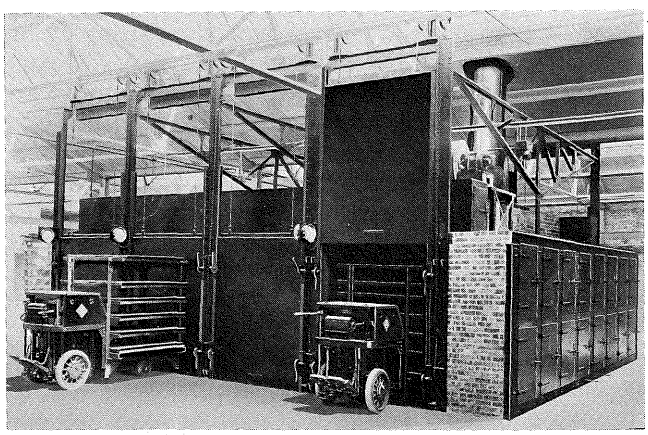


Fig. 9.8 — Rack oven installation with set in section for drying pasted cores.

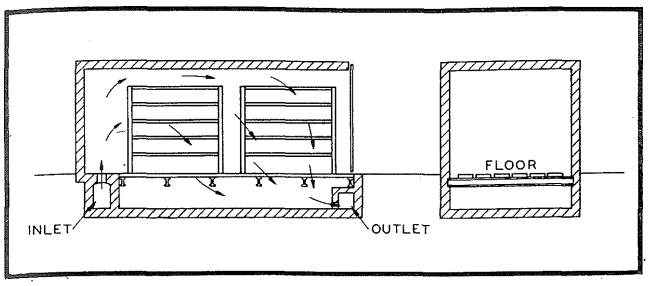


Fig. 9.9 — Diagram of mezzanine floor core oven.

ovens with a set-in section on the right for drying pasted cores. This section consisted of inside shelves with small insulated doors.

When the rack oven was being developed many trials were made to determine the best oven depth. An oven to take a single rack was far more costly than one for two racks in tandem, as the door and back wall, together with inlet and outlet flues, cost the same for one as two racks. The only additional expense was for floor, walls and roof for the additional length necessary for the second rack. Running the lift truck in far enough to get the second rack was found to involve no difficulty from oven heat. However, manufacturers ever on the lookout for further improvement in oven performance, experimented with three rack depth ovens.

When ovens of sufficient depth to accommodate three or more racks were tried, the heat of the oven made it difficult to change more than two racks and the extra time that the door was kept open resulted in a waste of heat and made smoke in the core room. Hence, ovens of two rack depth became standard.

Mezzanine-Floored Ovens

Even with forced draft, auxiliary air and a much more rapid circulation through the oven, it was found that there still was a marked return circulation along the floor toward the back of the oven. This led to the patenting of the mezzanine-floored oven as shown in Fig. 9.9.

In this arrangement, the floor of the oven proper was dropped about 30 in., in the case of a two rack oven, and a metal floor was constructed on the level of the core room. The heat came in at the rear as formerly, and rose at the back of the oven entering the racks. As the gases became colder and heavier, they settled to the floor and passed through the perforated metal mezzanine floor to the space below. The outlet was into a flue with openings at the level of the floor of the space under the front of the oven. As the gases settled in the space below the mezzanine floor, they tended to flow to the front. If the relation between the depth and length of the space under the floor is properly proportioned, the gases will not return to the back and recirculate in the oven. The result was that all the cores in the rack were properly dried, the baking time shortened, and the output increased about 15 per cent. With the rack type system, each coremaker worked at his own pace and always had a place to put his cores. The mezzanine-type oven was a distinct advance in design.

Continuous Ovens

With the advent of mass production in the foundry industry, and the resulting necessity for increased core room capacity, continuous movement of cores through the operations of making, baking, cooling, pasting and delivery to molders was suggested by progressive foundry engineers. This method was in keeping with the continuous transportation of molds already adopted.

An early type of continuous core oven conveyor, shown in Fig. 9.10, was successful enough to justify the idea that cores could be baked by continuous process. This type of oven was of brick and employed two sprockets with a conveyor chain placed above the oven. Slots through the roof of the oven permitted the suspension member connecting the trolley to the core rack to follow the travel of the chain.

The following objections were found in this design.

(1) Enormous heat loss due to slots in the roof of the oven and lack of heat seals at entrance and exit.

(2) Oven occupied useful floor space.

(3) Loading and unloading spaces limited.

(4) Insufficient cooling time.

(5) Transporting green cores due to inability to group coremakers adjacent to loading point.

The design which was offered to overcome some of these objections is shown in Fig. 9.11.

For a continuous oven to be successful, the following conditions must be met.

(1) Adequate and accessible loading space.

(2) Ample baking time.

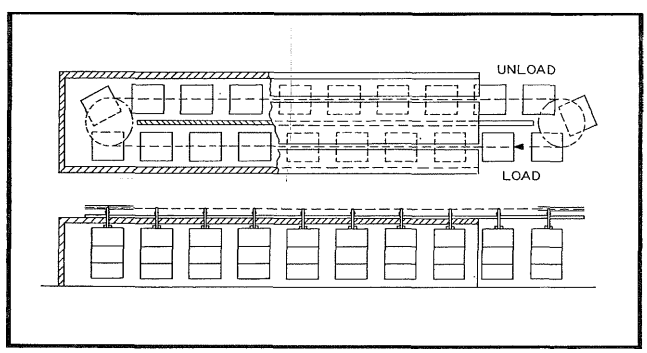


Fig. 9.10 — Early continuous core oven.

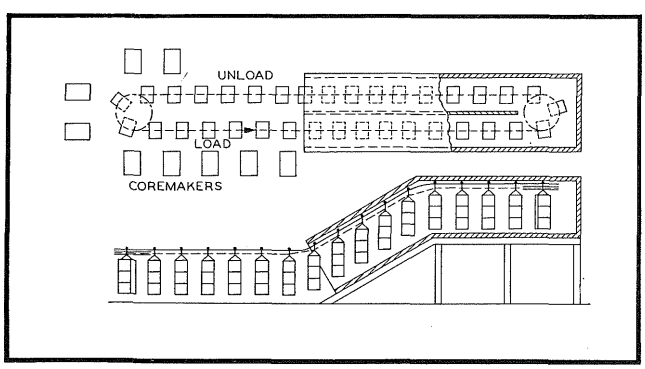


Fig. 9.11 — Horizontal core oven designed to overcome difficulties of oven shown in Fig. 9.10.

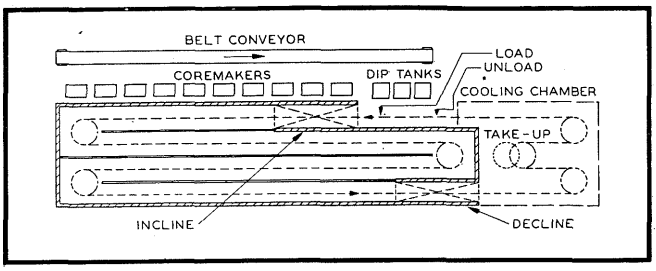


Fig. 9.12 — Layout of large horizontal core oven designed to serve bench coremakers.

(3) Sufficient time and apparatus for cooling.

(4) Well located unloading position.

(5) Produces cores economically.

An oven which illustrates all of these features is shown in Fig. 9.12.

This conveyor makes four passes through the length of the oven. As the conveyor leaves the oven, it passes through an enclosed cooling chamber. This chamber completely surrounds the drive and takeup mechanism, and is supplied with the necessary fans for directing a blast of air on the cores. The cores are cooled to a temperature so that they can be unloaded with the bare hands.

Cores, together with their plates, are placed on a gravity conveyor extending the length of the oven. Cores are unloaded, classified and stored on racks or transported to the foundry. The plates are returned to the makers' benches from the gravity conveyor. The makers' benches are located adjacent to the oven.

MODERN CORE OVENS

The types of modern core ovens fall, in general, into five classes, depending on the method of handling the work. Those classes are (a) shelf ovens; (b) drawer ovens; (c) portable rack ovens; (d) car ovens; and (e) conveyor ovens.

Shelf Ovens

Shelf ovens form perhaps the simplest type of oven construction. These ovens generally are limited to the baking of small cores, particularly in small core departments where the owner desires to keep the investment in oven equipment to an absolute minimum. In operation, the core plates carrying the cores are placed directly in the oven on shelves. The ovens are equipped with one or more doors which, when opened, expose part or all of the shelves.

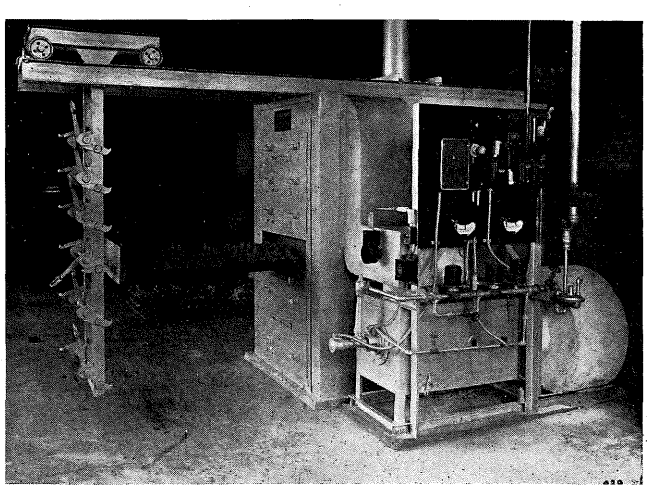


Fig. 9.13 — Typical rolling drawer core oven with gas-fired external recirculating heating system. The oven is also equipped with automatic control and protective devices against hazard due to flame, power or mechanical failure.

In opening an oven door, a large amount of heat escapes and the operator is accordingly exposed to a rush of gases from the oven chamber. Therefore, this type oven is wasteful of fuel and provides undesirable working conditions. Except for limited requirements, this type of oven has been replaced largely by the more efficient drawer ovens.

Drawer Ovens

A modern rolling drawer core oven installation is illustrated in Fig. 9.13. With ovens of this type, one or more drawers can be withdrawn for loading or unloading. The drawers are equipped with rear closing plates which prevent the escape of heat and gases when the drawers are withdrawn. Within the oven, the drawers are supported at the rear end by frictionless differential rollers which require no lubrication. The front end of the drawer is supported by an overhead drawer-puller with selective operating arrangement to permit engagement of any one or combination of drawers.

In modern ovens of this type, special attention has been given to the mechanical construction to provide smoothness and freedom from vibration in operation so that most delicate cores can be handled without danger of breakage or distortion.

From the standpoint of floor space occupied, a well designed drawer oven provides an efficient means for baking small and medium cores. For most efficient operation, a drawer size should be selected which will best suit the size of core plates being used.

A limitation in the use of ovens of this type is that the cores must be transported from the coremakers to the ovens, and after baking from the ovens to finishing or storage. Where coremakers can be grouped relatively close to the ovens, the item of transportation labor is more than offset by the general efficiency in operation of this type of oven. Figure 9.14 shows a battery of four drawer core ovens equipped with a recirculating heating system.

Rack Ovens

In many foundries, the transportation of the cores from coremakers to ovens and from ovens to finishing operations or storage is a very important item. The portable rack system of operation affords an important means of reducing transportation cost. The cores are loaded directly on steel racks by the coremakers and the loaded racks are then moved by lift trucks, either hand or power-operated types, to the core ovens. A variation of the portable rack system is the use of an overhead monorail system to transport the racks.

Ovens of the portable rack type generally are designed to take either one or two racks per oven, although the ovens may be constructed to hold a larger number of racks. Ovens of single or double rack ca-

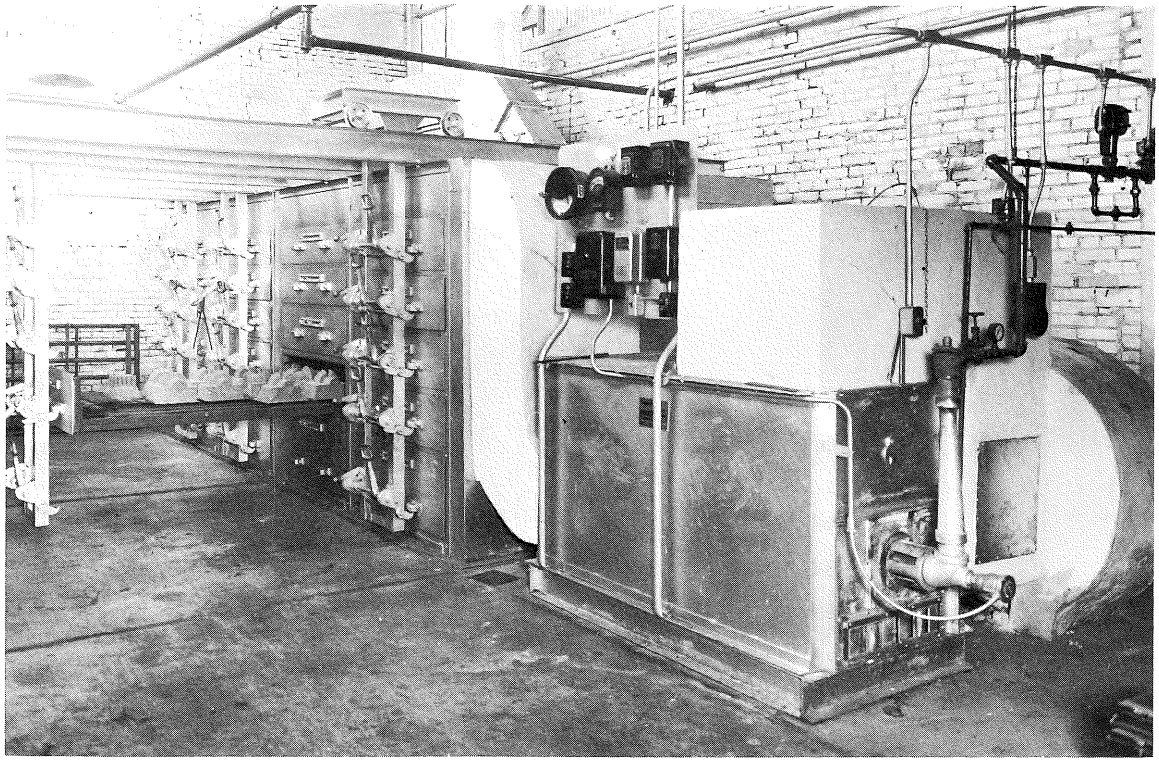


Fig. 9.14 — Battery of rolling drawer core ovens equipped with recirculating heating unit.

pacity permit a faster turnover and greater flexibility than ovens containing multiple racks.

The racks generally range in size from 3 ft wide x 5 ft long to 5 ft wide x 7 ft long. The racks should be of rugged construction to prevent wabbling, yet should have a minimum excess weight to eliminate unnecessary heat requirements. Figure 9.15 shows a battery of rack ovens in operation.

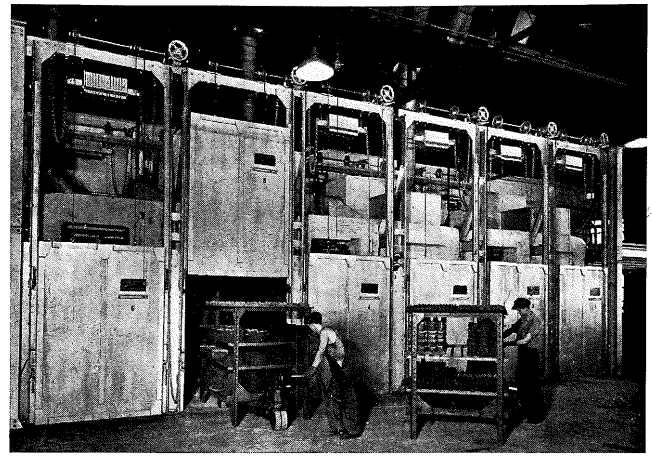


Fig. 9.15 — Battery of rack core ovens in operation.

Car Ovens

For large cores, car ovens generally are used. Due to the size of the work handled, cores usually are loaded by crane. Since a considerable portion of the day is required to load the cars, this type is considered as an over night oven. However, for more than single shift operation, several bakes per day are possible, depending upon the size of work.

To speed loading time and to obtain faster turnover of the oven equipment, a transfer car may be used in conjunction with an extra oven car. Tiering skids may also serve to reduce loading and unloading time. Figure 9.16 shows a car core oven installation while Fig. 9.17 illustrates the tiering method of loading core cars.

Conveyor Ovens

While at one time the use of conveyor ovens was limited to highly specialized production, continuous ovens now are obtainable in many sizes and capacities to suit a wide range of operating conditions. The ideal situation is where cores of approximately the same size can be baked in one oven. Therefore, if the requirements warrant the installation of several continuous ovens, each oven may be timed to do an efficient job. However, small and medium cores may be safely baked together. Even heavy work can be baked in the same oven by permitting the extra large cores to make a second trip through the oven.

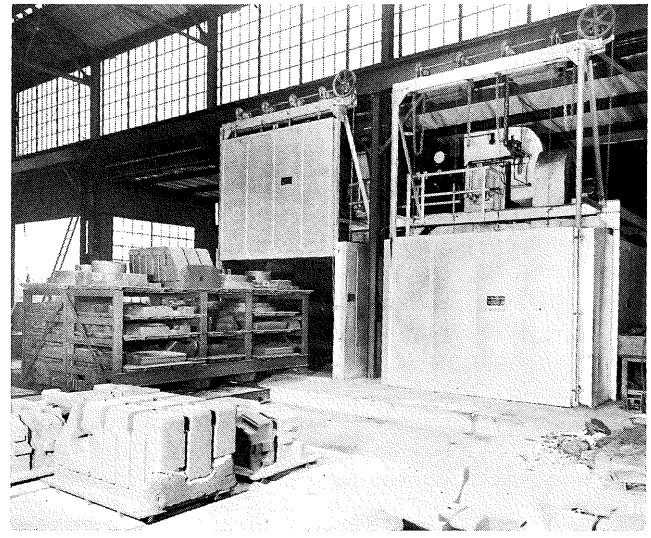


Fig. 9.16 — Large car core oven. Note transfer car and transfer pit to permit loading or unloading of spare car while ovens are loaded.

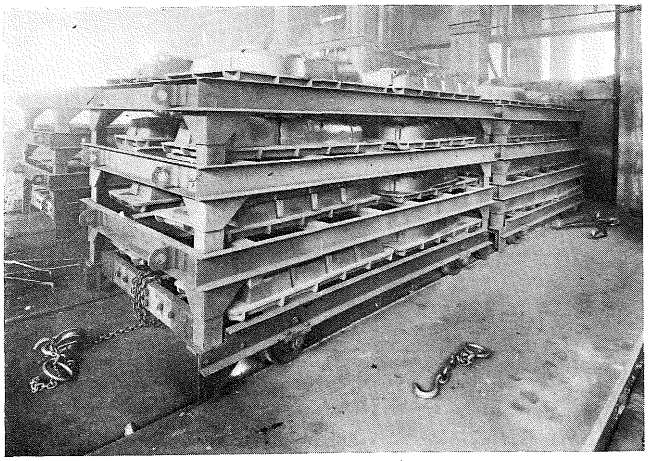


Fig. 9.17 — Core oven car equipped with tiering skids. Such an arrangement facilitates varying core oven loading requirements.

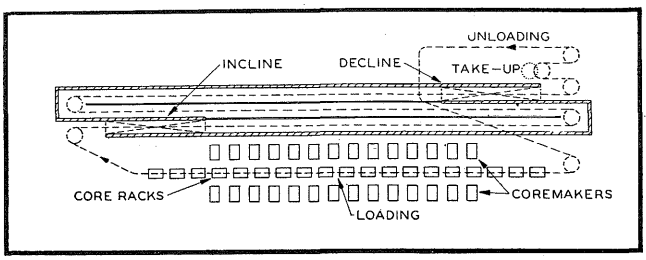


Fig. 9.18 — Layout of large modern continuous core oven.

Continuous ovens are largely of two types — vertical and horizontal. A combination of these two, with various modifications, can be obtained to meet special building conditions or operating requirements.

The vertical conveyor ovens have the advantage of saving in floor space. The coremakers may be grouped close to the oven with a large amount of work produced in a relatively small area.

Where the number of coremakers is too great to permit efficient grouping around a vertical oven, the horizontal type oven offers certain advantages. The conveyor carrying the core racks is arranged to pass between long groups of coremakers so that the various coremakers have but little distance to walk to dispose of their work.

Horizontal Ovens

The first oven of the horizontal type occupied a comparatively small floor space, due to the kind of cores produced. It was designed for cores requiring a short baking time. By making the length of the conveyor outside of the oven of sufficient length to include cooling period and unloading space, together with the space around which the coremakers were grouped, the objections found in the oven shown in Fig. 9.10 were overcome.

The inclination of the entrance and exit of the oven formed the heat seals. This construction required the use of sheet metal ovens instead of brick. Placing the conveyor in the oven eliminated the slots in the roof and reduced heat losses to a minimum. A large oven of the horizontal type is shown in Fig. 9.18.

Advantages claimed for horizontal continuous core ovens are listed.

(1) **Saving in floor space.** Space underneath the oven may be used for core or rack storage, sorting, filing, fitting, blacking, pasting or inspecting cores, etc. The ovens in many cases are supported above roof trusses, keeping the floor clear of supporting columns. Installations have been made where the oven extends over an areaway between buildings.

(2) **Labor saving.** With a conveyor located adjacent to coremakers' benches, the time spent in walking to and from distant racks is eliminated. The labor used in transporting racks from the makers to the oven is entirely dispensed with.

(3) **Reduced core breakage.** With the smooth operation of the oven conveyor, core breakage is negligible.

(4) **Uniformity of product.** With each rack load of cores receiving the same baking and cooling time, the product will be uniform.

(5) **Working conditions.** Heat is confined in the sheet metal oven with insulated walls and heat seals. With this construction, a comfortable temperature can be maintained in the core room.

Horizontal core ovens are used for both baking cores and for drying pasted or washed cores. Figure

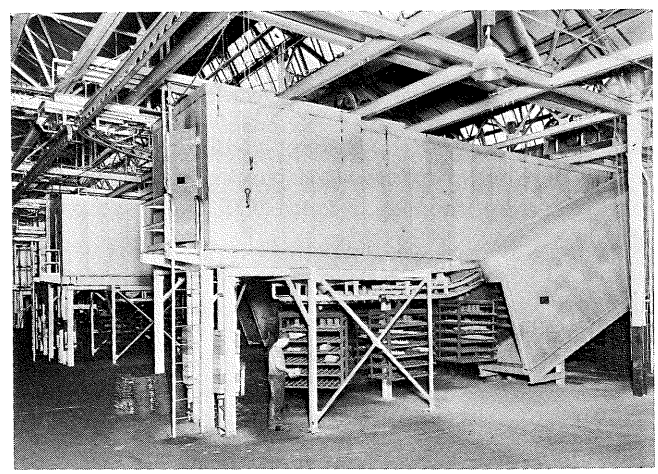


Fig. 9.19 — Battery of horizontal conveyor core ovens in a large automotive foundry.

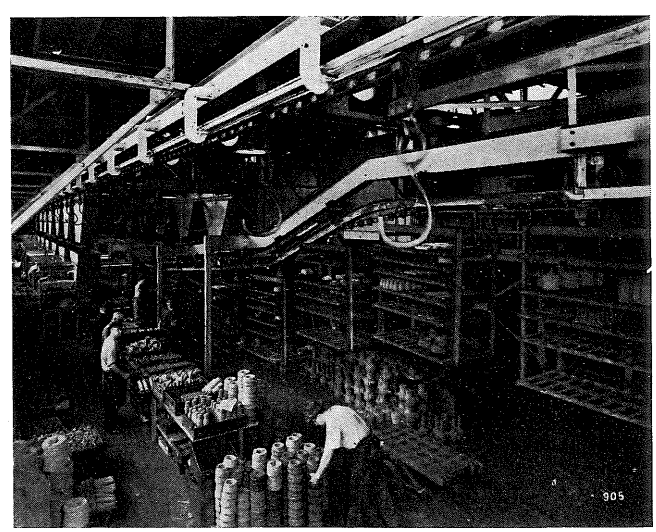


Fig. 9.20 — Unloading station of large continuous horizontal conveyor core oven with coremakers' stations in the background.



Fig. 9.21 — Horizontal core oven for drying pasted and washed cores.

9.19 shows a battery of horizontal conveyor core ovens in a large automotive production foundry, while Fig. 9.20 shows the unloading end of such an oven with the coremakers' stations in the background. Figure 9.21 shows a horizontal conveyor oven for redrying cores after pasting or washing.

Vertical Ovens

Due to architectural limitations of present core rooms, nature of the product and other limitations, the vertical oven has met with the approval of a large number of plant owners and operators. The vertical oven is used to advantage for: baking small cores; drying cores after blacking; and drying cores after pasting.

The limitations of the vertical oven for baking cores are based on the requirements noted under the heading *Continuous Oven Requirements.*

Numerous advantages are claimed for such ovens. A sketch of a vertical oven is shown in Fig. 9.22. It is said that vertical continuous core ovens require small floor space; give uniform and rapid baking with elimination of any burning; increase core production; have low fuel consumption; save in core oil; eliminate trucking; and eliminate fumes, smoke and gases in the core room.

The oven shown in Fig. 9.22 occupies a floor space 12 x 15 ft, and is 73 ft overall height of which 11 ft is below the floor level. Cores are carried on shelves 36 in. wide and 8 ft 4 in. long. The shelves, spaced 24 in. apart, are mounted two to a carrier. The carriers on 66 in. centers are supported by continuous chains on each side which ride on two 120 in. pitch diameter sprockets in the head shaft.

The total number of carriers is 26. Cycle is divided in the oven into a 3 hr baking period and a 1 hr cooling time. A baffle divides the oven into two separate sections to accommodate those periods. In addition to the baffle, a proper static balance is maintained in the oven to insure that no cooling air is drawn into the baking section.

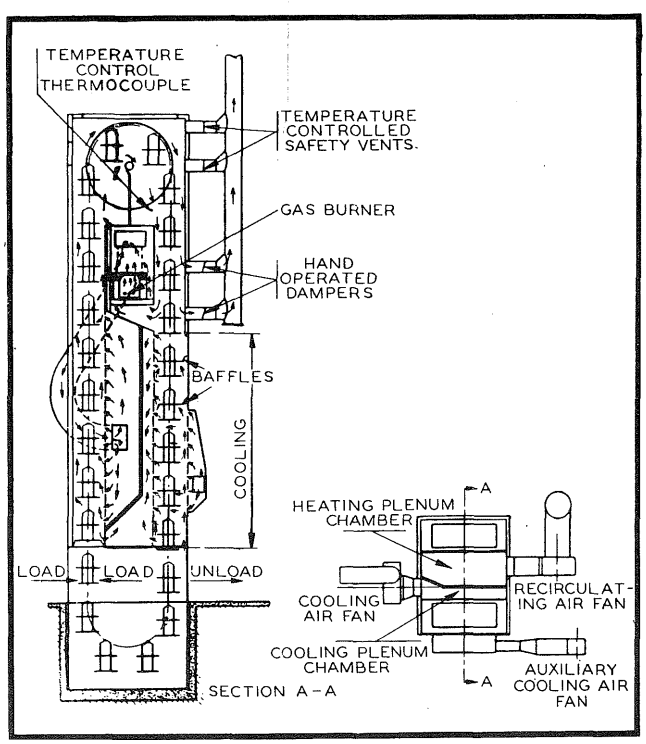


Fig. 9.22 — Diagram of vertical core oven showing travel of various heating and cooling currents.

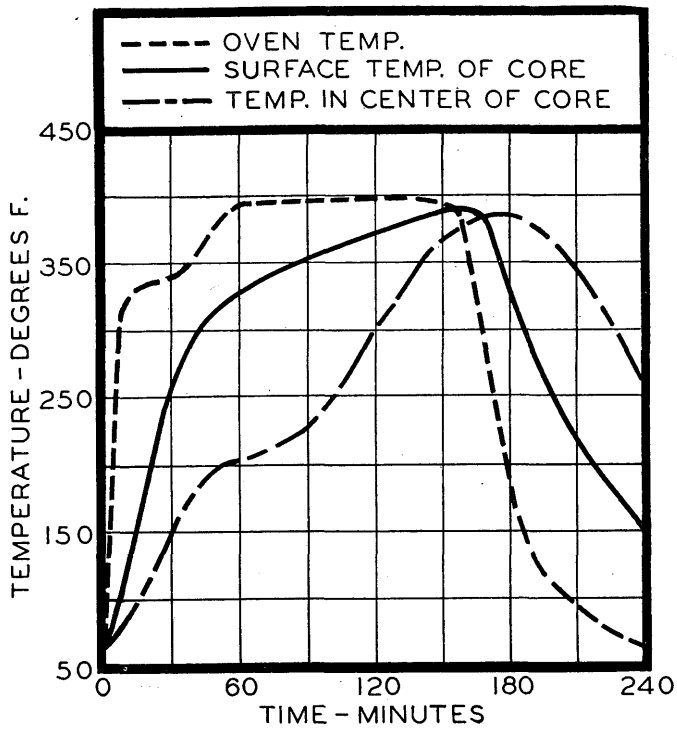


Fig. 9.23 — Time-temperature curve showing conditions in oven and cores in the vertical core baking oven in Fig. 9.22.

The heater for this particular oven is gas-fired and of the recirculating type. It is located approximately at the top of the cooling section, and is a semi-external type arranged so that no radiant heat enters directly into the oven. The heating gases are carried down to a series of ports beginning about 4 ft above the loading station, and extending up about 30 ft. By that arrangement, the gases travel parallel to the core movement. Heat is obtained from two inspirating type burners, and control of the burners is through a full floating valve which is actuated by a potentiometer controller. The thermocouple operating the potentiometer is located slightly above the intake to the combustion chamber.

As a further protection to insure that the hot gases entering the oven are never higher than desired for proper operations, a thermocouple is located in the delivery duct. That couple actuates a potentiometer controller which in turn operates a safety gas turndown valve. Temperature of the oven is maintained at 400 F (204 C) within plus or minus 2.5 F (1.4 C). Cooling occupies one hr, and the section of the oven devoted to that phase is cooled by drawing air up through the downtake shaft by an exhaust fan which discharges into the atmosphere.

A series of baffles forces the cooling air to travel around the cores, and in addition the cooling air can be passed across the trays during the last 20 ft of travel. The latter is used only in summer or during heavy loading when additional cooling is required. Chain travel is intermittent, and is controlled by a limit switch actuated by the trays and a repeating electrical timer which can be adjusted for any cycle that is desired.

Intermittent chain travel permits the core shelves or trays to be stationary and level during the loading period. The trays are quiescent for a period of 5 min and 45 sec during the present 4 hr cycle, and 15 sec is required for one shelf to move up and another to locate in position for loading. A heating and cooling curve taken in the oven is shown in Fig. 9.23.

Figures 9.24, 9.25, 9.26 and 9.27 illustrate various points of interest in connection with the use and installation of vertical core baking ovens. Figure 9.24 shows a battery of such ovens in a large malleable iron foundry. Figure 9.25 illustrates one method of grouping the coremakers around a vertical oven so that they have easy access to it. Such an arrangement also eliminates long distance of travel to place cores in the oven. Note the center passageway at the loading and unloading station. Such construction permits loading the oven from the center as well as the outside. A better view of this type construction is shown in Fig. 9.26. Figure 9.27 shows an unloading station of a vertical core baking oven.

A simple, vertical, gas-fired, continuous oven for drying assemblies of pasted cores is shown in Fig. 9.28. The cores are assembled and pasted on the assembly conveyor shown in the foreground. They pass up and down through the oven for paste drying. In other cases, a horizontal oven encloses part of the assembly conveyor but this arrangement takes up valuable floor space.

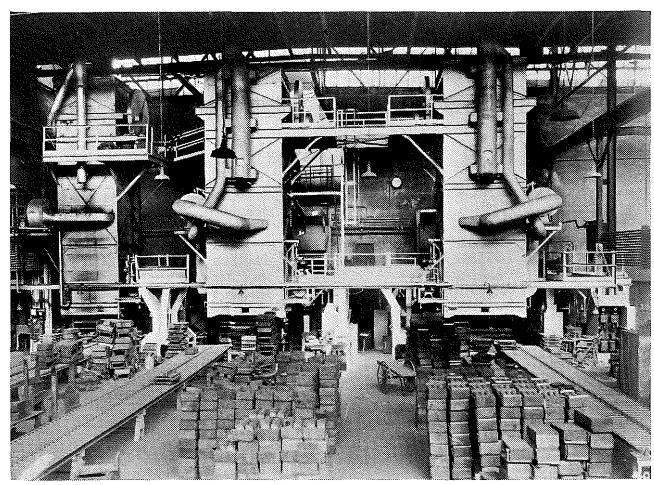


Fig. 9.24 — Battery of vertical conveyor core ovens in a large malleable iron foundry.

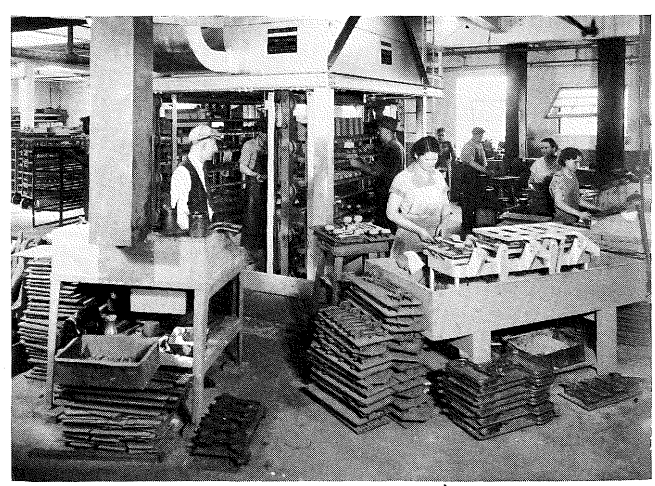


Fig. 9.25 — One method of grouping coremakers around a vertical oven.

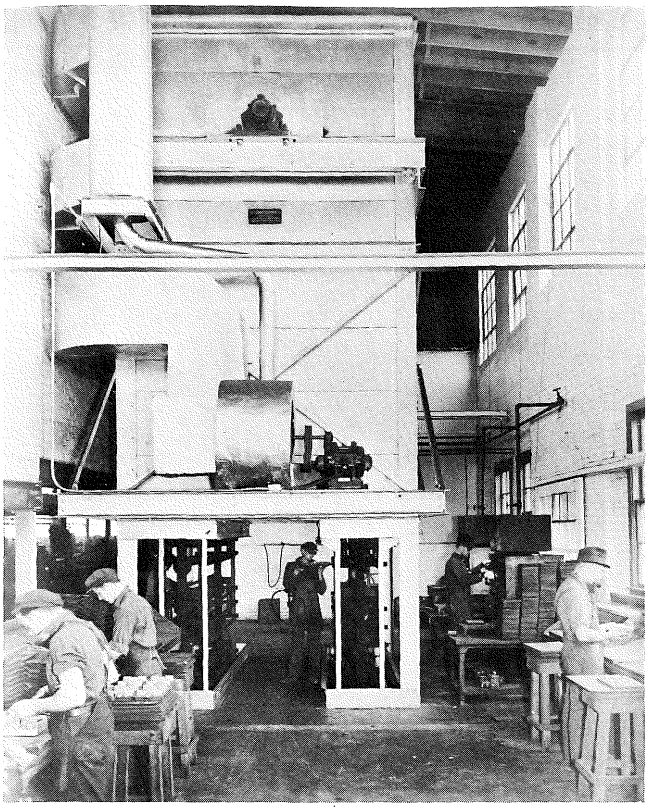


Fig. 9.26 — A central passageway at the loading and unloading stations permits these operations to be performed from either the inside or outside.

Combination Vertical and Horizontal Ovens

A much more elaborate oven is shown in Fig. 9.29. In this case, the coremakers work on each side of the conveyor from *A* to *B*. The core racks pass up into the oven through a seal at *C*. To avoid too great height and at the same time to get the required capacity, two vertical sections were used, as shown. The racks pass up at the left, down in the center, and up and down again. At *D*, the racks enter a horizontal cooling section. At *E*, they pass down to the take-off or stripping section which extends to *A*.

When installed, individual gas burners were arranged to give differential temperatures. The cold, damp, incoming cores were received in a section much hotter than the average baking temperature maintained further on in the oven. The oven used 650 Btu gas and was guaranteed to dry one-half pound of sand per cubic foot of gas. When properly adjusted, it produced twice as much. Later, 900 Btu mixed gas became available. At this time, large outside heater units were built and the recirculation principle was used. The result was a very marked increase in the amount of sand dried per cubic foot of gas. But it naturally varied as the ratio between sand and metal varied with the different runs.

In many continuous ovens, the coremakers load the cores directly into the ovens. In large production units, this generally can be worked out, but in many cases, and particularly where the cores vary in size and height, it pays to install a carrier to take the cores from the coremaker to the loading point of the oven. The handling of cores in a core room is discussed in Chapter 12, CORE HANDLING.



Fig. 9.27 — Unloading station from a vertical conveyor core oven.

In many cases, a set-off station is provided at the loading point where high or large cores can be held a few minutes until a proper shelf arrangement in the oven comes opposite the loading point. In the case of steel foundry practice, it is common to arrange to spray the cores on the conveyor that brings them to the oven and generally the man attending to the loading does the spraying.

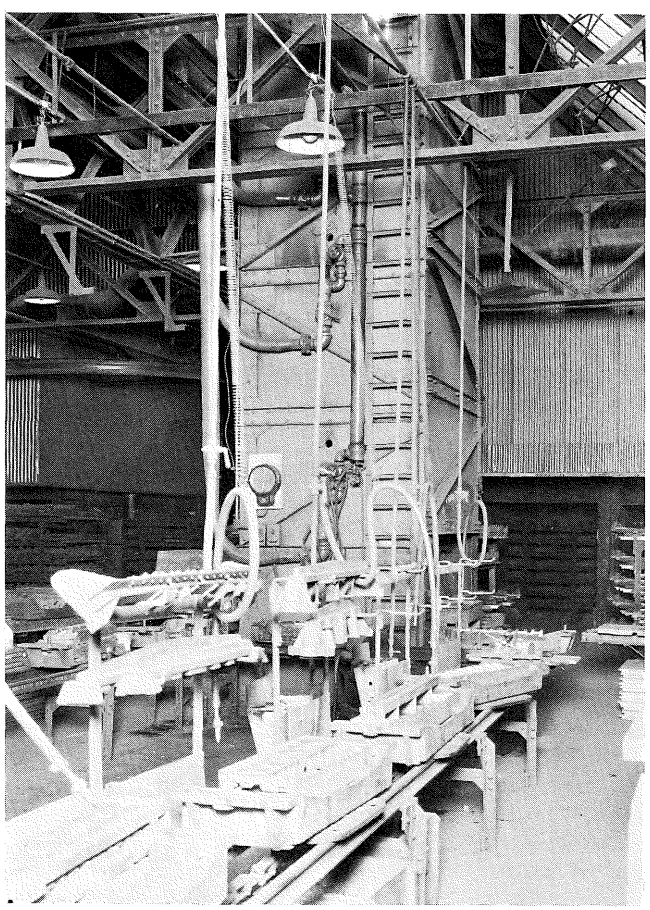


Fig. 9.28 — Continuous vertical core oven for drying pasted cores.

The entry and exit points of continuous ovens can be sealed by vestibules in which the walls of the oven come close to the outline of the racks as in Fig. 9.30, or by the gravity seal in which the carrier takes the racks up an incline into an elevated horizontal drying chamber at a higher level. In this case, the natural tendency of heat to rise is depended upon to seal the oven.

Steam-Heated Ovens

Steam-heated core ovens are used in some cases with good results. Table 9.1 shows oven temperatures generated by steam under various pressures.

One plant operating a continuous molding unit did not want to dilute the system sand with core sand and so used a system sand bonded with a little clay wash and glutrin. Dry sand mold parts were used as cores. They were dried in ovens in which the plates were set directly on steam coils using 75 psi steam or 320 F (160 C). The cores were very soft and had to be handled with great care but cleaned nicely, leaving very smooth holes, and the problem of core sand entering the system sand was eliminated.

A plant making magnesium castings uses a 500 psi pressure boiler, giving about 470 F (243 C) in the pipes, which are arranged in the space below the floor

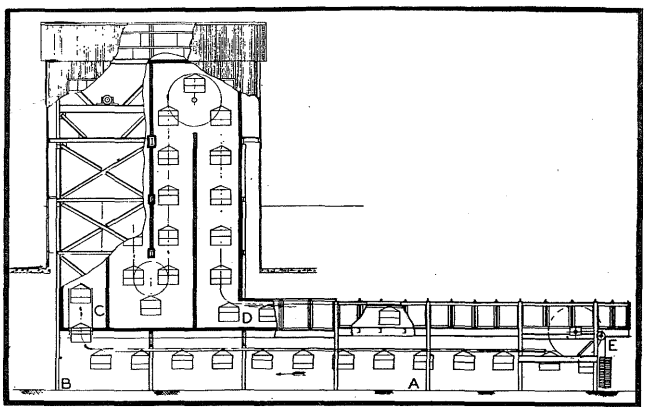


Fig. 9.29 — Layout for combination horizontal and vertical gas-fired continuous core baking oven.

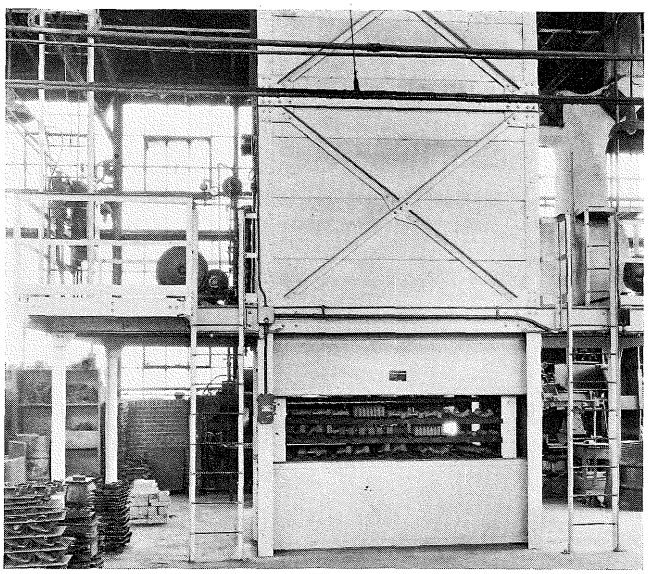


Fig. 9.30 — Gravity seal continuous vertical core oven.

TABLE 9.1 — OVEN TEMPERATURES GENERATED BY STEAM

Steam Pressure psi	Temperature Generated F	(C)
75	320	(160)
100	338	(170)
275	400	(204)
405	450	(232)
500	470	(243)

of the oven, and a forced circulation of gases is maintained by a fan and proper pipes or ducts.

In another plant a standard, steam, bread-baking oven is used. In this oven, a series of special steel pipes is used and a certain amount of liquid is sealed in each pipe. One end of the pipe extends through the oven wall to the fire box. By controlling the volume of the liquid in relation to the volume of the tube, they arrive at a point where, when all the liquid is vapor or steam, there will be a certain pressure with a corresponding temperature. The tubes are placed on an incline. The vapor passes up into the tube in the oven, but when heat is given off, part of the vapor is condensed and flows to the lower end of the tube over the fire, where it is again vaporized and sent up the tube. The amount of condensation is proportioned to the heat given off and so the process is self regulating. These ovens are more expensive than some other types but there is no danger of burning cores and a given core sand-binder ratio always gives the same results. All steam ovens are said to be free from burned core problems.

Core Oven Unit Heaters

About 1925, a Chicago company introduced an efficient unit heater for either oil or gas. It consists of a metal chamber with insulated walls. The two ends are bolted in place so that either end can be removed easily. The burner is arranged in the center of one end. In oil firing, the combustion chamber is refractory lined so a high temperature can be maintained to insure proper combustion. In gas firing, the gas flame enters directly into the center of the chamber and, in most cases, two inclined flames are used, the tips of the flames meeting in the center.

In all cases, a large volume of products from the oven are recirculated in such a way that the return gases surround the oil or gas burners. The return gases from the oven surround the products of combustion entering the mixing chamber and both are mixed with a certain amount of fresh air to introduce sufficient oxygen to insure the oxidation and hardening of the oil in the oil-sand cores. At the end of the mixing chamber, there is a baffle and a fan that forces all of the gases back to the oven. Either head can be taken off if it is necessary to repair or inspect the fan or the burner.

A separate heater unit, such as shown diagrammatically in Fig. 9.31, and installed in Fig. 9.32, can be applied to an old brick oven, a continuous oven or a new metal oven. The use of a rapid circulation insures the forcing of the heat to all parts of the oven and a more rapid drying rate.

Location of Oven Vents

In natural draft ovens, it was found best to take the

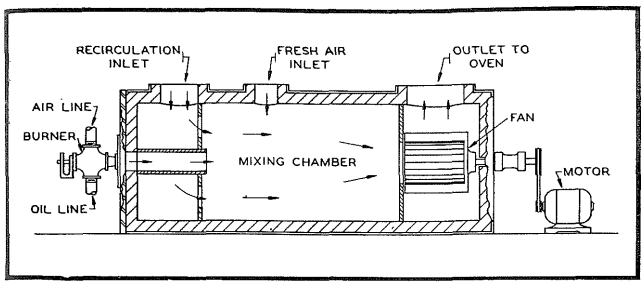


Fig. 9.31 — Diagram of separate heater unit for core oven.

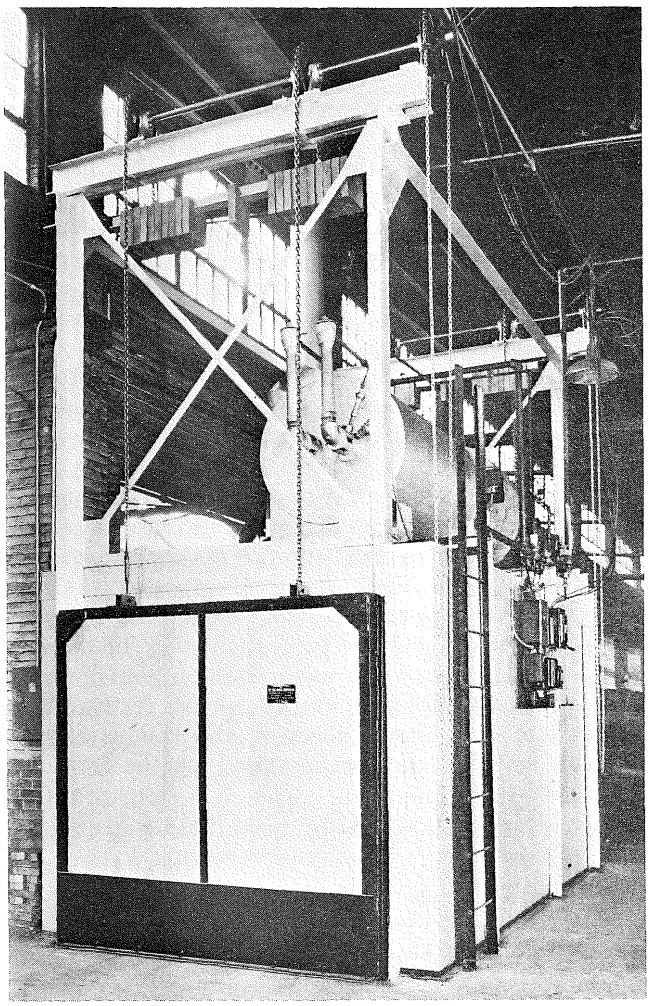


Fig. 9.32 — Installation of separate heater unit.

vent from the bottom of the oven. In the forced recirculation ovens, it has been found efficient to introduce the hot gases at the bottom and to take the vent and the recirculation gases from the top of the oven as shown in Fig. 9.33. It is probable that this reversal of the natural trend of the gases helps to give a more searching circulation into all parts of the oven as the gases are forced upward.

Efficiency

From the viewpoint of construction, modern core ovens are vastly improved over the first ovens introduced. The older type brick ovens hardly can be compared with the modern, metal-walled, insulated, controlled ovens. Many of the older type ovens suffered seriously from leakage. One instance is recorded where the leakage was so bad that a strong wind in the proper direction slowed down the operation of the oven to the point that it was necessary to double the usual baking time. Metal walls and insulation have eliminated leakage to a large extent.

The introduction of insulating materials into core oven construction increased the efficiency and reduced operating costs. In uninsulated ovens, of the coke-fired natural draft type, one pound of coke would bake from 3 to 6 lb of cores. Today, coke-fired ovens will bake up to 50 lb of cores per lb of coke. With 800 to 1000 Btu gas, it is possible to dry over 2 lb of cores per cubic foot of gas and in oil-fired ovens, up to 100 lb of cores per lb of oil.

Of course, all this increase in efficiency has not been due to insulation alone. Ovens today are better designed and heating equipment efficiency has been increased tremendously. In addition, great strides have been made in the use of control instruments, which have further increased oven efficiency and decreased operating cost.

FUELS

To meet present-day requirements of good control, accurate and uniform temperatures throughout the baking chamber, rapid heating up and fast baking, correct atmosphere and proper ventilation, the application of the convection or recirculating system is one of the most important recent developments in core oven design. The modern recirculating heating system is based on the principle that the movement of large volumes of heated air or gases around the work to be baked results in a speed of heat transmission with a uniformity of temperature that until a few years ago was absolutely unknown.

Regardless of the fuel used, the heat is developed in a heater and, after tempering with fresh air and recirculated gases, is forced to flow through the oven and back to the heater in a closed system. The entire sys-

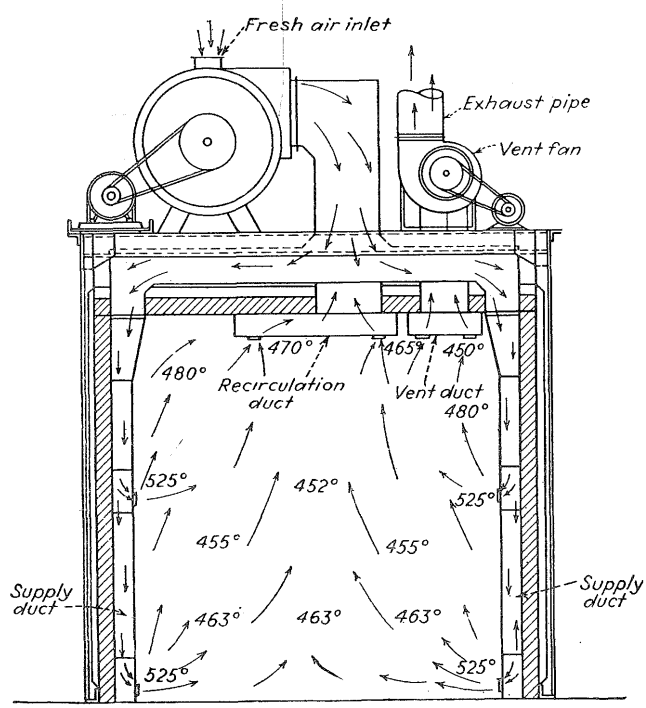


Fig. 9.33 — Diagram showing the even distribution of heat obtainable by proper venting of the oven and recirculation of oven gases. Compare with Fig. 9.1.

tem is under accurate control, and sufficient heat and fresh air are automatically admitted to meet the oven demand and to compensate for losses due to ventilation and radiation.

These modern recirculating systems are now built for operation with coal, oil and gas, all of which are adaptable to automatic firing and automatic control.

Coke

Although coke, under certain conditions, is a satisfactory core oven fuel, it must be fired by hand, and therefore its use involves a certain unavoidable personal element which makes it unsuitable for completely automatic systems.

Coal

With the development of efficient and dependable stoker equipment, very satisfactory core baking can now be obtained with coal. Proper heater design must be provided, of course, to assure good combustion. To obtain best results, recirculation is needed—first, to properly diffuse the high temperature of the products of combustion, and then, to insure uniform temperature distribution through proper rate of air change in the oven. However, core baking is decidedly different from boiler practice, and to merely install a stoker on what was formerly an inefficient core oven, may not change matters much; the result may still be a bad oven and possibly a worse one.

Powdered coal has been applied to core baking with some degree of success. This fuel, however, perhaps more than any other, calls for experienced engineering in the design of the combustion, ventilation and recirculating system, with provision for the precipitation and removal of the ash, which is a problem in itself.

Oil

Oil is a very satisfactory fuel, and is being used extensively. The lighter oils are more satisfactory than the heavier ones, which may require preheating and perhaps a little more supervision. If a good grade of oil is available at a satisfactory price, it is possible to obtain both very fine and economical operation.

Gas

Gas, of course, is probably the ideal fuel for a number of reasons, and as the cost of gas has been gradually lowered, it has become more widely used for core oven service. This includes the so-called liquid gases, such as propane and butane, as well as manufactured, mixed and straight natural gas.

In localities where gas is not always available, especially during winter months because of increased domestic demand, or where at times a lower cost of oil makes a change-over worthwhile, the heating system can be equipped with combination burner equipment, so that either gas or oil may be burned at will, with practically no delay in changing from one fuel to another.

Electricity

At the rates that generally prevail in most areas, baking cores with electric heat is almost out of the question from an economy standpoint, except where advantage can be taken of low off-peak rates, or possibly as a means to improve the power factor.

Infrared

Cores bonded with water soluble binders and those that soften on heating and harden on cooling may be readily baked in an oven provided with infrared heat lamps. The use of this type oven holds possibilities of increasing speed of core baking and savings in cost of equipment.

High Frequency (Dielectric)

The elemental form of equipment for producing dielectric heating consists of an oscillator for producing the high frequency electrical energy, and a pair of flat electrodes, spaced some distance apart to allow the introduction between them of the material which is to be heated. The polarity of the electrical potential between the plates changes many times a second in accordance with the frequency of the energy source, and when a nonconducting material is placed between these plates, the molecules of the materials are deformed as this polarity changes. The degree of deformation, and hence the amount of energy produced, is a function of the voltage applied to the electrodes, as well as some physical characteristics of the material, such as power factor and dielectric constant.

For any specified period of time, the total energy is proportional to the number of deformations during this time, so that the frequency, or number of reversals of force, is also a factor. In electrical terms, the total power can be expressed as being dependent upon the frequency of the power source, the square of the voltage across the material being heated, the dielectric constant of the material, and the power factor. When applied to a particular mass of material with given dimensions, this may be expressed by the formula

$$\text{Power} = 1.41\, E^2\, f\, F_1\, \frac{A}{t} \times 10^{-12} \text{ watts}$$

where

- E = Voltage RMS impressed on the material in volts
- f = frequency in cycles per second
- F_1 = the loss factor (power factor × dielectric constant)
- A = area of material between the electrodes in square inches
- t = thickness of the material in inches

Typical practical values of voltages in the above formula run on the order of 1,000 to 5,000 volts, while the frequencies will be of the order of 1,000,000 to 20,000,000 cycles per second.

The equipment which is used for dielectric core baking is, in general, of the conveyor type, where the cores are passed between the electrodes progressively, and thus the heating cycle is governed by the speed of travel of the belt. In practice the belts travel from a few inches up to 10 ft per min, depending upon the capacity of the equipment and the type of cores being baked. The belt is, in general, made of steel chain and acts as the bottom electrode, thus permitting the core plates and driers to ride directly on the belt through the electrode space. The units are flexible inasmuch as

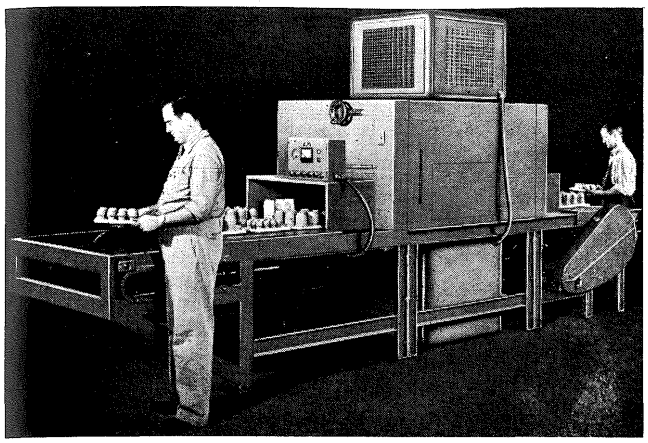


Fig. 9.34 — High frequency dielectric core baking oven.

any desired length of conveyor can be supplied at either the entrance or exit end of the tunnel. Standard units allow approximately 4 ft of conveyor at the in feed end and flush end of the conveyor at the exit end to permit auxiliary roller or belt conveyor to be used. Figure 9.34 shows a dielectric core baking oven.

The atmosphere within the tunnel proper is at room temperature and only the cores themselves heat up thus eliminating waste heat inherent to conventional ovens. An exhaust blower on the top of the unit is used to carry off the steam and vapor which is evolved when the cores are baked. This should be piped to the outside atmosphere if possible in order that the gaseous products carried off during the baking cycle do not become objectionable to operating personnel. The unit is completely housed with metal side panels, thus preventing any hazard to operators from the high voltages in the power supply. The units are thoroughly interlocked to prevent energizing if any access panels are removed.

The successful operation of dielectric core baking equipment is contingent upon the use of thermosetting resin type core binders, since there is no advantage gained in using a method that can heat the cores in a matter of a few seconds if the binder requires a few hours to set. Great advances have been made in the formulation and blending of thermosetting binders which have increased the productivity and applicability of dielectric core baking equipment.

A number of basic resins which lend themselves as core binders are available among them being phenol-formaldehyde, urea formaldehyde, the melamines, and the resorcinols. Each has its general field of application, with some specific advantages. A blend of urea formaldehyde and melamine, has proven to be the best general purpose binder found thus far, while a straight urea formaldehyde runs a close second. The phenols have proven more successful for certain cores for steel, because they do not liberate nitrogen in breaking down, while lignite base and resin binders have been found successful for gray iron and aluminum. The choice of binder, sand, and whether or not any further additions to the formulation are necessary, are more or less dictated by the geometry of the core and the requirements of green strength, collapsibility, hot strength and other characteristics as is true in any core binder formulation.

With dielectric core baking, a roller conveyor can be installed to take the core plates as they emerge from the tunnel and deliver them directly to the inspection table. The cores are cool enough for immediate inspection and service. This results in continuous flow of material from the coremakers right down through the inspection.

The rapid curing accomplished by dielectric core baking may reduce the problem of slumping and sagging of cores during the baking cycle.

The minimum baking cycle in conventional type ovens using oil binders is around 2 hr, and more often runs from 4 to 6 hr, depending on the type of core being baked and the mix. There is also a considerable period of time required for cooling after the cores are removed from the oven before they can be inspected and sent to the molding floor for use. Therefore, it is necessary to maintain a rather rigorous schedule in the core room whereby plans are made sufficiently far in advance to have cores available when they are needed on the molding floor. Dielectric core baking reduces the need of such rigid scheduling and makes available any core that might be required on the molding floor. With heating cycles of the order of 20 sec to 2 or 3 min, cores can be baked as they are needed, and changes in molding schedules can be effected without giving any thought to what cores are in stock.

With resin binders and dielectric baking, a fundamental general mix, might be as follows.

500 lb Jersey silica sand (70 mesh)
7 lb binder (urea formaldehyde base)
3 lb cereal
1½ lb boric acid
1½ qt kerosene
5½ qt water

This mix provides good green strength, good hot strength, high surface hardness, and can be turned out of the core box without sticking or breaking fine edges. It can also be used in core blowers with good results, provided the boxes being blown are not too intricate in shape.

Where this is the case, the following variation of the elemental mix has proven itself well adapted to general purpose work.

500 lb silica sand (70 mesh)
11 lb binder (urea formaldehyde base)
4½ lb cereal
1¼ lb boric acid
2½ qt kerosene
8 qt water

This mix produces higher surface hardness due to the increase in binder content, and also has a greater lubricity from the additional kerosene.

Where cores having thin cross-sections are to be made, a mix which produces a higher green strength and hot strength is needed, and the following mix meets these requirements.

500 lb silica sand (70 mesh)
11 lb binder (urea formaldehyde base)
4½ lb cereal
1¼ lb boric acid
2½ lb dextrin
3 qt kerosene
8 qt water

All of these mixes are mulled 2 min dry. The water is added and the mix is mulled for another 2 min. The kerosene is then added and the mix is mulled for a final 3 min. Experience has also shown that a binder of the urea melamine blend base can also be substituted in the above formulations in the same proportions, and a slightly superior core so far as hot strength is concerned will be obtained. These mixes have been used on gray iron, malleable, brass, bronze, and aluminum, and in some cases, steel. However, the higher pouring temperatures generally encountered in steel foundries may indicate the use of one of the following formulations which were prepared for such cases.

500 lb silica sand
50 lb silica flour
2½ lb cereal
6¼ lb binder (urea or urea melamine base)
1¼ lb boric acid
1¼ qt kerosene
7½ qt water

500 lb silica sand
20 lb binder (phenol base)
1¼ qt kerosene
10 qt water
(If higher green strength is desired, use up to 1 per cent cereal)

The mulling procedure for these formulations is the same as for the preceding mixes, and the choice between the urea or phenol base binders depends upon whether or not the nitrogenous compounds liberated by the urea binders affect the particular alloy steel being poured.

Naturally, many foundries will experiment and find a mix that seems to meet their particular requirements best, and one foundry pouring gray iron offers the following formulation with some of the physical characteristics obtained.

800 lb sand
24 lb binder (urea base)
2½ lb boric acid
20 qt water

Baking cycle—dielectric .....2½ min
Scratch hardness .....97-98 average leaving tunnel 90 after exposure to moist mold of 6 per cent moisture for 6 hr
Green strength .....1.5 psi

Driers

The power which is transmitted to the core is a function of the square of the voltage across the core. It is general practice to make this voltage as high as possible. Therefore, if any electrical conductor, such as a reinforcing wire, were placed vertically for the full thickness of the core, in all probability a voltage flash-over would occur and it would not be possible to bake the core. However, if this reinforcing wire were horizontal, in the plane of the electrodes, no harmful effect would ensue. The degree to which this wire can be off the horizontal is something which would have to be determined for the particular core in question so there is no fixed rule that can be given as to just what reinforcing wires can be used and what cannot.

The same thing holds true for chills, and each case must be investigated individually, but it may be stated that many reinforcing wires and chills are being used in dielectrically baked cores. In cases where there is a problem in reinforcing, wood dowels and plastic pins have been substituted for metal wires, with a reduction in overall cost.

Because of voltage failure and other rather involved problems of potential distribution and heat flow, the use of metal driers and core plates cannot be tolerated with dielectric core baking. This is not a great problem as far as core plates are concerned, since most foundries are using Transite core plates today, and these are satisfactory for dielectric heating. An additional feature to the use of Transite is that dielectric heating does not demand the so-called "heat treated" Transite which has already been brought to oven temperatures, where it warped, and then was planed flat to give a surface which would stand repeated heating cycles. In dielectric core baking, the plate gets only slightly warm, so there is no necessity for preheat and warping the Transite as is the case when using it in ovens. Plywood plates have been used successfully in many foundries baking cores dielectrically, and a material called Marinite, similar to Transite but of about one-third the weight, has found wide acceptance. Driers must also be nonmetallic and the manufacturers of dielectric core baking equipment have made a plastic drier which is made to the same tolerances as cast metal driers, is a fraction of the weight, and stands up well in service.

Whether the problem be one of core plates or driers, the number which must be used is dictated by the core baking procedure, and it is here that dielectric core baking is of economic value. For example, taking the best oven baking equipment, the minimum baking cycle might be of the order of 2 hr, and if two core boxes were turned out every minute, 240 driers would be the minimum required. For safety's sake, spares would have to be available, so approximately 300 driers would be required for this baking operation. The same core, when baked dielectrically, would probably have a min baking cycle and four cores would be made during this period. Therefore, four driers would be required for the blowing operation, four for the loading position, four driers in the baking position, four in the cooling area, four in the unloading station, and four spares; a total of 24 driers. The reduction in the number of driers in the ratio of 300 to 24 makes the resulting economies self-evident, and it can be stated that approximately one-twelfth the number of driers are necessary with dielectric core baking equipment as are needed with conventional ovens. The cost of plastic driers are about the same as metal driers. Plastic driers cannot be used in conventional ovens, since they will not withstand the operating temperatures.

Overbaking

It is impossible to overbake cores when using dielectric core baking equipment since the heating characteristics of the core mix fall off rapidly as the cores reach the baked state. Dielectric core baking insures that all cores going through the oven and all sections of the individual core are baked at the specified temperature. The uniformity of bake which is achieved guarantees that the physical characteristics of the entire core are also uniform and possible poor physical

characteristics at points unavailable for thorough inspection are eliminated. Thus, if one section of the core is inspected and found to have the proper qualities, it may be assumed that all sections of the core are satisfactory, and this greatly simplifies the inspection problem.

Energy Consumption

Dielectric core baking equipment consumes energy only when cores are being baked, and its overall thermal efficiency remains more or less constant regardless of load, at approximately 50 per cent, which is very high for any piece of heating equipment. There is no heat given off to the room where the equipment is located, resulting in better working conditions.

Space

Standard ratings of dielectric core baking equipment now on the market are in units of one-quarter ton per hour of cores baked, and a typical one-quarter ton unit will be approximately 5 ft wide, 17 ft long, and 7 ft high, with the exhaust duct extending from the top. The belt width varies from 2 ft to 3 ft, depending upon the manufacturer, and accommodates cores with overall height up to 12 in. The entrance and exit conveyors can be furnished to suit the particular requirement of the user. The units are completely enclosed in heavy sheet metal panels, and their sturdy construction fits well with other foundry equipment. There is a minimum of maintenance involved, since the only moving parts in the units are the conveyor and small blowers. The tubes which are used to produce the high frequency energy are especially designed for industrial service and are again furnished in both the air cooled and the water cooled type. If the core room is dusty, as is often the case, water cooled tubes will probably give better service since the problem of cleaning the air filter and the possibility of the air filter becoming sufficiently clogged to not provide adequate cooling is eliminated. Average tube life will run from 5000 to 6000 hr.

As the rating of the unit goes up to one-half ton per hour, the size of the unit also increases but does not double with the capacity. One manufacturer makes the unit sectionalized, and its capacity can be increased by simply adding heating unit and lengthening the conveyor. A unit rated at one ton per hour takes up approximately twice the floor space as a one-quarter ton unit. Layouts can be made where the dielectric heating units are located on a production line basis, and the sand comes in at one end of the core room and the finished cores leave at the other. The space requirements of dielectric core baking equipment is smaller than of other core baking equipment. The erection cost of dielectric core baking equipment is low since the only cost is the setting of the unit in place, and the electric and water services which must be brought to it. The equipment is relatively light in weight, so no special foundations are necessary.

Fuel Consumption

Cores can be baked dielectrically using 120 kw-hr per ton of cores baked, and at prevailing power rates of 1 cent per kw-hr, this is $1.20 per ton. A gas-fired oven in a foundry which is served with natural gas has a fuel cost of $0.87 per ton of cores, while an oil-fired oven in a Pennsylvania foundry runs $2.60 per ton. Cores baked dielectrically can be baked more economically than in many ovens. There are no start-up or shut-down losses, and if some minor repairs are to be made, there is no need to let the oven cool off before the maintenance man can do his work.

Available Heat in Various Fuels

A number of factors have an important bearing on the combustion efficiency of the various fuels, but the figures given in the last column of Table 9.2 indicate comparable values under relatively equal conditions.

TABLE 9.2 — RELATIVE HEATING VALUE OF FUELS

Fuel	Theoretical Heat Content	Approximate Available Heat for Core Baking
Manufactured gas, Btu, per cu ft	530	475
Mixed gas, Btu, per cu ft	850	765
Natural gas, Btu, per cu ft	1,050	945
Propane, Btu, per cu ft	2,500	2,250
Butane, Btu, per cu ft	3,200	2,880
Light fuel oil, Btu, per gal	140,000	125,000
Medium fuel oil, Btu, per gal	145,000	125,000
Heavy fuel oil, Btu, per gal	150,000	120,000
Coal (stoker), Btu, per lb	14,000	11,000
Coke, Btu, per lb	13,000	9,000
Electricity, Btu, per kwh	3,412	3,412

Fuel Cost Considerations

In addition to the cost of the fuel itself, due consideration must be given to its availability and to the cost of using the fuel. While gas and oil may involve little or no manual labor in their use, the matter of firing labor may represent a substantial item in the case of coke. Gas and oil-fired equipment of proper design may require relatively little maintenance expense. However, both coal and coke-fired equipment require more attention for repairs and upkeep.

The bare cost of the fuel accordingly should not be the deciding factor. The obtainable efficiency, amount of supervision required, labor of attendance, maintenance expense, and operating results, should all be considered.

While one fuel may appear to have a higher Btu cost, its overall cost, as applied to a particular core baking situation, may prove to be considerably lower than that of another cheaper fuel.

Fuel Economies vs. Oven Type

The question as to whether or not fuel can be saved, for example, in the continuous oven over a rack oven, presumes that the same sort of work is being handled. There are instances where in certain production, formerly baked in rack ovens but now baked in continuous ovens of the vertical type, the fuel consumption has been reduced fully one-third. However, that is not the entire story. In such instances the cores were formerly baked in inefficient, crude, home-built ovens, and the efficiency of those ovens might easily have been increased 25 per cent. The difference is not entirely due to the mechanical equipment.

It should be kept in mind, in connection with the fuel economy of continuous ovens, that the very na-

ture of the racks requires certain clearances between them in moving about the sprockets, and clearance above the trolleys, hangers and tracks, etc. Therefore, there is a certain amount of dead space in a continuous oven, which penalizes to some extent what would normally be the efficiency of the continuous operation. Large conveyor oven installations have been built which produced rather low fuel ratios. On the other hand, it has been possible, on batch-type installations, to obtain as low fuel ratios as the best of continuous installations.

The best opportunity to save fuel in a continuous oven lies in operating the oven loaded to full capacity. If the production is likely to vary, the fuel economy on a continuous oven is severely penalized when the oven is running under capacity, and a comparison with batch oven operation may favor the latter.

Utilization of Waste Heat for Core Baking

With regard to the use of waste heat, this depends upon how much is available, what its temperature is, and how far the source of this waste heat is from where it is to be used.

A number of years ago, an oven manufacturer was called to a foundry to figure on the installation of a battery of core ovens where the owner wished to use the waste heat from his cupola. The cupola was on an upper floor. The owner had already designed and built his own fan to take the waste heat from this cupola, and to deliver this heat through large ducts to the ovens, which were to be located on the floor below. The fan was of such huge size and the blades of such terrific weight that the actual power consumption of the motor to drive the fan would have cost a great deal more than new fuel to run the ovens.

The coordination of the equipment producing this waste heat and the operation of the ovens is another point which should be kept in mind. As an example, a large foundry wished to use the waste heat from a battery of pit, brass-melting furnaces to heat a group of core ovens. The furnaces operated all right as long as nothing interfered with the flow of the heat in the runner flue or waste heat duct. However, as soon as the velocity of these gases was reduced by passing them through the ovens, the normal operation of the furnaces was seriously affected.

Using waste heat from annealing furnaces or heat treating furnaces can be done in a number of ways. A recuperator can be used to preheat air by means of the waste heat being discharged from the furnace, and this preheated air could become a very good heating medium for a core oven, because all the elements of good economical operation are available. Such an installation provides convected heat in a desirable oxidizing condition, and if a sufficient volume and a constant supply is available, the desired result could be accomplished practicably.

The source of waste heat should be reasonably close to where it is to be used, so as to reduce to a minimum the investment in duct work, which must be well constructed and heavily insulated.

CONTROL OF CORE BAKING

Use of automatic control in the core baking process has become more and more prevalent until now, in most instances, it is demanded as an essential part of the baking equipment. The quality of the cores produced in any foundry depends to a large extent on the proper degree of temperature being applied to the core for the proper length of time. The proper degree of temperature and the proper length of time are prescribed for the bake based on the kind of binder used in the mixture. An automatic controller is capable of maintaining the temperature in the oven at the required degree with much greater accuracy than is possible with manual control.

Advantages of Automatic Control

The advantage of automatic over manual control is evidenced by appreciable savings in the amount of fuel used, in less core loss due to carbonization and crumbling, and in a greater uniformity of the product. When the desired temperature as set on the control apparatus is reached, the instrument will maintain that temperature accurately by utilizing only a fraction of the amount of heat required to bring the oven up to the proper temperature. There is no overrunning of temperature and consequent overheating of the product. Less fuel is used. The fact that the temperature can be maintained accurately is further assurance that a greater percentage of the cores produced will be perfect.

Methods of Controlling Fuel Supply

Method of application of the control is dependent on the type of firing used in the oven. The customary types of oil- or gas-fired burners are controlled by limiting the amount of fuel supplied to them through a motor-operated valve. On larger ovens, where more than one battery of burners is used, it is often sufficient to utilize automatic control on only one battery. The control functions to bring the oven up to the desired temperature and then closes the valve during the bake. The remaining burners usually are sufficient to hold the required temperature. If the motor operated valve is controlling the total fuel supply to all burners, it must be so adjusted that there will always be a minimum opening, or a bypass arrangement provided around the control valve, thus eliminating the danger of a complete shutoff of fuel supply.

Another commonly used method of heat control is accomplished on injection type burners by adjusting the amount of air supplied to the burner. In this case, the automatic control is accomplished by installing a motor-operated valve in the air line or by arranging for automatic operation of the existing valve.

The baking time in batch ovens usually is taken care of by the attendant equipped with a schedule of baking time and some sort of timing device. In continuous ovens, the time of baking is governed easily by regulating the speed of the conveyor passing through the oven.

The controller most often used for core baking is that commonly called the open-and-shut, or on-and-off type. As the name implies, this instrument functions in such a manner that the control valve is either in the fully open or fully closed position, or at the limit of closure determined by the minimum opening adjustment. The valve, or controlling device, will remain in full open position while the oven is being

heated to the baking temperature. When this set temperature is reached, the valve will close quickly and will alternate from open to closed position as rapidly as is necessary to maintain the temperature accurately at that point.

Temperature Control

Before any temperature can be controlled, it must first be measured. The measuring element, or thermal system, commonly employed may be one of two types, depending on whether the filled system or the electrical type is preferred.

The first type is that which is filled with some medium which, when heated, is caused to expand and effect motion of a hollow helical coil spring. This motion is transferred directly by linkages to the control mechanism.

The second type is that employing the thermocouple method in which two dissimilar metal wires are welded together at a point and connected to the instrument by means of suitable lead wires to form a circuit. When a change in temperature occurs at the point of union of the dissimilar metals a small current of electricity is made to flow through this circuit. This current causes deflection of a sensitive galvanometer. The amount of deflection of the galvanometer is an indication of the amount of current flowing in the thermocouple circuit which, in turn, is proportional to the degree of temperature at the end of the thermocouple. A motor-operated sensing mechanism inside the instrument detects the amount of galvanometer deflection accurately and effects motion of the mechanism to control the temperature accordingly.

Air-Operated Control Valves

The operating medium on the control valve can be either compressed air or electricity. An air-operated valve is illustrated in Fig. 9.35. A rubber fabric diaphragm held between the flanges at the top of the assembly raises a piston attached to the valve plunger when air pressure is applied beneath it. The coiled spring acts in the reverse direction to return the valve plunger to its original position when the air pressure is released. The air pressure is delivered to the air motor by the instrument.

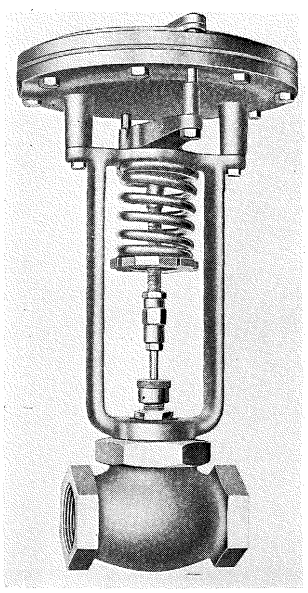


Fig. 9.35 — Air-operated control valve for open and shut control of oil or gas.

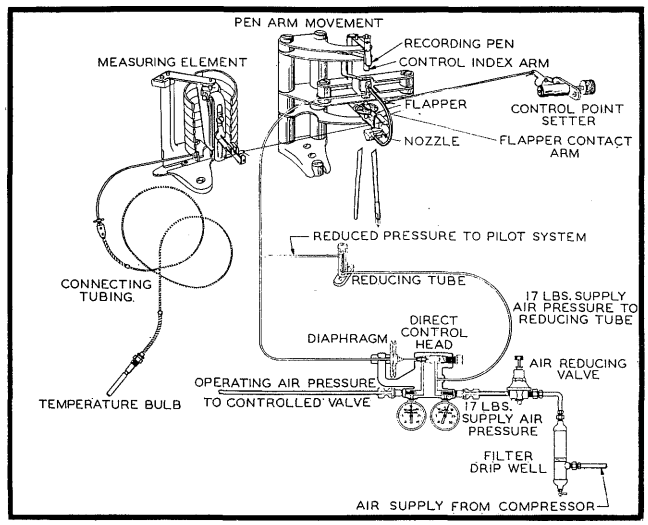


Fig. 9.36 — Schematic layout of open and shut air system for control of core oven temperatures.

Air-Operated Control System

A schematic layout of an open and shut air system is shown in Fig. 9.36. In this system, supply air at a given pressure is delivered to the instrument from an outside source. Compressed air is available in most industrial plants and can be reduced to the required operating pressure by means of a suitable pressure reducing valve. Air at the reduced pressure, indicated by the right hand gage, is delivered to the control head, which incorporates a small air relay and, with the relay in the position shown in the diagram, this air pressure is passing directly through the control head to the control valve in the fuel line. This same air pressure is being delivered from the control head through the bypass and reducing tube to the nozzle on the pen arm movement and, with mechanism in position shown, there is bleeding to atmosphere.

Filled Thermal System

At the left of the diagram, Fig. 9.36, a filled thermal system is shown with the temperature bulb connected to the measuring element or hollow coiled helical spring by means of capillary tubing. The link from the measuring element to the pen arm movement is connected to the bracket carrying the movable flapper. The nozzle is on a separate bracket which does not move except when the temperature set point is changed manually by the control point setter.

To describe the action of this mechanism, assume it is encased as a recording temperature controller of the kind illustrated in Fig. 9.37 and installed with a control valve (Fig. 9.35) for the purpose of maintaining a constant temperature in a core baking oven. When the temperature is below the set point and the oven is coming up to heat, the control head air relay is in the position shown, passing air pressure directly to the control valve diaphragm and holding the valve open. Fuel is supplied to the burners in maximum amount.

When the temperature reaches the set point, the mechanism is so adjusted that the measuring element has been caused to unwind sufficiently by the pressure of the expanding medium in the thermal system to

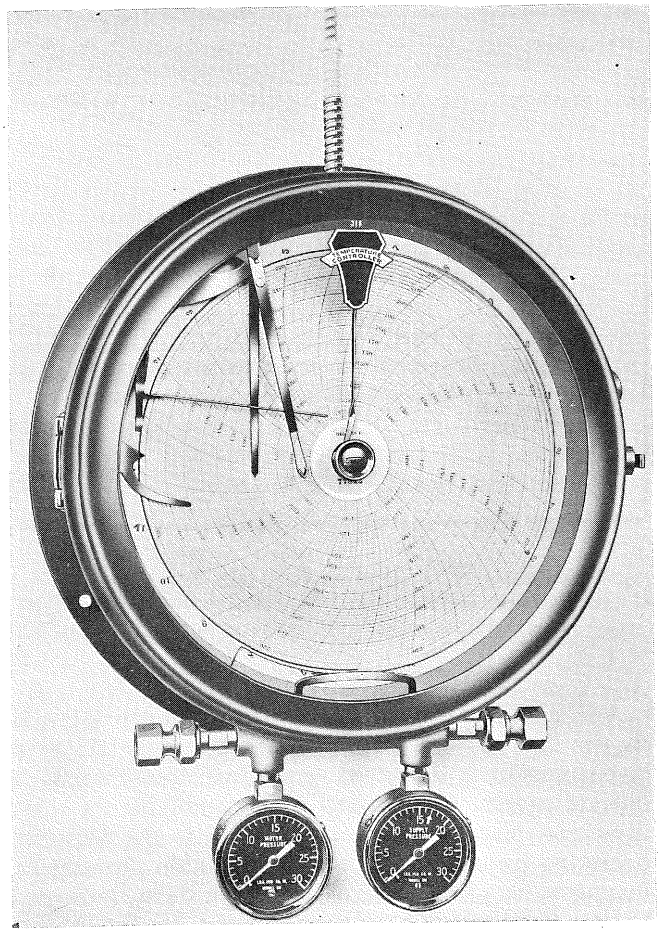


Fig. 9.37 — Recording temperature controller for air system control.

bring the movable flapper up to cover the point of the nozzle. The air is thereby further prevented from bleeding at the nozzle because, although the air pressure at that point is 15 psi, the area of the nozzle is very small and only a slight pressure by the flapper is needed to close the opening. Therefore, the air pressure is backed up from the nozzle and will immediately take effect to cause an expansion of the light metal diaphragm on the control head.

The expansion causes the small air relay valve to change its position, to unseat from the position shown, and to become seated at the opposite end of its stroke. The passage of air from the supply to the control valve is shut off and the pressure, which has been maintained on the diaphragm motor, is allowed to escape through the control head at the passage opened by the air relay when it changed position. The action of the coiled spring beneath the diaphragm motor of the controlled valve, now that the air pressure on the motor has been released, causes the valve to close and the fuel supply to the burners is cut off, or greatly lessened, if a minimum amount of opening is maintained by an adjustment of the control valve.

When the set temperature is reached, the action of the control mechanism is rapid, although to describe it in detail would seem to indicate a considerable lapse of time. With the controller at the set point, the control is maintained by the same rapid functioning of the mechanism. As soon as the fuel supply to the burners is cut off, the temperature in the oven tends to decrease slightly. The filling medium in the thermal system contracts and the measuring element winds up a slight amount. The flapper is backed off the nozzle and the air again bleeds at this point. The pressure on the diaphragm of the head is released as soon as the air bleeds at the nozzle and the diaphragm assumes its original position. The air relay again returns to seat, as shown, and air pressure is passed again to the controlled valve diaphragm. The diaphragm is raised, carrying the piston with it, the valve is opened, and fuel is again passed to the burners. The reverse action now takes place until the fuel valve is again closed.

This reversal of control action is so rapid that it is evidenced on the chart record only as a slightly wavering line. If the oven should be required to operate at one temperature for a full 24 hours, or one revolution of the recording chart, the record would appear as a perfect circle. The recording pen arm is mounted on the same bracket that carries the movable flapper, while the index arm or pointer is on the same bracket with the nozzle and indicates the set temperature.

The controller described is only one of several types applicable to core baking ovens but is probably the one most commonly used. A continuous record of each day's process is kept on the chart and may be filed for future reference. The time and duration of each cycle of operation and the temperature of the bake is permanently recorded.

Air Thermocouple Control System

The controller pictured in Fig. 9.38 is designed with an air-operated control mechanism very similar to that already described, but with a measuring system of the electrical themocouple type. The transfer from electrical measurement to mechanical, air-operated control is easily effected in the instrument because of the action of the balancing mechanism, in the potentiometer circuit in this case, to position a flapper against a nozzle as illustrated in Fig. 9.36. This type controller has the advantage that it can be used in much higher temperatures than is possible with the filled thermal system controller which is usually limited to about 800 F (427 C). Furthermore, it is possible to replace the thermocouple or lengthen the lead wires between the thermocouple and the instrument merely by disconnecting the old and adding the new, whereas the

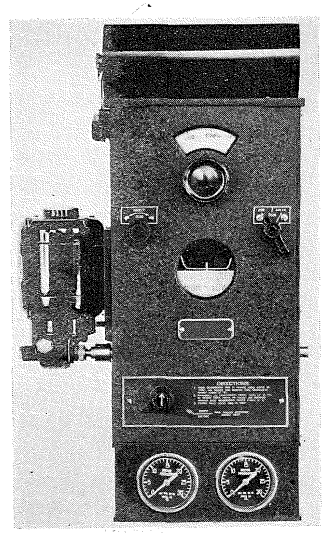


Fig. 9.38 — An indicating temperature controller for thermocouple and air operating system.

filled system is an integral unit and must be treated as such.

Filled Measuring, Electrical Control System

Another type of controller used a great deal on this and similar applications is one having the filled measuring system with an electrically operated control mechanism. One advantage of this instrument is that it can be used wherever a compressed air supply is not available or is inadequate.

One typical example of a controller with the measuring system connected directly to a pen arm movement is the same as that illustrated in Fig. 9.36 except that the flapper and nozzle assembly is replaced by a rotating commutator contact assembly and the required number of sliding contact brushes. The control head assembly and air tubing, shown in Fig. 9.36, are replaced by an electric control relay and the necessary wiring. This provides a load circuit for direct operation of the valve and assures isolation of the rotating contact assembly as protection against any heavy overloads or short circuits that may occur.

The operation of this mechanism to control the process is analogous to that previously described and illustrated in Fig. 9.36. As the measuring system moves the pen, indicating a deviation from the control point, the commutator contacts are moved away from or into contact with the brushes opening or closing the circuit to the control relay. The relay, in turn, opens and closes the circuit to the electric motor-operated, or solenoid, valve in the fuel line to the burners, and the temperature of the oven is maintained at the set point.

This form of control is accomplished in various ways by the various manufacturers. Essentially, the control results obtained are the same and they differ only in the mechanical means provided to effect the transfer of the measured temperature change to the control valve.

Installation

The sensitive bulb of the filled measuring system and the thermocouple of the electrical measuring system should be installed through the wall of the oven at the point where the temperature is expected to be highest. In the batch oven, this normally will be at the top; in the horizontal continuous type, approximately half way from the entrance to the exit; and in the vertical continuous oven, at the top. The instrument itself can be located to suit the convenience of the user. It may be desirable to have the controller mounted directly on the oven, or it may be preferable to mount it on a centrally located board at some distance from the oven. This latter can be accomplished at a slight increase in cost for the additional length of connecting tubing or lead wire necessary in the measuring system.

Safety regulations governing the manufacture and use of equipment of the class of core baking ovens require that certain automatic safety devices be supplied with the equipment to prevent accident because of extinguished burners, or overheating. These devices, which are provided by the manufacturer as a part of the oven equipment, usually function on a closed electric circuit which is broken when difficulties arise and which causes a valve to close and an alarm to ring, or whatever may be the requirement for the particular equipment involved. The temperature controllers always can be designed to provide additional safety measures by arranging them to close the fuel valve in case of failure of air supply.

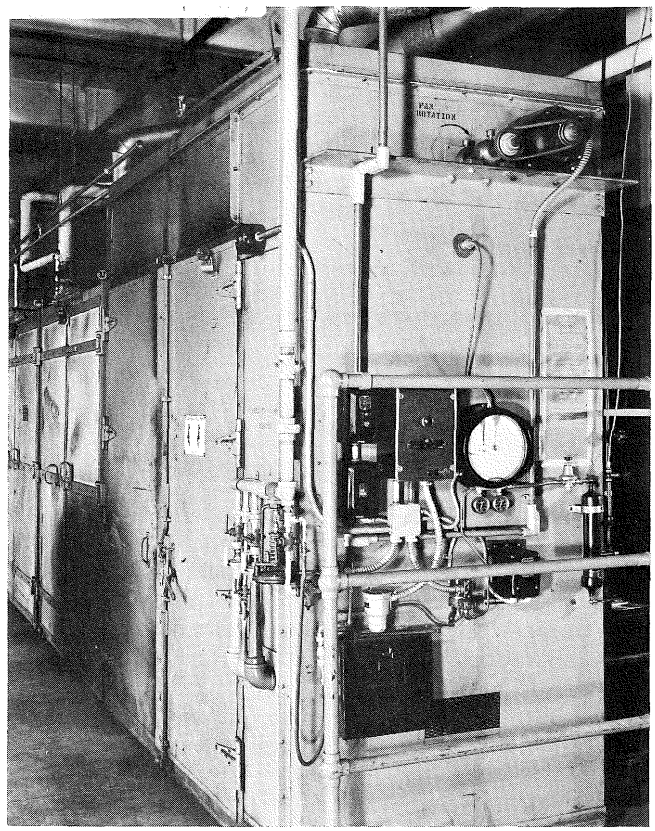


Fig. 9.39 — Typical installation of a recording temperature controller.

Figure 9.39 illustrates a typical installation of a recording temperature controller mounted directly on a small batch oven. Note the motor driven circulation fan at the top of the oven. The tubing connection can be seen leading from the top of the instrument case to the sensitive bulb which is installed across the top center of the oven above the trays. The control valve in the gas line is mounted with the diaphragm motor below the valve itself. The standard safety equipment will be noted to the left of the controller. One of these safety devices is arranged to cut off the air supply from the instrument to the control valve should the burner flame be extinguished for any reason. The valve in the fuel line will close immediately and prevent danger of flareback of any excess fuel when the burner is relighted. This same effect is accomplished in the electrically operated control system when the safety device breaks the circuit between the instrument and the electrically operated valve.

No attempt has been made to describe all types of control nor to explain all possible combinations of the types mentioned. It is possible to demand application requirements which would necessitate the use of more complicated control mechanisms to accomplish control of the process, but the usual requirements are easily and satisfactorily accomplished by the simplest forms of control corresponding to those described.

Chapter 10

CORE FINISHING OPERATIONS

INTRODUCTION

The modern trend in core practice is toward greater accuracy and closer control. There is no place where this is more important than in the final stages of core production. After the sand is correctly mixed and the core properly shaped and baked, there may be several more operations before the core or cores can be set into a mold prior to casting.

The finishing work performed on cores after baking is completed may be divided into three divisions.

(1) Cleaning operations
  (a) Trimming
  (b) Brushing
  (c) Coating
  (d) Mudding
  (e) Venting
(2) Sizing operations
  (a) Templates
  (b) Filing
  (c) Grinding
(3) Assembly operations
  (a) Pasting of cores
  (b) Bolting of cores
  (c) Leading of cores

Depending on the type of cores to be produced, finishing operations may vary from a simple trimming of fins to a complicated assembly of close dimensional accuracy. Castings with metal thicknesses of as small as $\frac{5}{32}$-in. leave practically no leeway in the size of the cores used and this makes the use of many gages and templates imperative. Figure 10.1 shows a core finishing line at the unloading side of a vertical core oven.

CLEANING OPERATIONS

Under this heading may be listed any operation performed on or to the surface of a core to produce a smooth casting or to prevent a defect in a casting.

Trimming Cores

During the process of making cores, any one of the following projections may be left on the surface of the core.

(1) Fins caused by a loose joint or a worn loose piece in a core box. Where ram-up driers are used in a core box, a fin usually results which must be removed. This is especially so in the case of water jacket cores for cylinder blocks.

(2) A hump on the surface of the core, caused by a worn surface in a core box, due to a peculiarity in ramming or directly underneath a blowing hole in a core box.

(3) Excess sand left on a blown core, which is not really part of the core but part of the sand that fills the blowing hole in the core box. All blowing holes in core boxes used for blowing cores should be slightly tapered with the smaller opening nearest the core. After considerable use of such a core box, the tapered hole will become worn and permit the sand to adhere to the core instead of parting at the core surface in withdrawing the core from the box.

The removal of any of the above named projections from the surface of a core is known as trimming, whether it be by filing, by rubbing with emery cloth or with emery stone, or by trimming with a wire or small rod.

Brushing Cores

Where limited production of irregular shaped cores will not warrant the use of core driers, as in the case of most experimental cores, the cores are turned out on

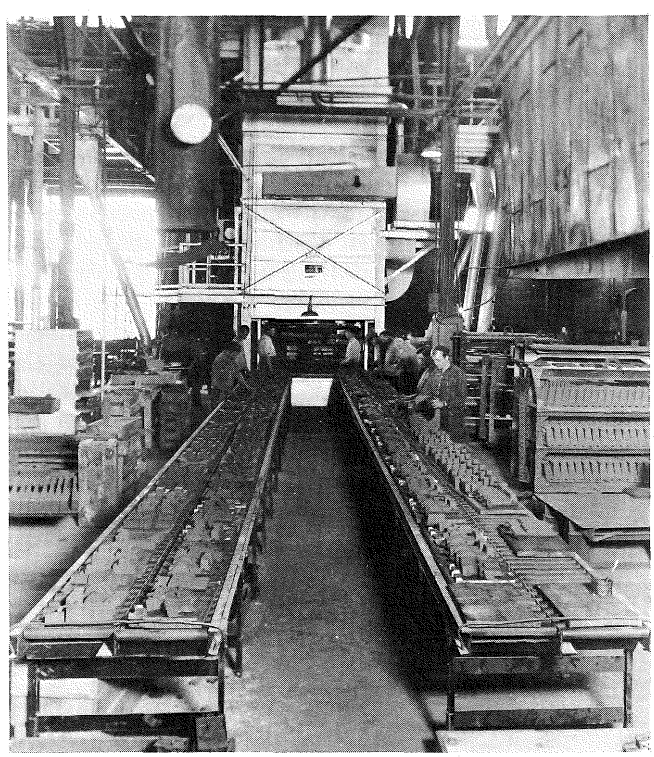


Fig. 10.1 — Core finishing line at unloading side of vertical core oven.

bedding sand for support during the baking period. The removal of this bedding sand from the surface of the core with a brush is known as brushing.

Coating of Cores

It is often necessary to coat the surface of cores with a protective covering of core wash. This covering may be applied by dipping the core into the core wash or by brushing or spraying the core. This will be dealt with more extensively in Chapter 11, CORE COATINGS.

Mudding of Cores

The interior surfaces of castings formed by cores generally must be smooth. Any rough spots must be made smooth and any soft rammed places must be filled with some easily applied material. This material also must be sufficiently refractory to withstand the action of molten metal.

Either red talc or graphite, moistened with water to the consistency of soft mud, is ideal for this purpose. The material used usually is applied with the index finger and then smoothed with another finger or with the palm of the hand. If the operator is not dexterous enough in the use of his fingers, it will be necessary to use a brush to smooth the mud.

A composition for core mud used successfully in many corerooms consists of 3 per cent bentonite, 3 per cent dextrin and 94 per cent silica flour. Sufficient water is added to form a thick putty.

Care should be taken that these spots are sufficiently dried before setting the core in a mold. If the time interval between cleaning and setting the core is short, it should be either dried with a torch or placed in an oven long enough to evaporate the water from the material used to mud the core. In the writer's opinion, 4 hr is a sufficient length of time to let these spots become air dried before the cores are set in molds. Daubing is a term also applied to the same operation.

Venting of Cores

When the design of a casting is such that nearly all of the core is surrounded by metal, it becomes imperative to supplement the natural venting properties of the sand by creating additional passages that will lead from the interior of the core, through core prints, to the outside of the mold. These passages will lead off the gas generated during the pouring of the casting and prevent blow holes which would cause the casting to be defective.

From the viewpoint of core finishing, we are mainly concerned with the work done on venting after the core is baked. In some cases, all the work is done after baking and, in others, it becomes merely necessary to see that the vents are open. In the latter case, it becomes merely a matter of inspection. For a clearer understanding of this phase of core work, it will be well to discuss each type of vent and the relation of the core finishing operation to the vent.

PRICK VENTS

Prick vents are those formed during the coremaking process by pushing a wire or rod into the core before it is baked. If the rod used is of $\frac{1}{8}$-in. diameter or larger, and the sand has any appreciable green bond, an inspection of the opening will be sufficient. In the case of smaller rod diameters, it will be well to insert a wire to make sure that the vent is open.

WAX VENTS

Wax vents are those made by ramming a string of vent wax in the core. During baking, this wax melts and leaves a fairly open passage through the core. It is merely necessary to open the end of a wax vent, but care should be exercised in the method of opening it. The surface of the core must be broken or scraped off at the point where the vent is led off. To insert a rod or wire may pack the wax and sand tightly together, and thus defeat the purpose of the vent by closing it.

COKE

Cores of the large chunky type may be vented by ramming up a coke bed in the interior of the core. If there is no passage made from this coke bed to the exterior of the core, it will be necessary to dig or drill one.

RAM-UP VENTS

Ram-up vents are those produced by ramming wires or rods in the sand and withdrawing them from the core before it is removed from the core box. To successfully vent a core, it may be necessary to use several such vent wires and to connect them to a main vent leading to the exterior of the mold, through a core print. Where the diameter is small and the wire is long, small posts are used to support it in the core box so that it will remain in the correct position during the ramming operation.

This type vent causes more work for the core finisher than any other, for he must see that the vents are open, then connect the different passages, and lastly, see that all the holes are closed except those that are to be used to conduct the generated gas to the outside of the mold. This is accomplished by inserting wires in the vents and making sure that they touch each other. While these wires are in the core, all openings made by supporting posts should be filled with core mud.

The wires are then removed and core mud squeezed into the proper opening. The latter operation is the same as mudding a rough spot on a core, except that a little stiffer mud should be used. A slight amount of core paste sometimes can be mixed with this mud to make a harder filler. If the opening in the core made by a ram-up vent is quite large, a plug core of the correct size can be used to close the end of the vent. If the plug core is a loose fit, it should be dipped in some thin core paste before inserting it in the vent opening.

GROOVE VENTS

Groove vents are made by using either a file or hacksaw blade to cut a groove in a core. The best illustration of this type vent is the one connecting several ram-up vents to the ground surface of the two jacket cores in a water jacket assembly. In the case where cylindrical cores are made in halves, it is general practice to groove a vent in one or both halves before the pasting operation is performed.

SIZING OPERATIONS

Sizing cores, when desired, is performed after the

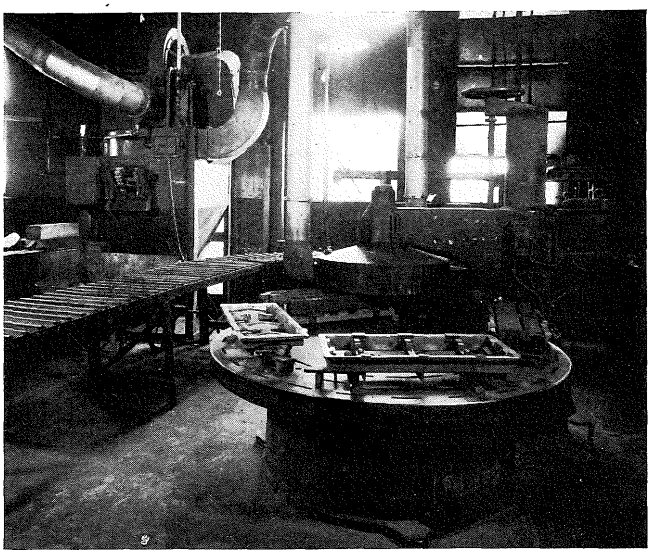


Fig. 10.2 — Core grinding machine setup. Note empty fixtures in the foreground and the two fixtures with cores at either side of the machine.

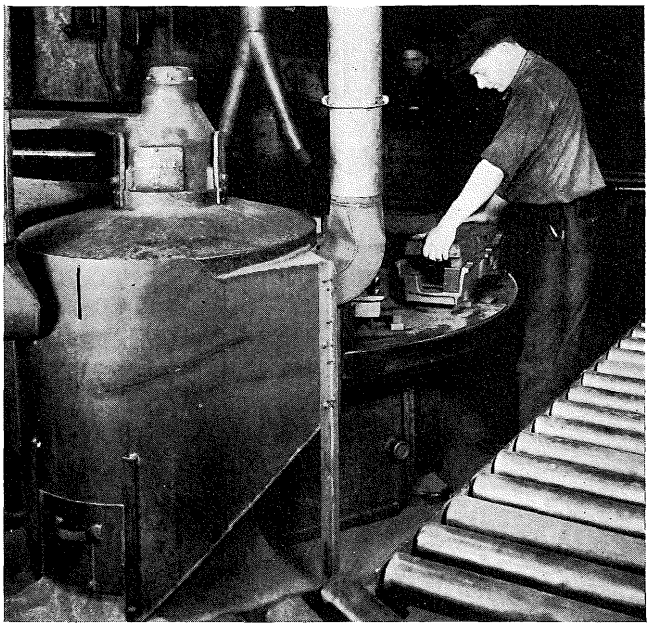


Fig. 10.3 — Inserting core in fixture for grinding operation.

core has been baked. Depending on the design of the core and the accuracy needed, a core may be checked for size by a simple gage, by a template, or by grinding or filing the core to a specified dimension. With the exception of the grinding and filing, all sizing operations are in the nature of inspection and may take place at any time during the core finishing process.

Templates

A template is a sheet or piece of metal, usually steel, about 1/8-in. thick, with a cut-out the same size or shape as the core to be checked. When the core is placed on a machined plate and the template dropped over the core, the metal edge of the cut-out in the template should fit closely around the core. This method will check the height and width of the core and will prevent the use of cores that have sagged out of shape. If the need for accuracy is sufficiently great, two templates may be used, one for the cross-sectional width and another for the cross-sectional length. It may not be necessary to check every core by this method, but practice will prove the necessary percentage to size.

Filing of Cores

When a core does not fit a template, it may be possible to alter the size sufficiently by filing to produce a usable core. In this case, filing is used to mean the alteration of a dimension by use of a file or a piece of emery stone rather than trimming off any projections from the surface of the core.

Where dimensional accuracy is imperative, but the production is limited and does not warrant the use of expensive grinding fixtures and other equipment, it is general practice to substitute a wooden filing fixture to file the cores to size. The wooden fixture is built to fit the core and the surface over which the file moves is protected with steel strips. The core box is made slightly oversize to allow for filing. The cores are placed in the fixture and filed down to the steel-topped surface, thus making every core alike. The most common illustration of this type of filing is the sizing of water jacket cores made for experimental cylinder blocks from wooden core boxes.

Grinding of Cores

Where it is necessary that each core be of exactly the same size, the best results can be gained by grinding. The core is located in a grinding fixture and passed under a grinding wheel which is set to produce cores of the correct dimension. There are two types of grinders. On one the wheel is stationary, and on the other, the wheel is located on a carriage which is passed over the core. The stationary wheel grinders are more in use than the other type. The latest type grinder has a stationary wheel and a rotary table on which several different grinding fixtures can be located thus saving set-up time. An installation of such equipment is shown in Figs. 10.2 and 10.3.

There is no case where the precision grinding of cores is more necessary than in the production of water jackets for cylinder blocks. To maintain an even metal thickness between the water jackets and the port cores, it is necessary that the jacket cores be held very accurately to a specified dimension.

The ideal set-up for grinding cores is where the rotary table, upon which the fixtures are located, passes under the revolving wheel which is adjustable in height. Where there are several such fixtures and it is found advisable to alter the size of only one of the cores in the set-up, the alteration must come from a change in the location of the fixture or a change in this fixture. When building fixtures for such a set-up, it is good practice to have four set screws incorporated in the base of any fixture so that minute adjustments may be made to the size of any core without changing the height of the grinding wheel itself. It will probably be necessary to change the wheel position after grinding about 1200 cores but the size should be checked after each 400 cores are ground.

The size of the ground core may be checked by simple snap gages, by trial gages similar to filing fixtures, by the position of a core in an assembly fixture,

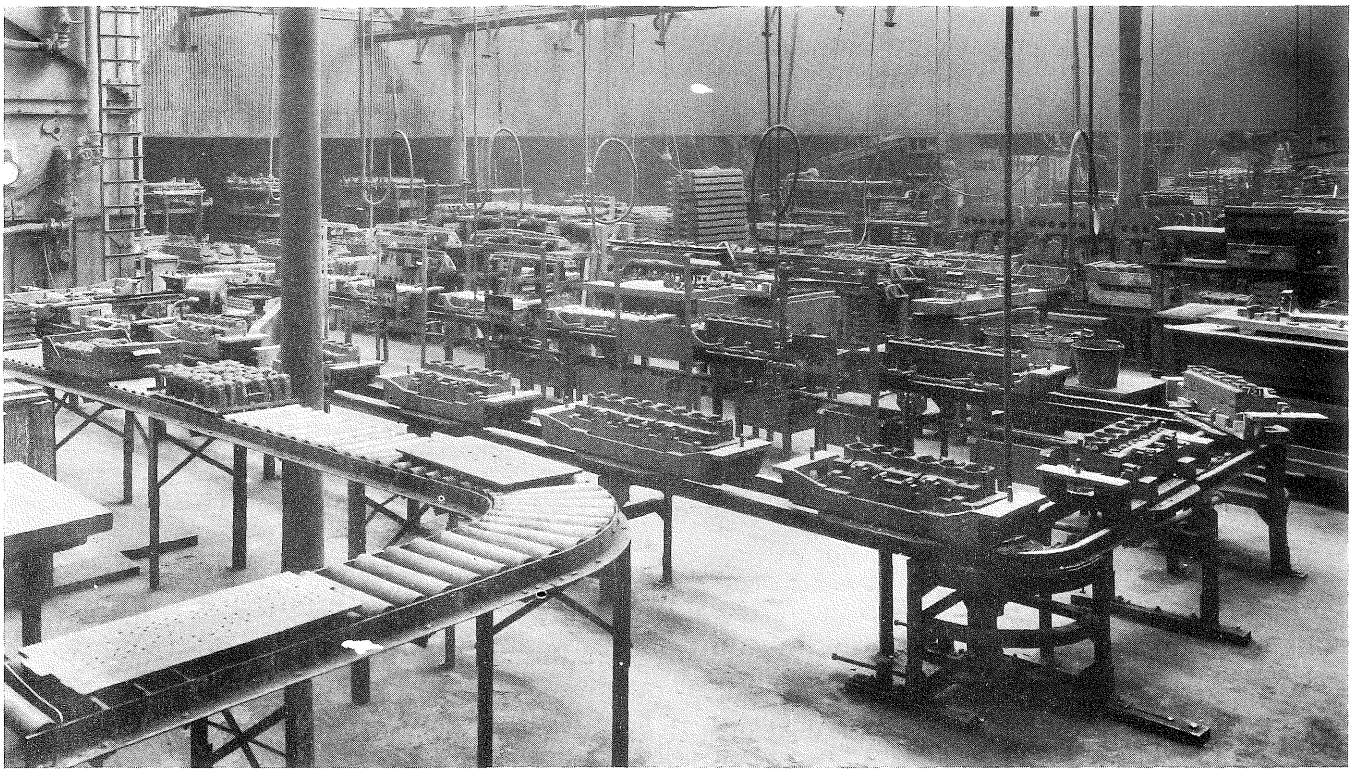


Fig. 10.4 — View of core assembly department in large automotive foundry.

by the use of calipers or by a contour gage or template. Finished core assemblies of any size should be rechecked in a contour fixture because, although each individual core may be of the correct size, there is a possibility of error or distortion in the assembly operation.

Some of the reasons and conditions that necessitate the grinding of cores are listed.

(1) Crooked or imperfect plates on which the cores are baked. The plate surface should be specially ground if it is to be used for a pasting surface in any assembly.

(2) The need for uniform accuracy, as in the case of water jacket cores.

(3) To compensate for any sagging that may occur before or during the baking process.

(4) To produce a definite and uniform location point, as in the case of a base or bottom core set in a mold; the location of several other cores may depend primarily on this core, hence the reason for accuracy.

ASSEMBLY OPERATIONS

To assemble means to fit and hold together, but in core assembly work the operations performed are those that hold the cores together rather than fitting. All cores reaching this stage of production have been prepared and are uniform so that the fitting is almost nil. However, this is not true in experimental work, for the same operator usually does all the fitting and also makes the necessary provision for holding the cores together. The three main methods of holding cores together in an assembly are pasting, bolting and leading or any combination of these methods.

Pasting of Cores

A good grade of core paste can be secured from any reliable firm dealing in foundry supplies so the question of material will not be discussed. It appears to be more economical to use a prepared paste than to attempt to make a paste from talc, dextrin, flour and molasses, although satisfactory results can be obtained by so doing.

The paste may be applied to the core by the fingers, with a brush, by squeezing from a paste tube, or by the use of a pasting fixture. The method of application will be governed by the design and size of the core, by the surface area to be pasted and by the speed of operation desired. Small cores usually are pasted by applying a dab of paste with the index finger or by using a small brush. In case it is desired to apply paste



Fig. 10.5 — Assembling cores. The operator is mudding up the joint of the assembly.

to a number of female core prints, the use of a paste bulb probably will be best. Where it is necessary to apply the paste in long thin lines, quite accurately positioned, the use of a pasting fixture is the best method.

A pasting fixture is a metal form, usually of brass (because of its noncorroding qualities), that has the same outline as the flat surface of the core to be pasted. By means of pulleys, wire cable, a slide and a foot pedal, it is immersed in a paste tank and then withdrawn. The core is placed against this form thus placing the correct amount of paste at the correct location. The paste used with this method of application usually is mixed thinner than when applied by any of the other methods.

When two or more cores, to be set in the same mold, cannot be anchored successfully with available core prints, it may be possible to paste them together and set them as an assembly. Another reason for pasting two cores together is to secure the joint from metal penetration, as in the case of two halves of a water jacket assembly being pasted to seal the joint and prevent metal from entering the vents filed in the joint surfaces. The design of castings for transmission cases and gear boxes usually calls for a bearing in the bulkhead wall and this cannot be made in a single core. The collar core or trimmer core, as they are commonly called, makes one side of this wall and is pasted into the main or body core. In this case, it is a good idea to paste the trimmer core into the main core before the body core is baked, as this method will save considerable handling time in the cleaning operations.

Bolting of Cores

Cores are bolted together whenever pasting does not produce a strong enough assembly. If, due to design, there is a lack of sufficient core prints to hold down the cores and pasting is not strong enough to keep the metal pressure from raising the cores or breaking them apart, it probably will be best to bolt them together. Here again, we are limited to a certain extent by the design of the cores because it will be necessary to leave the required opening through core prints for the entry of the bolt, although this is not always true.

The threaded end of the bolt should be brought into a boss prepared in the core, so that there is ample room to fasten the nut on the bolt. The conventional type nut can be fastened better with small socket type wrench mounted on the end of a Yankee screwdriver. If the bolt is rammed up in one of the cores in the making process and is rigid in location, it may save time in assembling to use speed nuts instead of the conventional type nuts. Speed nuts may be described as thin steel washers that can be forced onto the threaded end of a bolt by straight pressure.

After the cores have been bolted together, it is necessary to close over the ends, if such end is in part of the core that will form part of the surface of the casting. This can be accomplished by pasting a small special plug core in the opening or by merely mudding over this spot, if it is not too large.

Leading of Cores

Leading also is used in the assembly of cores whenever pasting does not produce a sufficiently strong core

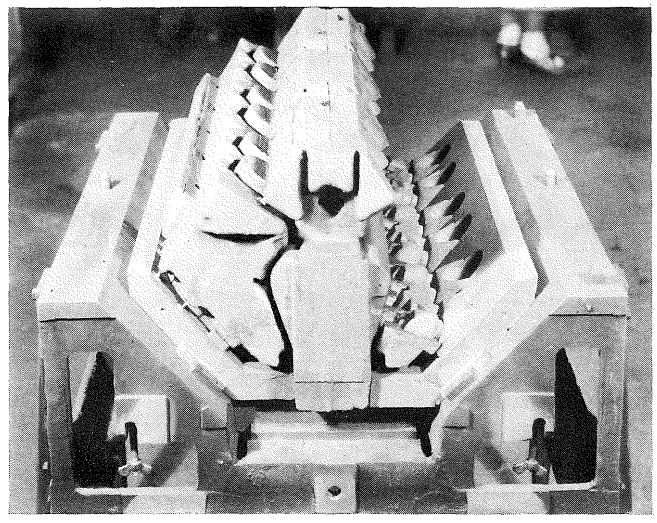


Fig. 10.6 — Core assembly fixture for V-12 engine block. Several parts of the core assembly are shown in position.

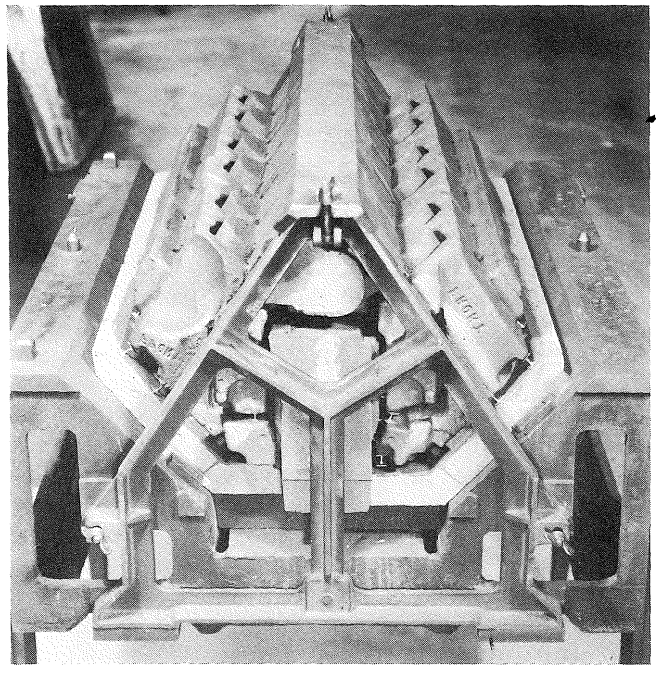


Fig. 10.7 — Core of V-12 engine block completely assembled in fixture.

assembly. Preparations that must be made before the cores are baked are much the same as in the case of bolting, as provision must be made to leave holes in the cores into which the molten lead is poured.

When the molten lead solidifies, it makes a strong tie between the cores and they can never be disassembled. To prevent leakage of metal, there must be a tight fit between the cores where the leading posts meet. If the cores are to be leaded through core prints, it may be necessary to paste the prints to prevent leakage, but usually a tight fit will be sufficient. If the cores are blackened before assembly, it is imperative that the core wash entering the leading holes be perfectly dried, otherwise the molten lead will kick out or, if it bubbles as it is poured, the tie will be imperfect when the lead solidifies.

A small ladle, which holds exactly the correct

amount of molten lead for one pouring, should be used so that there will be no overpouring. The molten lead should be held at an even temperature in a pot over a gas burner. If the lead is too hot, it will take too long to set and thus waste time in the assembly operations.

FIXTURES IN CORE ASSEMBLY

Many castings are so designed that it is necessary to make the internal portion of a large number of cores. An automotive engine block is an excellent example. Figure 10.4 is a view of the core assembling department of a large automotive foundry. In this view, several different types of assembling fixtures may be seen. Note the core assembly on the conveyor in the foreground. The assembly fixtures really are cradles which aid the operator to accurately assemble the various cores. The cradles are resting on steel plates which are linked together by a motor driven chain. A close-up view of the actual core assembly is shown in Fig. 10.5. The operator is mudding up the joint.

Figure 10.6 shows a core assembly fixture for a V-12 engine block core with parts of the cores in place. Figure 10.7 shows the complete assembly.

T.C.
ANADOLU ÜNİVERSİTESİ
Merkez Kütüphanesi

Chapter 11

CORE COATINGS

INTRODUCTION

The term "core wash," as generally used in the foundry industry, refers to all refractory materials applied by means of a liquid carrier to sand cores. These materials also are referred to as: blacking, core dip, facing, graphite, etc.

FUNCTIONS

The primary functions of a core wash or coating are twofold: first, to improve the casting surface; second, to reduce cleaning costs. When applied to the surface of a core, the fillers in the wash fill the voids between the sand grains and cover the surface with a fine mesh material, thus preventing metal penetration into the core and also providing a smooth surface against which the metal can solidify.

A core wash or coating also acts as an insulator between the hot metal and the sand and reduces the temperatures to which the sand is subjected. The reduction in temperature prevents the sand from fusing and sticking to the casting. This reduces cleaning operations and results in a net reduction in the cost of the casting.

TYPES OF CORE WASHES

Core washes can be classified as carbonaceous and carbon free, also as dry and wet. Carbonaceous coating materials are used in water mixtures. Carbon free coating materials are used with water and other liquids such as core oil, gasoline, alcohol and naphtha.

Another group of core washes contain hard rubber cement which produces a strong tight bond which is moisture proof. The rubber cement bonded core washes may be mixed with graphite carbon, silica or zircon flour.

COMPOSITION

Carbonaceous core washes contain carbon as graphite or some other form of powdered carbon. Their value as coatings lies in their capacity to form an insulation between the molten metal and the sand grains. Graphite and other forms of carbon will burn, but, since the oxygen in the mold cavity is quickly exhausted as the molten metal flows in, the burning is sufficiently retarded to maintain a protective film far beyond the point where sand fusion might occur, or metal penetration take place.

Carbon free core washes, on the other hand, owe their merit to the refractoriness of their ingredients, such as silica, talc, magnesite, alumina, zircon, asbestos and mica, and to their ability to withstand penetration by molten metal.

Black washes used for gray iron, malleable and nonferrous castings generally contain carbon in one form or another. These washes may contain various grades of good or poor graphite; some contain pulverized hard and soft coal; others, coke, coal tar, carbon black and petroleum pitches, in various combinations and percentages. In addition to the carbon containing materials, they may contain silica flour, clays of various kinds, talc, inorganic by product materials such as fly ash, grinding refuse from glass plants, etc.

The white or light colored washes are usually composed of silica flour, talc, high fusion point materials, such as magnesite, silicates, aluminum oxide, asbestos.

PHYSICAL CHARACTERISTICS AND INGREDIENTS

The physical characteristics of core washes are principally color, fineness, and bond. The color is of minor importance and depends largely on the materials used to give the desired results. The fineness is of considerable importance. For some classes of work and some types of cores, a finely ground core wash is superior. Other classes of work and cores require a coarser, more open material to allow easy escape of moisture in drying of the core and to minimize shrinkage.

CORE WASH BONDS

The bonds used in core washes are important and often govern the results obtained. These bonds must function through a wide range of conditions; i.e., application, drying and pouring. Bonds used must allow the core wash to be applied as a smooth coating to the sand and retain the smooth surface until the metal has solidified.

In addition to its protective action between metal and sand, a core wash must adhere to the core surface with enough tenacity to prevent it being dislodged by flowing metal and it must remain in suspension in the dispersing medium to maintain a uniform coating film. If the film is washed off by the metal, it may be trapped in the casting as dirt and the casting surface will be rough. If the solid matter settles out of solution due to poor suspension, the cores soon will be too thinly coated.

Proper adhesion is obtained by incorporating the right amount of binder in the core wash. Unless oth-

erwise specified, such binder is of the water soluble type, since it is assumed that the core wash will be used with water. It should be borne in mind that water soluble binders are not adhesive where volatile solvents are used. A special binder is necessary in this case. On the other hand, binders that are effective in volatile solvents, are quite useless in water. It should be pointed out that an excess of binder may cause blows if the gas formed by its burning is not properly vented off.

In job shops, where there is a wide variety of castings both as to size and type, one may, for the sake of flexibility, purchase a core wash without binder and vary the percentage of binder in the mixture according to the requirements of each job.

Many users of manufactured core wash make additions of other materials, such as plumbago, to the solution to get characteristics more suited to their work. Where the additions exceed 15 to 20 per cent, more binder should be added, since there is only enough binder in a compounded core wash to take care of its own ingredients.

To insure good suspension in water, compounded core washes contain colloidal clay, for example, certain bentonites. A variation of this ingredient varies the number of pounds of dry core wash required per gallon of water to give the same solution consistency and also affects the deposition of solution on the core. Colloidal clay will not suspend wash in any liquid other than water.

Bonds used are of two general classes; organic and inorganic. The organic bonds are generally highly soluble in water. When water is dried from the core wash, these bonds set. The drying may be accomplished in one of several ways. Core wash may be applied to a green core and dried at the time the core is baked. It may be applied to a warm or hot core, drying from the residual heat in the core. It may be applied to a cold core and put through a drying oven. It may be applied to a cold core and dried with a torch. These various methods indicate the wide range of temperatures to which bonds are subjected. They also indicate the speed of temperature change to which they are subjected.

Most soluble organic bonds begin to deteriorate at relatively low temperatures. The soluble organic bonds depend on heat to perform. The temperature must be raised to a point where the bond will liquefy and then reset on cooling. Bonds of this type, such as starches, dextrin, sugar, molasses, etc., when subjected to excessively high temperature for sufficient time, give off volatile material and burn out.

Inorganic bonds, consisting chiefly of clays, bentonites, silicates and oxychloride, function through a wide range of temperatures. The fusing point of clays or bentonites is generally below the base materials. The physical action of clays or bentonites is widely different from the base materials at the various temperatures encountered, and an excessive amount of this type of material results in undesirable features.

The hardness of a core wash, when dry, should be less than the hardness of the core surface. When the core wash is harder than the core surface, the wash has a tendency to lift or peel from the surface on drying or to peel off at the time the mold is being poured.

BASIC REFRACTORY CORE WASH MATERIALS

Basic refractory materials used in core washes are graphites, coke, mica, silica, aluminum oxide, magnesium oxide, asbestos, etc.

Graphite

Graphites are of two general types, crystalline and amorphous. Graphites are mined from the earth and are found in many locations on the earth's surface. The location of the mine governs the type of graphite which is produced. The quality and price of graphites are generally measured in terms of carbon content. The carbon content of the majority of graphites used in core washes runs from 50 to 90 per cent. The majority of the graphites used probably fall in the 60 to 80 per cent carbon content range. The materials other than carbon are impurities such as alumina, silica, iron oxide, etc. The producer of graphites has little control over these impurities. They may or may not be detrimental to performance of the core wash.

Coke

Several grades of coke are available for core wash manufacture. Each grade is relatively uniform and a strict control can be maintained over the impurities which are present. The carbon content of the coke is uniformly higher than the majority of graphites.

Mica

Mica of the proper grades has been employed to a limited degree in core washes.

Silica

Silica, when finely ground and of high purity, provides a satisfactory base material for core washes. Other materials have been tried, such as aluminum oxide and magnesium oxide, and have been employed to a limited degree.

FORMS OF CORE WASHES

The largest tonnage of core wash is sold in dry powder form. However, two other forms are available. One is a pre-mixed paste that must be diluted by the user, and the other is a ready to use mixture containing a volatile solvent and designed for fast air drying.

Most core washes are mixed with water as a dispersing medium. Special conditions, such as insufficient core storage or overtaxed oven capacity, sometimes necessitate the use of such mediums as gasoline, naphtha or alcohol for fast drying.

CONDITIONS GOVERNING BEHAVIOR OF CORE WASHES

The sand and binders from which cores are made form the foundation for core washes. The type of sand, i.e., sharp or bonded, and the type of binder, i.e., oil, cereal, pitch, etc., have an important bearing on the quality of the foundation.

The physical properties of the core mixture and the final core, such as moisture, permeability, green strength, dry strength, hot strength, expansion, and contraction, all help to determine how the foundation will act under the conditions to which it is subjected. There are so many combinations of these many contributing factors that only a thorough knowledge of



Fig. 11.1 — Dipping cores in large automotive foundry.

their behavior will assist in forecasting results or correcting unsatisfactory cores.

In selecting a core wash, consider all important conditions to be met, such as sand foundation for the wash, type of metal, temperature of metal, method of application, drying conditions, core setting, pouring and storage.

PREPARATION OF SOLUTIONS

Experience has proved that much better core coating can be obtained from the same core wash if the solution is mechanically mixed than if mixed by hand. This is due to the fact that, to give a smooth film, free from bubbles, every grain of the powder must be wetted thoroughly and all of the air in the powder must be replaced with water. Hand mixing will not accomplish this.

If a core wash is high in colloidal clay, it will be found that, after mixing with water, the solution gets somewhat heavier on standing for several hours. Colloidal clay requires an appreciable length of time to reach its water saturation point and mechanical mixing greatly reduces the time interval. Some foundries have found that thickening of the solution can be prevented if the core wash is soaked over night with a smaller amount of water and then mixed to proper consistency the next day.

The capacity of a mechanical mixer in gallons of solution per day can be increased by as much as 50 per cent if the solution is mixed very heavy and diluted in the dip tanks. Thorough stirring when diluting is very important.

Proper procedures in preparing core wash solutions will greatly reduce the mixing time. Start the mixer, put in some water and then some dry or paste core wash. Alternate additions of water and core wash until the batch is complete. This will prevent the formation of large lumps of powder which are difficult to wet.

SOLUTION CONTROL

When the ideal consistency of the core wash solution has once been determined, such consistency should be maintained by measuring the specific gravity (Baumé) or viscosity of each batch and diluting to the predetermined standard. Uniformly coated cores will result.

Baumé is in reality a measure of specific gravity reduced to a simple scale of numbers. It is determined by means of a hydrometer for liquids heavier than water, a suitable range being from 10 to 70 degrees. Ten degrees Baumé means a very thin solution and 70 degrees Baumé means a very heavy and thick solution. Somewhere between 10 and 70 degrees Baumé the most suitable gravity will be found.

Viscosity can be measured by means of a metal cup with a hole in the bottom. By placing this cup on the solution surface and clocking the time required for it to fill with solution through the bottom hole, the flow, and therefore the viscosity, is determined. The Baumé hydrometer is much simpler to use.

MAINTENANCE OF SOLUTION

If a solution has stood over night in a tank, it should be stirred well before cores are dipped. More solution can be added from time to time as the level lowers, but the specific gravity (Baumé) should be checked after each addition to insure uniformity.

Core wash tanks should be scraped and flushed out every few days to prevent fermentation, particularly in hot weather when spoilage can start much faster than in cold weather. Fermentation is identified by a frothing action together with an odor of putrefaction. The froth cannot be skimmed off clean because it forms continuously and will form a rough surface on coated cores.

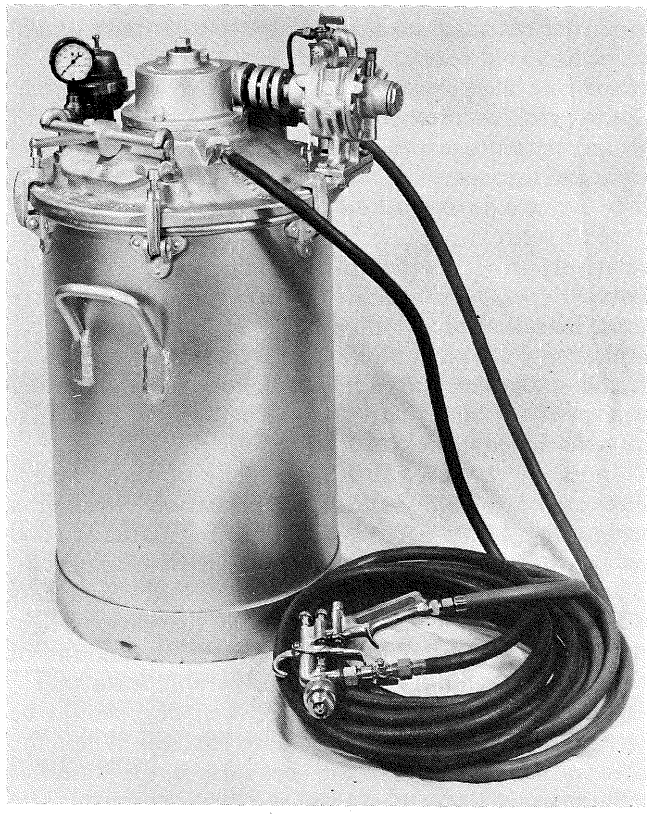


Fig. 11.2 — One type of core spraying unit.

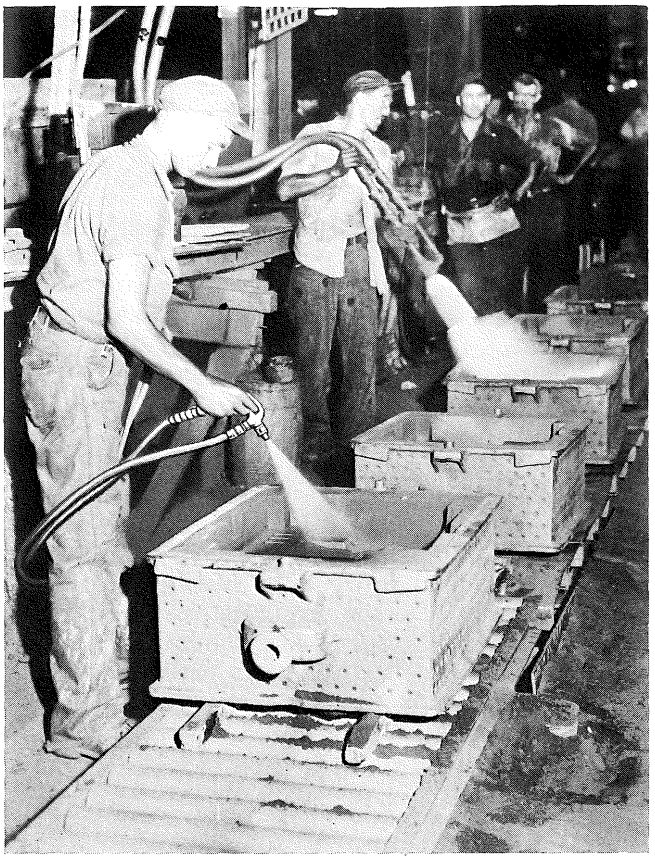


Fig. 11.3 — A syphon spray gun being used on molds. The same kind of gun may be used to spray cores.

There are conditions under which a thin, low Baumé solution must be used or the core wash must be low in colloidal clay content. In such cases, the solution may require continuous agitation while cores are dipped. Two methods of agitation are in use: (1) revolving paddle wheels near the bottom of the tank, and (2) perforated pipes on the tank bottom through which air is bubbled. The dipping operation in a large automotive foundry is shown in Fig. 11.1. In this case, the dipping tank is lifted as the core carrier becomes centered over it and the core is immersed to the proper depth automatically by controlling the level of the coating in the tank. In other instances, the cores are placed on a platform which is lowered by an air cylinder into the stationary tank containing coating.

The paddle wheel method is better because it does not inject air into the solution. Where bubbler pipes are used, it is advisable to provide an oil trap in the air line to prevent oil from the air compressor contaminating the solution surface. A large number of small holes and low air pressure is better than a small number of holes of large diameter and high air pressure, since, in the latter case, the solution is too violently stirred and may even act as a centrifuge to deposit a sludge of coarser particles in the corners of the tank.

METHODS OF APPLICATION

Cores may be coated while green by spraying or dipping. Dry cores may be coated by dipping, swabbing, spraying or brushing. Coating green cores by dipping results in all cores being coated exactly the same. Spraying, if carefully done, avoids accumulations of excess solution in pockets. Most dry cores are dipped, some are brushed and few are sprayed. Figures 11.2 and 11.3 show two types of guns used for spraying.

Figure 11.2 illustrates a core spraying unit with the spray gun in the foreground. The core coating material is placed in the tank at the left, which is tightly sealed. The coating material is agitated constantly with a paddle during operation, to ensure proper mixing. Corrosion resisting materials are used in the spray gun and for the mixing paddle.

The spray gun, shown in Fig. 11.3 is of the syphon type and has no fluid valve. It is built in two types, one in which the material comes on the outside and the air on the inside nozzle and the other in which the material comes through the center and the air through the outside nozzle. The latter type is claimed to give a finer and better atomized spray.

Coating Small Cores

Small to medium size cores are usually dipped. In some core rooms, where two or more coats may be required on large cores, they may be sprayed while green, placed in the oven where the cores are baked and the wash dried, removed from the oven, allowed to cool to about 180 F (82 C), and a second coat at a higher Baumé brushed on. Cores can be dipped while hot, provided their temperature is not above the boiling point of water (212 F [100 C]). If they are hotter than this, the coating will boil and the surface of the core will be very rough.

Coating Large Cores

Very large cores are sometimes coated several times by brushing to build up a thick protective film. Where two or more coats are required and a fine finish is not necessary on the castings, the first coat may be medium thin (about 27 degrees Baumé) to penetrate the sand and to coat several layers of sand grains. The second coat can be heavy (about 40 degrees Baumé) to build up the film. Brush marks will show on this second coat and, if they must be covered, a third coat of thin wash (about 20 degrees Baumé) lightly applied, will leave a smooth surface.

Green vs. Dry Cores

It is sometimes necessary to use a different type core wash for coating green cores than for dry cores. This is particularly true where the cores are bonded with oil, since unbaked oil is more water repellent than baked oil and the core wash solution does not penetrate the green core to a sufficient depth. In automotive core work, it has been found practicable to coat those cores which are opposite pouring gates, then to assemble the cores and finally dip the core assembly. The cores that must withstand the most severe action by the flowing metal are thus double coated.

Gravity of Solutions

In general, low specific gravity solutions are used for spraying (20 to 28 degrees Baumé), medium gravity solutions for dipping (25 to 37 degrees Baumé) and heavy gravity solutions for brushing (35 to 50 degrees Baumé), although many exceptions occur.

DRYING OF CORE WASH

For the most part, a core wash is dried by passing the coated cores through a drying oven. Some are coated while hot and the film dried by the residual heat in the cores. Air drying core wash, mixed with a volatile solvent instead of water, allows cold cores to be dipped and dried without passing them through a drying oven.

In some special cases, cores may be dried by means of heat from a hand operated gas torch. Care must be taken in drying cores in this manner to prevent overheating and burning out the binder from the core wash. Excessive heating may even weaken the core to a considerable depth, particularly at corners, resulting in the core breaking down when metal is poured around it. Another method is to place the coated cores on sheet steel plates heated by steam.

Where cores are coated green, the core is baked and the coating dried in one trip through the oven, the cores will bake faster if the wash is of an open type or, in other words, if it has high surface permeability to allow for the escape of steam and core oil volatiles from inside the core.

NATURE OF THE FILM

A core wash should penetrate into the sand to a great enough depth to insure anchorage of the film and to provide more than just surface protection on the core. However, it should not soak in so deep that it becomes of little value because it is too far from the point of contact with the metal. Too much penetration causes the cores to be rough. The wash must adhere sufficiently so that metal will not dislodge it, yet it should not be too hard and tight. Metal will lay more easily against a soft texture surface than against a hard, glazed surface. Glazed core surfaces also allow the incoming metal to skid and to become too turbulent.

Properly compounded core wash, if used at the correct specific gravity, should not, after drying, show tear drops nor runs, nor should it run to such an extent that it builds up a heavy ridge at the bottom edges of the core. All such imperfections require extra time for removal or else they will produce a like defect on the casting surface.

Unless cores are coated green, there is no point in specifying a core wash that forms a highly permeable film, since no venting action is required through the film and all gas originating inside the core passes off through the core vents.

The ideal gravity at which any core wash should be used is that which gives a film with protection between metal and sand, yet does not use an excess of material, nor form tears or runs. Coverage should be complete and uniform.

The best core wash will not protect poorly made cores nor cores made from poor core sand. It is not a panacea for all core ills, but it will give smoother casting surfaces with fewer defects and will reduce expense and time in the cleaning room.

COATINGS USED IN STEEL FOUNDRIES

Coatings used in steel foundries are principally composed of silica flour, although in recent years some zirconium oxide and magnesite have been used. The silica flour, as well as the zirconium oxide and magnesite, is mixed with water and a binder. The binders used are molasses, dextrin, paper mill sufites, corn, wheat and rye flours, and commercially prepared wash bases which are used in paste form. Clays, bentonites and starches are used as emulsifiers.

The commercially prepared coating bases act as emulsifiers or suspending materials for silica flour and zirconium oxide. Such bases also contain binders and some contain waterproofing agents, which prevent the coating from absorbing moisture after it has been dried on the surface of the cores and molds. One coating contains a wetting agent, which causes the coating to penetrate and adhere to the surface of sand.

Fire clay and silica flour are more resistant to high temperatures than other binders and therefore are desirable in mixes and washes for heavy section castings of either cast iron or steel. Scabbing and flaking often are caused by cores that are too hard or too close or where the coating is very hard and the surface of the core is soft.

The problems of applying silica wash before or after the cores are baked, and the further problem of the method of application, resolve themselves into a simple question of convenience. Some cores can be

WASHES FOR CORES FOR STEEL CASTINGS

	Plumbago, Parts	Talc, Parts	Magnesite, Parts	Resin, Gal	Zircon Flour, Lb	Silica Flour, Qt	Silica Flour, Lb	Bentonite, Parts	Bentonite, Lb	Bentonite, Qt	Cereal, Parts	Clay (Kaolin), Lb	Chrome Ore, Lb	Core Oil, Lb	Core Oil, Qt	Salt, Lb	Dextrin, Lb	Water, Gal
1. Chrome Steel (light)	8	2						2			1							As Required
2. Chrome Steel (light)				1			150											30
3. Manganese Steel			100					20			20							As Required
4. Carbon Steel					300					4					4			
5. Silica Flour Wash							150		12							3		25
6. Silica Flour Wash							150		4			15						As Required
7. Silica Flour Wash							150						18				6	As Required
8. Silica Flour Wash							150		6					18				
9. Silica Flour Wash				3/8		8				1								3-4

washed more conveniently before they are placed in the oven, while others, especially those which lend themselves to the dipping process, can be handled more conveniently in the dried state. One objection to the after-baking process is that unless the cores are washed while they are quite hot, they must be returned to the oven for a supplementary drying. As far as the ultimate result is concerned (the ability of the silica wash to prevent penetration of the steel), experience would seem to indicate that no particular advantage can be claimed for one method over the other.

Obviously the wash may be applied more rapidly with a spray gun than with a brush or swab. However, the method has certain limitations, particularly in the hands of men who are not sufficiently expert. Large, plain surfaces present no difficulty, but in deep pockets and on irregular surfaces, the distribution of the wash may not be uniform and an excess amount of solid material will be deposited in the bottom of depressions.

In the steel foundries, coating mixtures frequently are compounded by the proprietor, some of which are given in the table.

Silica-base core coatings generally are used in steel foundries. However, for light chrome steel castings, the carbonaceous washes Nos. 1 and 2 shown in the table, have been used. Spraying the mold and core surface with linseed oil while hot has proved useful for cores for manganese steel castings.

Coatings using magnesite as the base are also found in use for the manganese steel castings. An example is No. 3 in the table.

A core coating frequently in use in European foundries making manganese coatings consists of a mixture with a base of Austrian natural magnesite mixed with water. For carbon steel castings, silica base washes are almost universally in use. However, exceptions may be found, as No. 4 in the table.

Examples of silica base coatings of interest are those that use: (1) bentonite, (2) fire clay, (3) dextrin and (4) core oil as binders. Mixtures Nos. 5, 6, 7 and 8, shown in the table are examples of each.

In steel foundry cores bonded with resin binders, the coating, No. 9 in the table, has been used successfully. This wash is prepared by first mixing thoroughly the dry ingredients, putting the mixture through a fine riddle three or four times, then adding to the water in a mixing barrel equipped with good agitation. A wash of this type should be made up a day ahead of use, and then thinned to the desired consistency. This wash should be applied to green cores, since it hardens only on baking.

The coating mixtures given in the table are not particularly examples of good foundry practice, but are examples of various combinations of ingredients that are used today in steel foundry practice.

COATINGS FOR BRASS AND BRONZE CASTING CORES

When the surface of cored holes or cavities is not of vital importance, no core wash need be used for the average brass or bronze alloys. However, if penetration or cutting is a problem, such cores may be coated with a core wash of a talc, plumbago or silica base. For high leaded alloys and phosphor bronzes, some sort of core wash often is advisable to offset the searching qualities of these metals. In some cases, cores for castings made of those metals are coated by rubbing them with a paste made from plumbago and either a weak silicate of soda or molasses water. Such treatment following a thin spray of a regular core wash is particularly effective. The core wash fills the spaces between the sand grains and the paste still further seals the core surface against the searching of these metals. In some instances, it is sufficient to spray the cores with molasses water before baking. This provides a fairly hard surface. Black lead core washes often are applied to such cores by dipping or brushing after baking. If the black lead wash is made with water, the cores should be redried in an oven after the coating has been applied. If the core wash is made with a small amount of core oil, the core should be rebaked for a short time after the application of the wash. If the core wash is made with a volatile vehicle, no reheating is necessary.

In heavy sectioned brass and bronze castings, it may be necessary to put on several coats of core wash and, in such cases, care must be taken to dry each coat thoroughly before the next coat is put on the core. For such heavy sections, a wash may be made with water, molasses water, glutrin, kerosene or water glass, depending on the wash used and the local practice.

A wash of one part water glass and two parts water also is used for cores in bronze castings where burning in, penetration, etc., are serious problems. Cores of heavy sections, which burn in badly, may be wrapped in asbestos paper or asbestos may be put in the sand mixture.

Claims are made that a mixture of 10 lb graphite, one lb of patented wetting agent, plus sufficient water to make 5 gal, makes an excellent wash for oil-sand cores for nonferrous castings. The procedure is to dip the core after it has been baked and then rebake after dipping in the previously mentioned solution. Such a procedure is said to produce an exceptionally fine finish on the cored surface.

A core coating suitable for dipping or brushing may be obtained by mixing 11 parts of plumbago, one part bentonite and 15 parts water.

CORE COATINGS FOR ALUMINUM CASTINGS

A core wash of either the talc or graphite type may be used to improve the surface smoothness of cores in aluminum castings. However, many foundrymen prefer to use finer sands and thus produce sufficiently smooth cores without the application of a core wash. Either practice will reduce the core permeability somewhat and may require considerable care to ensure the desired results.

Rubber cement core spray may be used to quickly form a dry skin on the surface of fragile cores so that they will not collapse in handling before baking. An improved finish is often obtained due to the facing value of the rubber.

Chapter 12

CORE HANDLING

INTRODUCTION

While the introduction of the core oven was a boon to the foundry industry, it introduced problems of handling which became more acute as the industry progressed. With the first type ovens, the coremaker was expected to carry his cores to the oven and also get the plates after the core had been baked. With the realization that shop efficiency could be increased, as well as production, if the coremaker made cores and spent as little of his time as possible doing anything else, the handling problem came to a head.

As a result, various solutions were advanced, depending on the layout of the core room. Racks on which the coremaker placed his core plates filled with cores were placed near the core bench and the rack was transported to the ovens, where they were unloaded and returned to the coremaker with a supply of core plates. Some of the first racks were equipped with wheels and were pushed from the coremaker to the oven and return.

With the advent of the rack core oven, hand and industrial lift trucks of various types came into prominence as a transportation medium in the foundry. These were, and still are, used for the purpose of conveying cores to and from the oven and to the molding department.

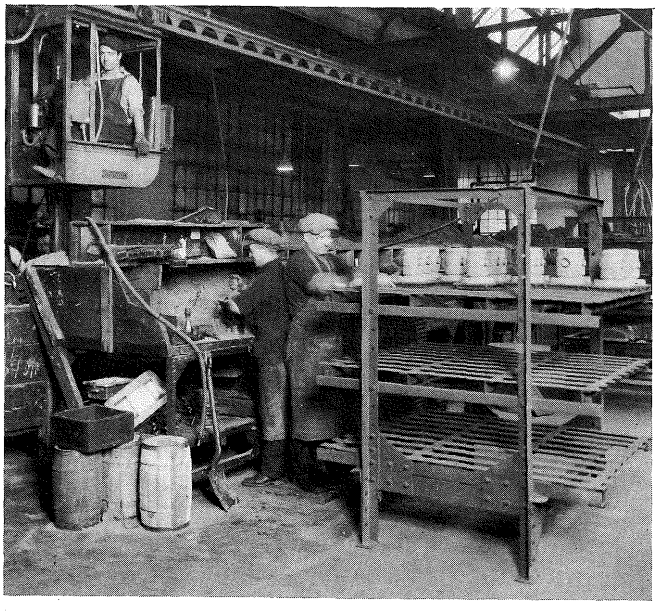


Fig. 12.1 — Coremakers loading a core rack.



Fig. 12.2 — Racks filled with cores ready to be placed in core ovens.

The size and type of core determine to some extent what equipment will best suit the requirements of a core transportation system. In many foundries, the floor rack has proved to be an efficient medium. In such an installation, after the racks have been loaded with cores, they are transported by hand or power lift trucks to and from the oven. Figure 12.1 shows a rack being loaded by the coremakers, while Fig. 12.2 shows racks of cores ready to be placed in the core oven.

When a coremaker transfers cores from the bench or core blowing machine onto core plates, every precaution must be exercised to eliminate any possible shock or vibration that would tend to chafe, crack or break cores. This hazard is much greater when cores are in transit to and from core ovens, storage and foundry.

Cores vary in size and shape. Many cores are made with few or no reinforcement wires because the design of the casting makes it impossible to remove the wires. Conversely, many cores are made with reinforcement wires because of the danger of cores breaking or cracking in transit. However, if proper core trucks or other conveying units are used, it is unnecessary to use reinforcement wires in many cases.

For example, one reputable gray iron foundry was obliged to deliver cores to one of its foundries located across a city streetcar line. To keep core breakage to a minimum, it was necessary to use wire reinforcement. The core in question was used on a domestic gas stove oven burner casting. This core was approximately 15 in. long, 8 in. wide with four 1 in. diameter cores

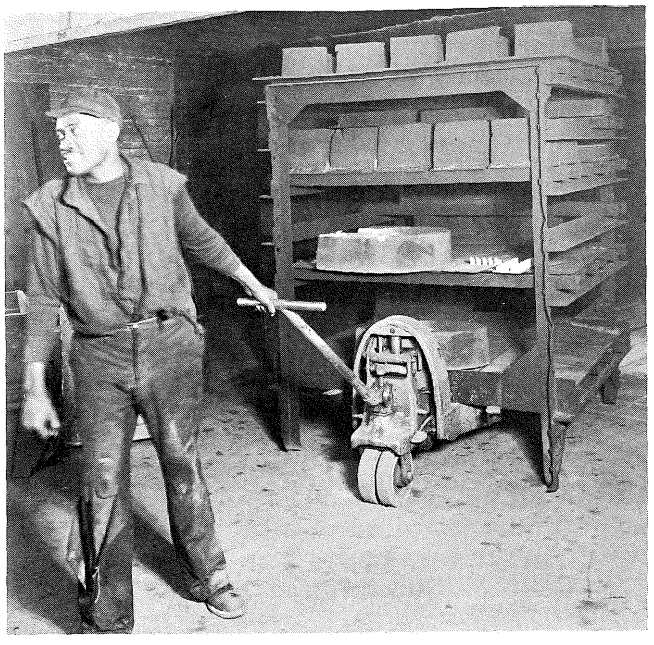


Fig. 12.3 — Cores being conveyed from core oven to the foundry by hand lift truck.

coupled together to the ends. The cost of removing the reinforcing wires was more than the cost of the core itself. This same company now makes the same core without reinforcing wires and, in addition, increased the speed of handling these cores and reduced the core loss appreciably. This was all accomplished by using the correct core truck.

CORE TRUCKS

One type of hand powered core truck has a triple resilient action feature. A combination of coil springs is used in connection with the loading top. This is intended for sensitive resilient action under light loads. Elliptical springs are located between the loading tray and running gear, offering the correct resilient action for heavier loads. Pneumatic tires smooth out or absorb any vibration transmitted from the floors or obstructions.

CORE RACKS

Several kinds of core racks are made. Some racks are made with piping as shelving, others with flat strips. One company makes a core rack with what it calls T-bar construction for its shelving strips. Another company features a resilient core rack in which the rack shelves are sustained on coil springs. These springs are made of a heat resisting material and are not materially affected by the oven heat. It is claimed that when this core rack is used in conjunction with hand or power driven industrial lift trucks, core breakage can be kept to a minimum.

The one point to be kept in mind in the selection of the core rack for use in a core room is that it should contain only sufficient metal to do its job. Too heavy racks retard baking because the metal in them must be heated up along with the cores. Under such circumstances, oven efficiency also is reduced and more fuel than necessary required.

CORE BARROWS

When delivering cores to hard to get into places in a foundry, the core barrow has proved very helpful, more so when handling a large core that must be conveyed through narrow gangways in and around molds. One such barrow is so constructed that the entire load is sustained on coil springs and pneumatic tires. It is available with one or two wheels.

HAND LIFT TRUCKS

Hand lift trucks were among the first pieces of core transportation equipment used by foundries. In many foundries, this type core transportation still is economical and efficient, depending to a large extent upon the physical attributes of the particular plant. Their economical usage depends on the distance of travel to and from the coremaker to the oven, the width of the passageways, number of cores made and used per day, etc. Figure 12.3 shows a hand lift truck being used to transport cores to and from the core oven.

The hand lift truck, illustrated in Fig. 12.3, is the hydraulic type and is claimed to be excellently suited for heavy duty in the core room. This truck, as its designation implies, lifts the load hydraulically, is equipped with rubber tired wheels, and cantilever, or semi-elliptic, springs. The lowering of the load is controlled by foot pressure on the release mechanism and consequently the load can be lowered to the floor gently and without jar. It is claimed that with this truck as much as 250,000 lb can be moved by one workman per day without tiring him unduly.

Requirements for core transportation vary considerably. Some foundries require a combination of rubber tired wheels and spring suspension in lift trucks to meet their requirements. Others may require only one of these features. Some foundries handle extremely fragile cores and therefore require an extremely slow acting release to lower the load smoothly and without any jar. Various type lift trucks are made to conform to the individual requirements of foundries.

POWER LIFT TRUCKS

Where the transportation problems are greater and the physical layout of the plant such that the use of hand lift trucks is uneconomical, and the installation of overhead or conveyor systems is too expensive, the

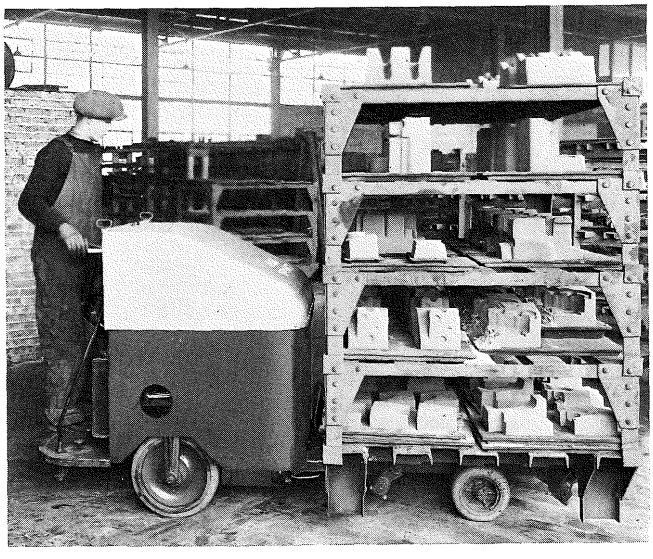


Fig. 12.4 — Power lift truck for transporting cores.

power lift truck has been utilized because of its speed, flexibility, general foundry utility, etc. Figure 12.4 shows a power lift truck transporting cores to an oven. Two general types of such trucks are used in the core room, gasoline and electric. In each case, the platform is suspended over wide tread tires by heavy springs. The springs cushion the road shocks and tend to hold breakage to a minimum. They also enable the operator to move the racks swiftly about the core room.

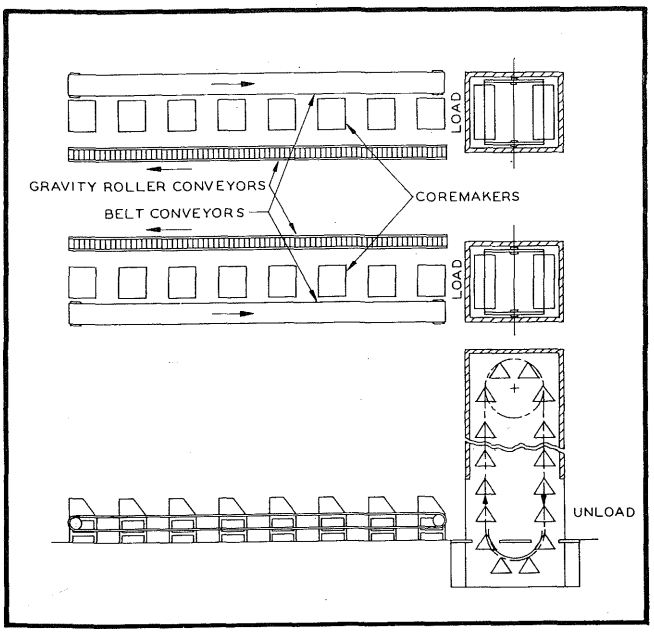


Fig. 12.5 — Two ovens equipped for large production with coremakers grouped parallel to belt conveyor. Conveyor delivers cores to a point where they are unloaded and reloaded onto rack before entering oven. When cases are unloaded after leaving oven, the plates remain on racks for distribution to coremakers by gravity conveyor section which extends the length of the bench layout.

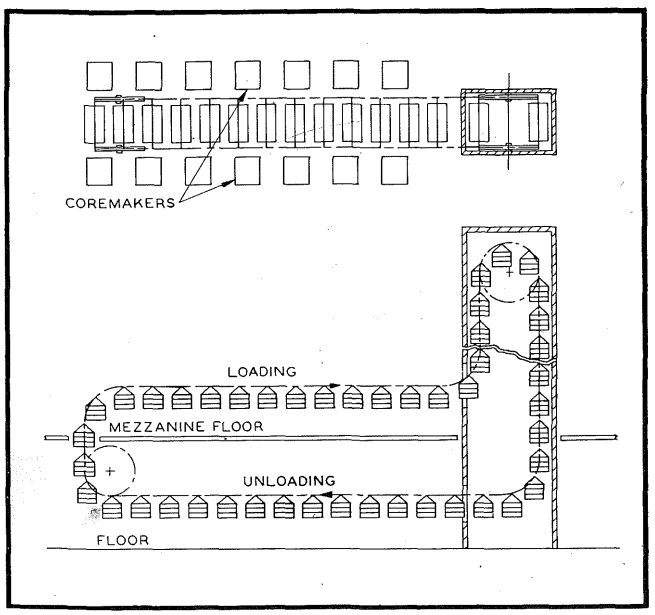


Fig. 12.6 — Design of vertical core oven adaptable to large or small cores. It provides for proper cooling time, unloading space and return of plates and driers to operators located on the mezzanine. The inclined conveyor permits easy loading of both top and bottom shelves. On leaving the oven, cores are cooled by fans so that they can be unloaded with bare hands.



Fig. 12.7 — View showing second floor core room where cores are loaded in vertical oven at left and removed from the conveyor on the first floor.

CONVEYOR LAYOUTS FOR HORIZONTAL CONTINUOUS OVEN INSTALLATIONS

With the further development of the industry and mass production, the demand for additional service to the coremaker led to the adoption of tramrail, belt and roller conveyors in the core room. As will be noted in Fig. 9.10, Chapter 9, Core Ovens and Their Control, the first continuous ovens were merely the baking medium for the cores. Later, extension of the oven conveyors to serve the coremakers was introduced. Figure 9.18, Chapter 9, shows the layout for a large horizontal continuous core oven designed to serve bench coremakers. A conveyor passes between the two rows of benches. The coremakers face the approaching conveyor and rack, permitting the makers to select a location to place their cores. A half turn of the body and a step is the only movement required to load the rack. The conveyor track is inclined so that the lower shelves of the rack are loaded as easily as the upper.

The conveyor leaves the oven over an incline, converges into a horizontal track, then passes the drive and take-up, finally passing around a roller turn to a portion of straight track where the racks are unloaded into filing, sorting and fitting benches. From this point, the empty racks pass underneath the oven to the original starting point.

In the arrangement shown in Fig. 9.12, Chapter 9, Core Ovens and Their Control, cores, together with their plates, are placed onto a gravity conveyor underneath and extending the length of the oven. Cores are unloaded, classified and stored on racks or transported to the foundry. The plates are returned to the makers' benches from the gravity conveyor. The makers' benches are located adjacent to the oven.

A belt conveyor is situated directly behind the makers and transports the cores parallel to the oven. Cores are removed from the belt conveyor, dipped into a blackening tank and loaded onto the conveyor racks at a point prior to entering the oven.

CONVEYING LAYOUTS FOR VERTICAL OVEN INSTALLATION

Where a core room is equipped with vertical core ovens, it is often difficult, if the production is very large, to place the coremakers in an accessible position for loading directly onto the core racks. To overcome

this, the coremakers sometimes are grouped parallel to a belt conveyor which serves to deliver the cores from the makers to the oven. The belt conveyor is usually constructed as a gravity carrier, with idler rolls on the carrying side to prevent undue sagging and resultant vibration in the belt.

As the cores reach the oven, an operator is required to unload the belt and place the cores onto the racks. The cores are usually unloaded on the opposite side, the plates remaining on the racks, and are unloaded by the loading operator. These plates are distributed to the coremakers by a section of gravity conveyors extending the length of the bench layout. A view of two ovens used in this way is shown in Fig. 12.5.

A unique design employing the vertical oven together with a conveyor, and which serves the coremakers, provides ample cooling time, unloading space and return of plates and driers to the operators, is shown in Fig. 12.6.

The operators on this installation are all girls. They are placed on a mezzanine floor and segregated from the male employees. The core room is fully enclosed. Proper lighting and ventilation are provided, making this department ideal for this type of work. A view of such a core room is shown in Fig. 12.7.

The benches are located adjacent to the upper run of the conveyor. The conveyor is inclined so that the top and bottom shelves are loaded without undue exertion on the part of the operators. The conveyor passes through the vertical runs of the oven. On the descending side, cooling fans are placed so that the cores are sufficiently cooled to be unloaded with the bare hands.

Cores are sorted into tote boxes placed on gravity conveyors. These conveyors may be placed in suitable locations on either side of the lower horizontal run of the oven conveyor. The plates and driers are placed on racks and are returned through the floor to the operators on the mezzanine floor.

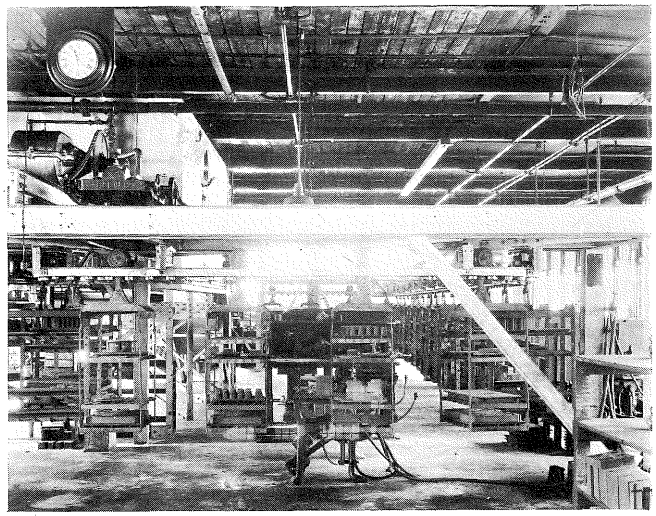


Fig. 12.8 — General view of coremaking unit in large eastern machine tool foundry. On the right, the conveyor is progressing between the coremaking stations. On the left, the end of the cooling zone with speed control located over the conveyor. The left background shows the oven.

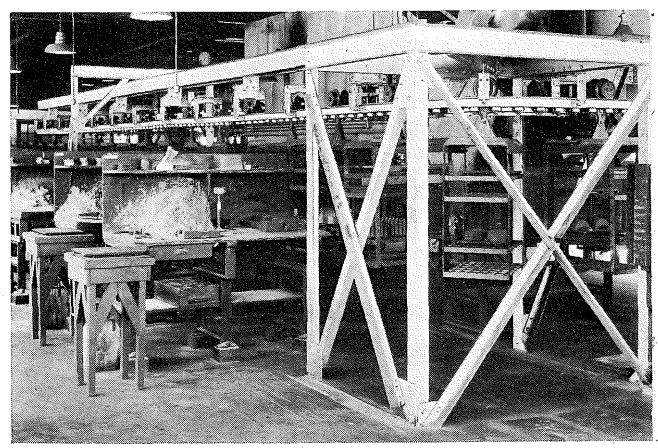


Fig. 12.9 — Another view of layout shown in Fig. 12.8. This view shows the close proximity of the coremakers to the conveyor.

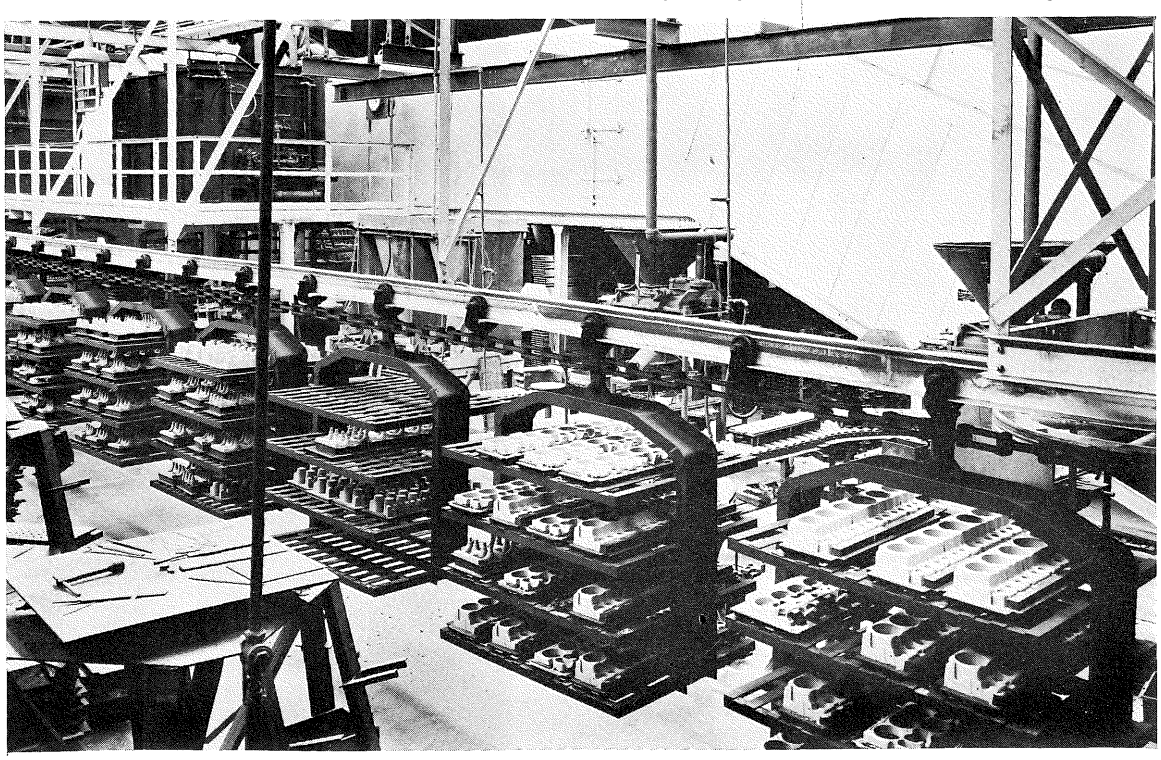


Fig. 12.10 — View of the core room of a large automotive foundry where miscellaneous cores are made.

Figure 12.8 shows a core room equipped with a continuous core handling and oven unit in a large eastern machine tool foundry. The unit is built about a conveyor that travels through three stations: the coremaking, the oven and the cooling zone.

As the conveyor advances from the cooling zone, it travels between two rows of coremaking stations. Figure 12.9 shows the close proximity of the coremakers to the conveyor. The coremakers each have their own plates so that when the conveyor approaches their individual station, they may remove them. The core sand is delivered to the coremakers and other necessary materials are readily accessible. When the last coremaking station is passed, the conveyor is at the entrance to the oven.

After leaving the oven, the conveyor advances through an S-shaped path allowing the cores to cool to nearly room temperature before they are removed. Cores so large that they are not thoroughly baked are sent through the oven a second time.

Figure 12.10 shows the layout and conveying system used in a large automotive foundry for transporting and baking miscellaneous cores.

TRAMRAIL SYSTEMS

In the handling systems previously discussed, the core room conveying systems have been closed circuits in which the cores were conveyed from the coremaker, to and through the baking process, and finally from the oven, where the cores were unloaded by hand for distribution to the molding floors. The racks are an integral part of the system. In the following, a description is given of a system in which the racks are suspended from overhead tramrails and are not an integral part of the transportation system. This allows the cores to be conveyed to the molding floors so that distribution of baked cores to the molding department becomes a regular part of the entire conveying system.

In the previously described core conveying systems, after the cores are baked, they are transported to the molding department on racks or skids by hand or power lift trucks, such as shown in Fig. 12.11, or by other means, such as the core barrow or by roller or belt conveyors.

Figures 12.12 and 12.13 show installations of overhead tramrail core transportation systems. Such equipment is available which can handle core racks up to a 5 ton total load. They can be propelled from the core benches to the baking oven, and to the molding floor, by one man for loads up to 3 tons, and by not more than two men on loads above 3 tons. In Figs. 12.12 and 12.13 the racks are suspended on a tramrail system which passes through the ovens and then is

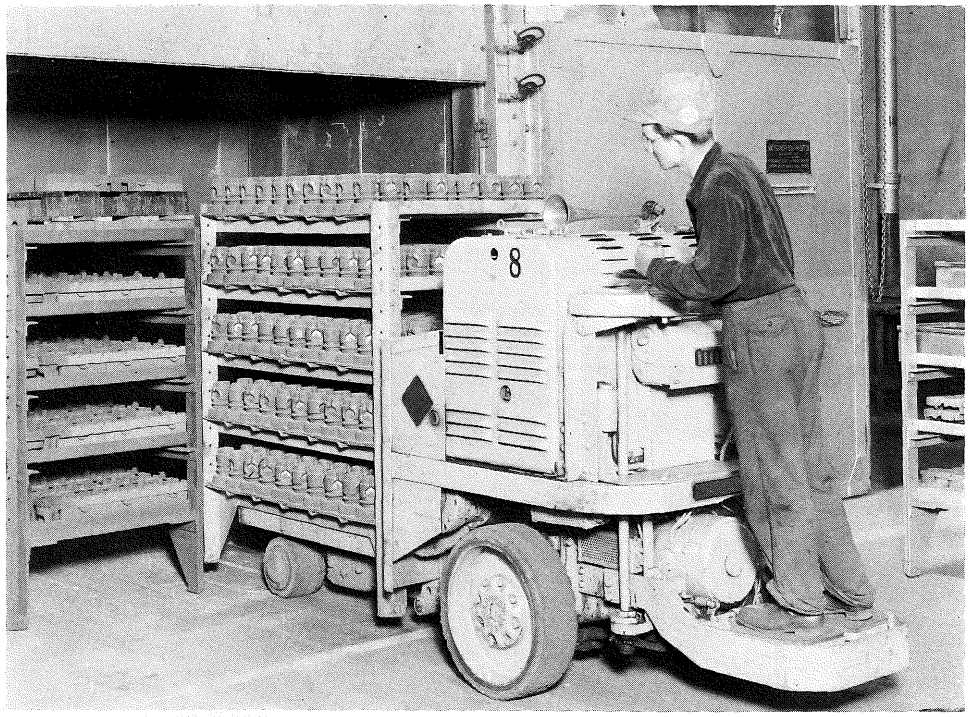


Fig. 12.11 — Electric lift for transporting cores.



Fig. 12.12 — Overhead tramrail core transportation system used to carry cores to and from the core ovens and to distribute the baked cores to the molding department.

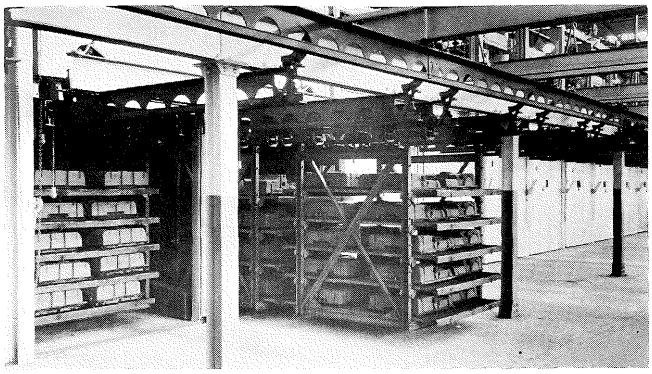


Fig. 12.13 — Illustrating how racks are pushed into ovens where the cores are baked.

propelled manually onto the system in the foundry proper. With such an arrangement, cores can be delivered to the molding floor without rehandling. Since the cores must be provided before the molds are poured, any interferences because of racks being transported to the molding floor area are not possible because, before the pouring operating begins, the racks can be shifted to the coremaking department, leaving all lines free for the pouring operation.

In the manufacture of large cores, the transportation problem becomes more serious as such cores cannot be handled economically by hand, and it is necessary to introduce handling equipment to perform such operation.

Figure 12.14 shows an application of overhead tramrail cranes provided with an electric hoist having twin cables, making it possible to remove the core from the coremaking or blowing machine onto shelves which can be placed on a core rack, adjustable for various heights and types of cores. When a shelf load has been accumulated, it is picked up by the electric hoist and placed in the racks, which are suspended on the double track, the arrangement being such that the hoist can deposit a shelf load on the rack without interference with the overhead supporting structure.

After a rack has been loaded, it is moved manually from the loading point across the double track tramrail system onto a transfer bridge, as shown in Fig. 12.15 where the rack is then moved into the oven for the baking operation. Figure 12.15 shows the general arrangement of the transportation system. One man is able to move a load of approximately 4 tons down the main distributing aisle.

After the cores are baked, the racks are removed from the ovens. By means of the transfer bridge, the racks are conveyed to an area in the foundry proper adjacent to a floor roller conveyor. The same handling equipment that is used for loading the racks is also used for unloading the cores onto the roller conveyor.

In one particular layout, the first roller conveyor parallels another roller conveyor on which the actual molds are placed after removal from the molding machine. The two conveyors are synchronized so the molds and cores reach the core setting zone at the same time, so the core can be picked off the conveyor and set in the mold by means of an electric hoist.

While some of the photographs mentioned illustrate operations in a large foundry, the same basic plan and handling principles can be applied in the small foundry, with the necessary variations in the equipment to suit handling needs.

EQUIPMENT LIMITATIONS

The limitations, which formerly existed because of inability of conveying equipment manufacturers to supply equipment capable of withstanding temperatures up to 450 F (232 C) in conveying equipment that passes through core ovens, have been removed by the development of bearings which will withstand these heat conditions satisfactorily. The problem is not a serious one where a conveyor, be it a floor type or overhead type, transports the cores through the oven continuously as the bearing is in constant rotation and lubricants are available which will not completely burn out and freeze the bearings as long as the wheel is in motion. On handling applications where a unit load is placed in a compartment type oven, since the rack is not in motion during the baking operation, overhead track wheels or floor type roller bearings must be of such design that lubrication is not essential because no lubricant has been found which will withstand coking.

Most of the unsatisfactory applications of handling equipment have been due to the fact that the bearings would stick, making it impossible to remove the loaded core rack from the oven. Fortunately, manufacturers of material handling equipment have developed antifriction bearings, especially for use in ovens, which require no lubrication and have a life factor equivalent to that of bearings used on conveyors operating at ordinary temperatures.

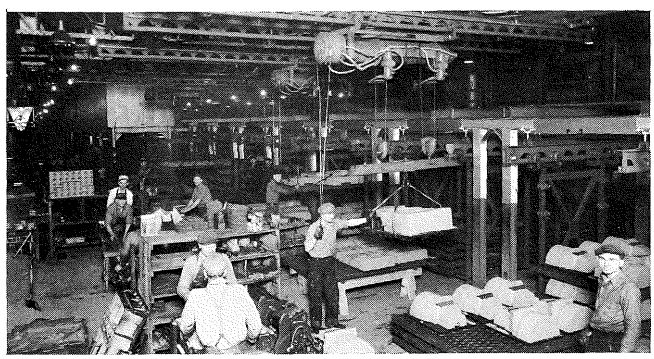


Fig. 12.14 — Handling equipment for large cores which cannot be handled economically by hand.

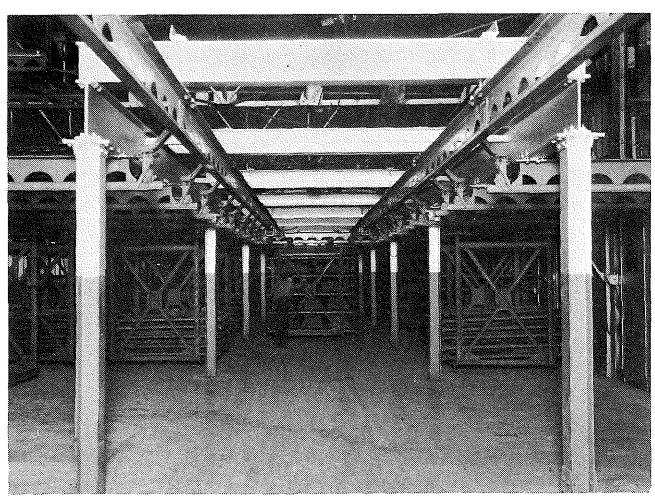


Fig. 12.15 — Transfer bridge for tramrail conveyor system.

Chapter 13

PROCEDURES FOR DETERMINING THE PROPERTIES OF CORES AND CORE MIXTURES

INTRODUCTION

The physical property testing of cores plays an important part both in the selection of materials used in a core and in determining and controlling core room practices. There is a fairly unanimous opinion that chemical testing of the materials used in a core is not as conclusive as physical tests.

SAND

Selection of a sand to be used as a standard in testing core binders should receive careful study. One must make certain that an ample supply is available over an extended period of time and that it is of a given fineness and cleanliness. A supply of a selected stock sand may be set aside as standard testing sand. For control tests, silica sands, as used in core room practice, may be used.

The Ottawa Silica Sand Co., Ottawa, Ill., has available a testing sand meeting the AFS specification as a standard testing sand. A secondary standard sand is also available under AFS specifications and may be obtained from New Jersey Silica Sand Co., Millville, N.J. This sand is used widely as a standard core testing sand and has the advantage that one can compare test figures with other foundries using this sand. It is recommended for all standard test work.

SPECIFICATIONS OF AFS STANDARD TESTING SAND

The standard sand shall consist of washed and dried, rounded grain, silica sand. All the grains shall pass through a No. 40 mesh sieve, 95 per cent passing the No. 50 mesh sieve and remaining on the No. 70 mesh sieve. Any grains passing the No. 70 mesh sieve shall remain on the No. 100 mesh sieve. This sand shall have an AFS Fineness No. of 50 ± 1.

STANDARD MIXING PROCEDURE

The sand and binders may be mixed either by hand or by machine. For control work, mixed sand from a hopper may be used for testing. The method of mixing procedure, for standard testing, is well defined by the following AFS specifications.

Sand to be used in the test shall be dried for 2 hr at a temperature not less than 221 F (105 C) nor higher than 230 F (110 C). Weigh out a 2,500 gram sample of dried sand in a 1,000 cc beaker.

Cereal Binders

Machine Mixing

Weigh out the desired quantity of cereal binder and add to the sand. Mix for a period of 2 min in laboratory mixer.

Add sufficient water to temper mix as desired. Water added is measured with burette, making it possible to add definite percentages of moisture to the sample. Operate the mixer for a period of 2 min.

Hand Mixing

When sand is mixed by hand, place sample in an agateware bowl of 10 in. diameter. The sand sample shall be rubbed between the palms of both hands, using the same timed procedure as used in machine mixing.

Oil Binders

In standard tests, a sand to oil ratio of 100 to 1 by weight (which is substantially 60 to 1 by volume) shall be used. In control tests, other ratios may be used. The ratio used is to be recorded with test data. Where the ratio of 100 to 1 is used, 25 grams of oil is weighed.

Weighing

The procedure to be followed in weighing is as follows. Fill a 50 cc beaker with oil to be tested. Pour all oil out of beaker, upending the latter so that its side makes a 45 degree angle to the horizontal. Hold beaker in this position for one minute; time with stop-watch. Place beaker on a balance and add 25 grams of oil to be tested.

Mixing

Place weighed sand sample in mixer. Pour the oil on top of weighed sand sample, again holding beaker in same position for one minute by stop-watch. Operate mixer for a period of 2 min.

Discard the first batch mixed because some oil is absorbed by the metal parts of the mixer or mixing bowl. Make a second batch and use this sand for test sample.

Water Addition

Experiments have been conducted which indicate that water should be added to oil sand mixtures following the oil addition. In view of these experiments, it is recommended that, in testing core mixtures to

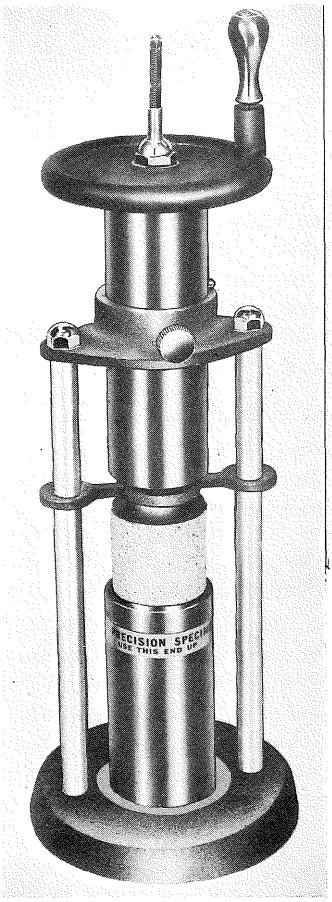


Fig. 13.1 — (Left) Compression tester for determining green compressive strength of core sand mixtures.

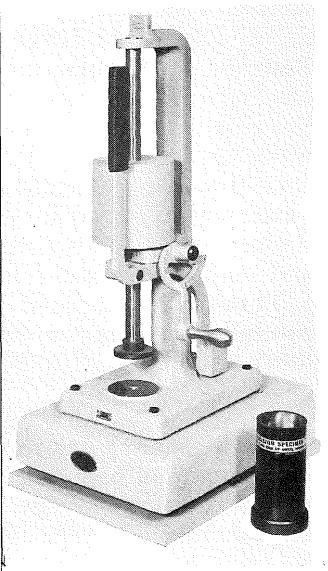


Fig. 13.2 — (Above) Standard ramming apparatus.

determine the properties of a given core oil, the water be added after the oil.

The method of adding the water in mixtures containing green strength binders should be as outlined for the moisture addition in the section on cereal binders.

GREEN STRENGTH

The green strength of a core mixture may be determined by compression test or by a tensile test, both of which are AFS tentative standards. A compression tester, as illustrated in Fig. 13.1, reading to 0.02 psi and with a maximum load capacity of 30 psi, is widely used. The AFS specification for making the standard test specimen is as follows.

"Weigh out a sufficient quantity (150 to 175 grams) of tempered sand from the prepared lot to make, when rammed, a column 2 in. (5.08 cm) high. Place the sand carefully in the specimen container which rests upon the auxiliary cup. Fit the specimen container pedestal cup in place on top of the specimen container. To insure standard conditions of packing, invert the closed specimen container, which holds the sand, once. Remove auxiliary cup, which is now on the upper end of the specimen container. (See Fig. 13.2.)

"Place the pedestal and specimen container with the sand in position beneath the rammer, care being taken to keep the specimen container vertical so as not to disturb the loose sand in the specimen container.

"Gently lower the rammer rod with head into specimen container until they are supported by the sand. Raise rammer weight to the upper stop and let fall. Repeat twice, making a total of three rams. Note whether the upper end of the rod corresponds with the 2 in. height indicator or is within the tolerance for control work. If not, discard the specimen and place a sufficient quantity of the tempered sand in the specimen container to yield a column of the required height.

"Lift the rammer rod until the ramming head at lower end of rod is free from the specimen container and remove specimen container from pedestal cup.

"A green core permeability test may be made on the rammed specimen before removing the specimen from the specimen container.

"For the green compressive strength test, the test specimen is removed from the container by first placing a 2 in. diameter by 1/8-in. thick steel disc on top of the stripping post, then placing the container over the stripping post and pressing the specimen out.

"The core specimen is handled by grasping the steel disc and placing specimen in the compression tester, Fig. 13.1. The stem of the tester is turned at a rate to give a loading of 30 lb per minute."

A precision green compressive strength testing unit is shown in Fig. 13.3. This strength testing unit has a range from 0 to 1.87 psi, reading accurately to 0.01 psi.

The green compressive strength of clean silica sand-oil mix usually is between 0.5 to 0.7 psi. Addition of cereal binder, bank sands, clay substance and/or other bonds increases the green strength to values above one pound. A green compressive strength of 1.4 to 1.6 psi is used quite extensively for cores that are slender and tall.

In case the specimen cannot be removed from the specimen container without deformation, or the specimen shrinks on drying or baking, or where the sand used has little green bond, a special split specimen

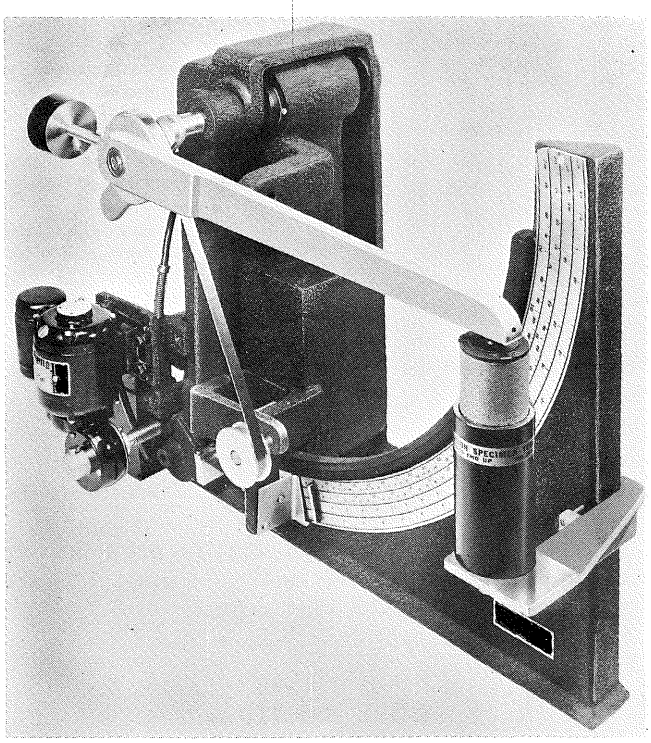


Fig. 13.3 — Precision green compressive strength testing of core mixtures.

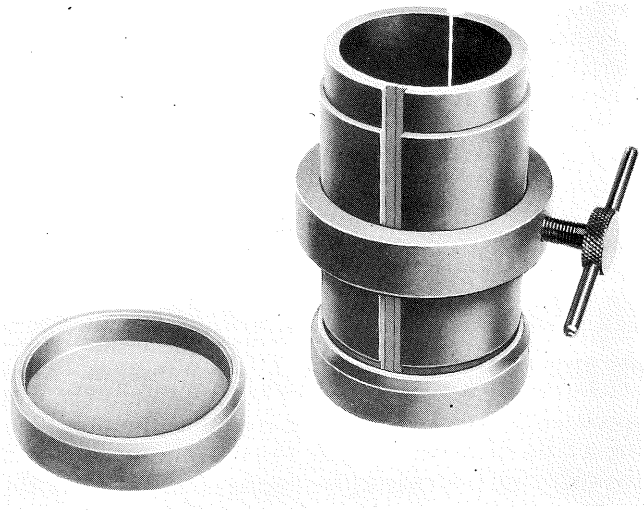


Fig. 13.4 — Special specimen container and pedestal for ramming specimens for core permeability tests.

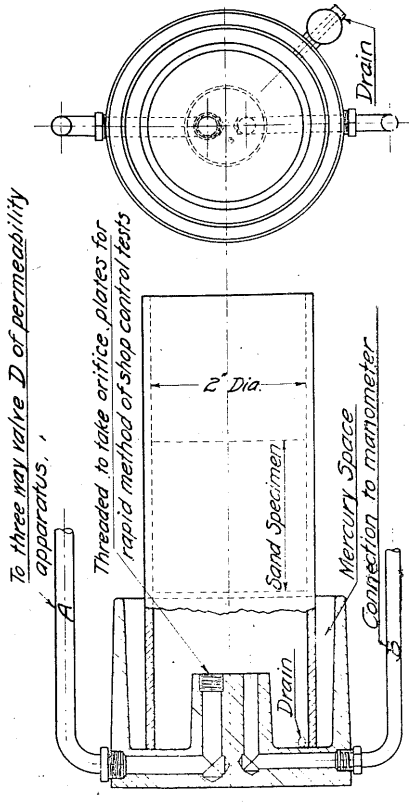


Fig. 13.5 — Mercury cup attachment to permeability air flow apparatus for determining permeability of baked core sand specimens. Specimen container is set in mercury cup and the permeability test conducted in the usual manner.

container, shown in Fig. 13.4, which may be opened to permit the removal of the specimen to a drier, should be used. In these cases, the permeability apparatus is equipped with a mercury cup attachment, shown in Fig. 13.5 in detail, and attached to the apparatus in Fig. 13.6.

A green tensile strength test may be made on core mixtures by ramming the sand in a special tensile container with the AFS sand rammer, see Fig. 13.7. The specimen is broken in tension as illustrated in Fig. 13.8.

CORE MOISTURE

The quantity of moisture in a core sand or core mixture may be determined by drying a 50 gram sample of the sand or core mixture in an oven heated to 221–230 F (105–110 C) for a period of one hour. Reweigh and express moisture in percentage of the original moist sample. Determine percentage weight loss of a core mixture made with dried sand without water addition, using above heating procedure. Subtract this blank percentage loss from above moisture percentage to correct for evaporation of binder during drying period. This correction value is quite small and may be eliminated in control testing.

Three types of rapid moisture determinations in routine testing are moisture teller, speedy moisture tester and moisture indicator.

Moisture Teller

The moisture teller, shown in Fig. 13.9, consists of a cast aluminum base (A), direct motor driven fan (B), electric heating element and sand pans (E) to hold the sample.

Operation

To operate the machine, turn on the motor switch, insert the sand sample, allow the heated air to blow through the sample until dry and finally reweigh the sample and determine the loss as percentage moisture.

Air, sucked into the unit by the fan, is blown over the electric heating unit, built within the vertical

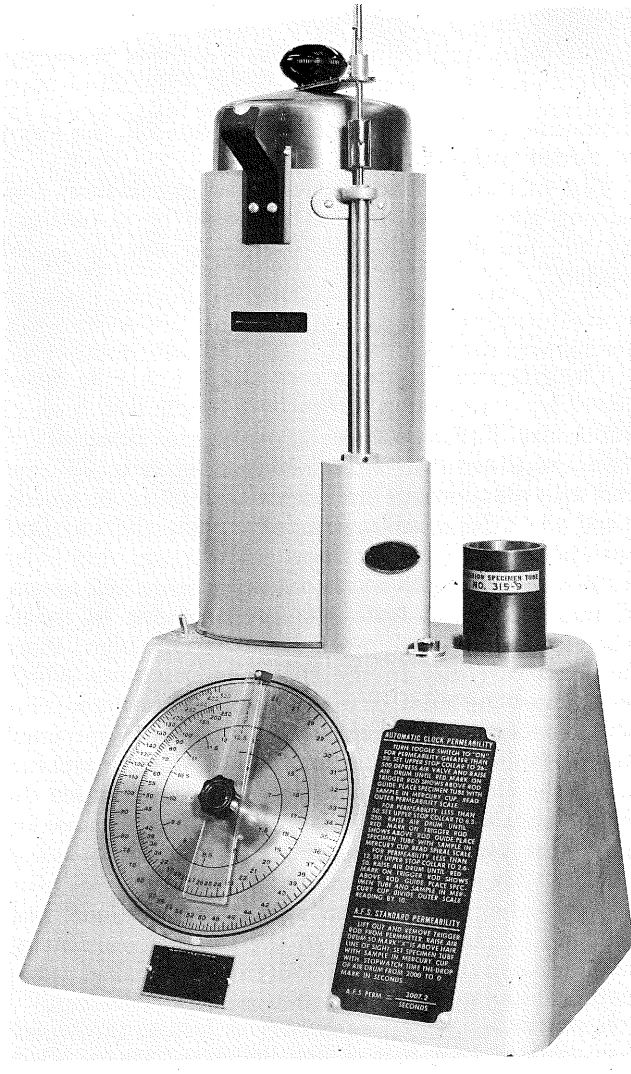


Fig. 13.6 — Permeability air flow apparatus.

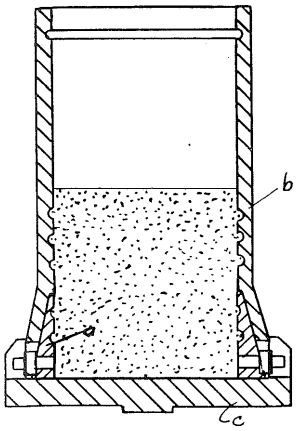


Fig. 13.7 — Special specimen container for determining tensile strength, showing manner in which it is assembled for ramming operations.

tube of the blower unit, which heats it to 230 F (110 C). The heated air then passes into the diffuser, which forms the lower portion of the blower unit. The diffuser spreads the heated air over the entire of the sand pan.

The sand pan is circular, 5.21-in. (13.33 cm) diameter. The bottom of the pan consists of monel metal filter cloth, 500 mesh.

The sand pan is held in position against the diffuser by a spring-loaded holder (D). By depressing the holder, the pan may be inserted or removed from the machine easily.

Procedure

Weigh out a 50 gram sample of the sand to be tested on a balance with the sensitivity of 0.02 gram, and place in pan, spreading the sand sample in a thin layer.

Depress the spring-loaded holder and insert pan containing moist sand sample in the machine, turn the timer switch to start motor. After the sample is thoroughly dry, remove the pan containing dried sample from the machine. Reweigh the sample when cool.

Loss in weight between moist and dry samples multiplied by 2 is the percentage moisture in the sample.

Speedy Moisture Tester

Figure 13.10 shows the speedy moisture tester. The principle on which this apparatus for the rapid determination of moisture in foundry sands operates is the close intermixture of the damp sand and calcium carbide to generate acetylene. The gas generated sets up a pressure in the air tight vessel and the pressure is registered on a gage as percentage moisture.

Description

This moisture tester consists of three parts. The shaker, into which the calcium carbide reagent is placed; the cap, which fits on the top of the shaker and which generally contains the sand to be tested; and the stirrup, an inverted U-shaped piece, securely fastened to the shaker on opposite sides and containing a set screw at its top center which is screwed down onto the cap to make an air tight seal. The gage, which reads moisture percentage, is located in the bottom of the shaker.

A measure is provided to secure the correct amount

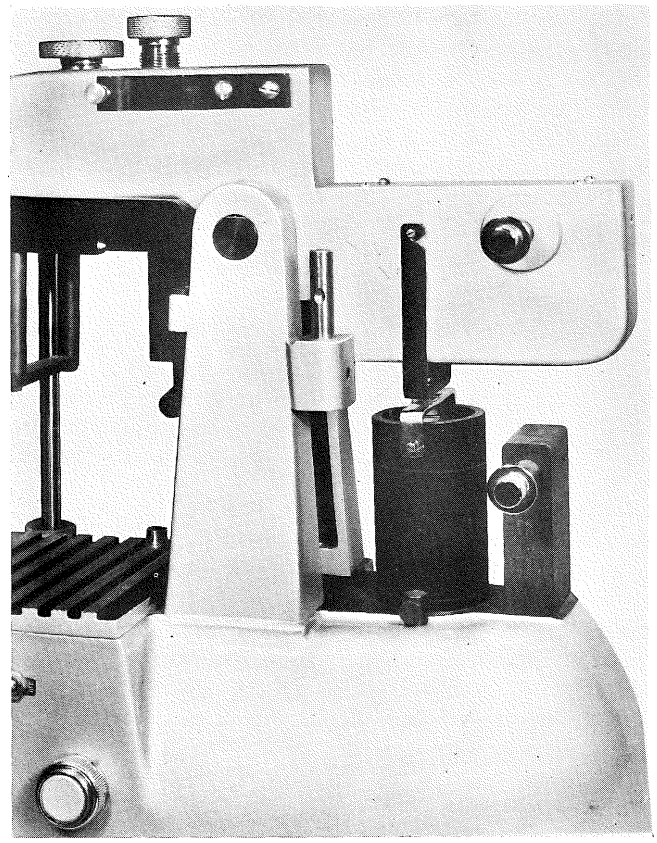


Fig. 13.8 — Special specimen containers as in Fig. 13.7, showing method of breaking.

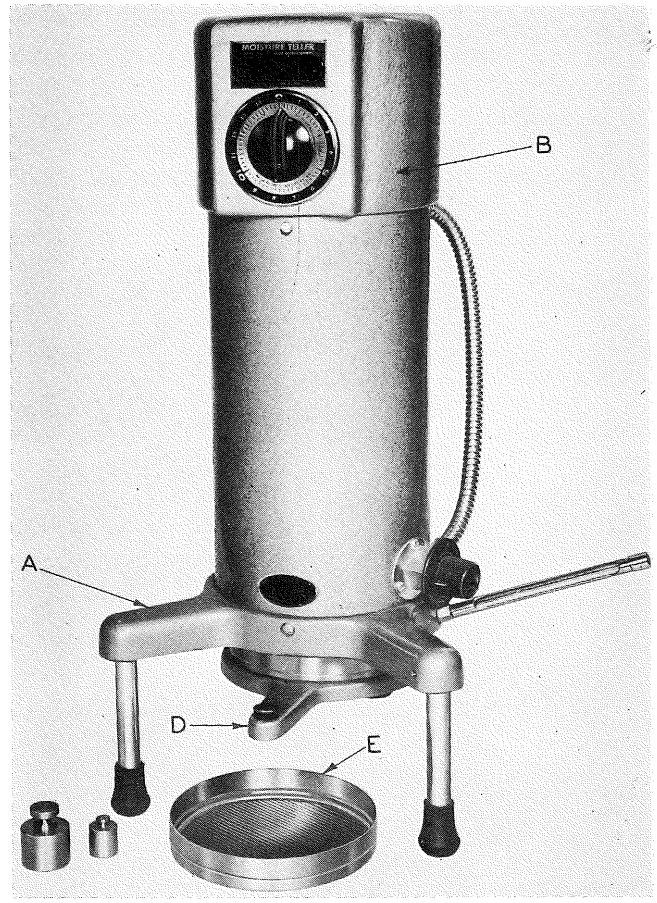


Fig. 13.9 — Moisture teller used for rapidly determining the moisture content of core sands.

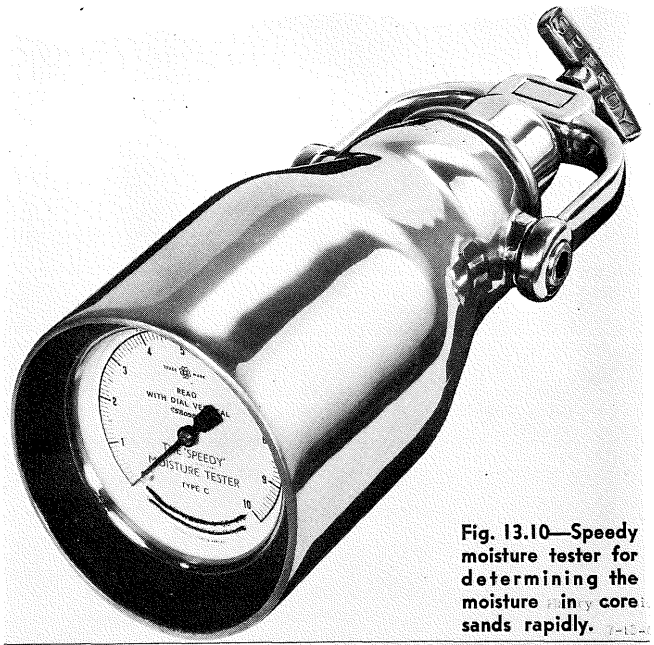


Fig. 13.10—Speedy moisture tester for determining the moisture in core sands rapidly.

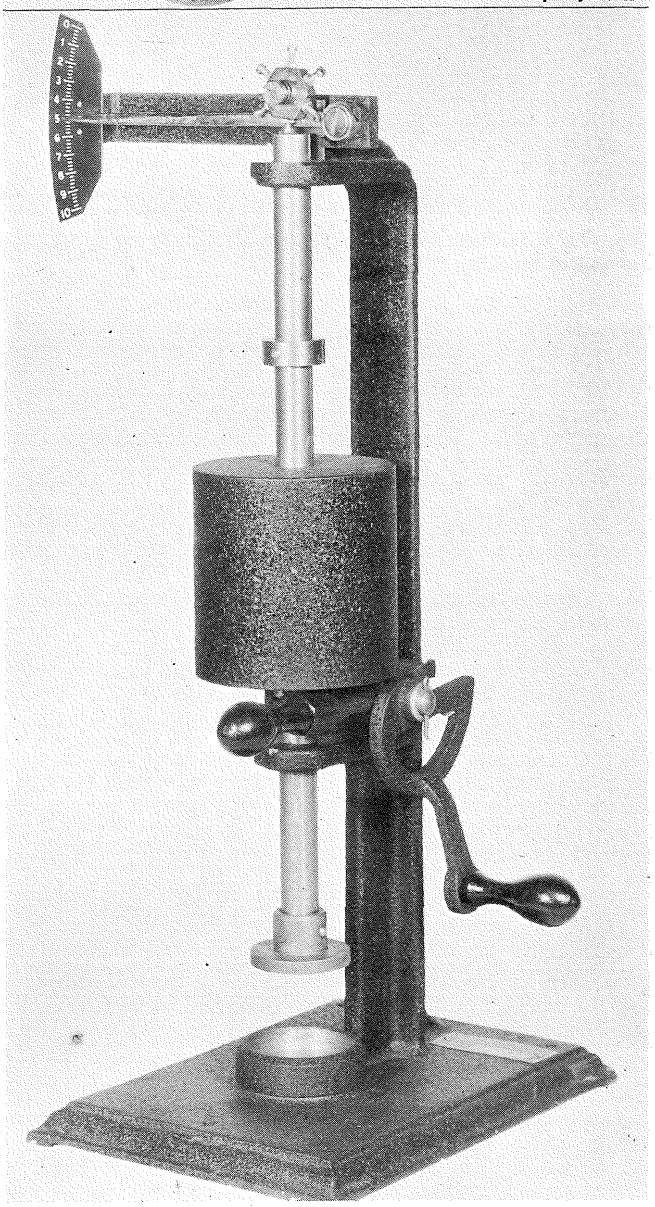


Fig. 13.11 — Moisture indicator attached to top sand rammer furnishing a means of rapid moisture determination for core sand and core sand mixtures.

of reagent, which is supplied with the apparatus and which is ground to a uniform fineness. A balance, sensitive to less than 0.005 grams, also is provided to weigh the sample.

Operation

Accurately weigh out the sample of sand to be tested and place the sample in cap of instrument.

Take a measure of the calcium carbide reagent and place in shaker. The cap and shaker should be placed in a horizontal position so that the sample and reagent do not come in contact.

Place the cap on the shaker, adjust stirrup, fasten cap to shaker with set screw on stirrup and finally shake the contents. This brings the sand and reagent into close contact, the moisture of the sand acting on the calcium carbide reagent to generate acetylene. The higher the moisture content of the sand, the larger the volume of gas generated, and the greater the pressure within the shaker.

Place the apparatus in a horizontal position and read moisture content on gage in bottom of apparatus.

Precautions

If sand sample is bulky, reverse the procedure of placing the sample and reagent as given in preceding paragraphs.

Both shaker and cap must be thoroughly cleaned after each test.

Moisture readings should always be taken with the shaker in the horizontal position.

Moisture Indicator

The moisture indicator (Fig. 13.11) employs the principle of decreasing volume of a constant weight rammed specimen. A definite weight of the sand or sand mixture, for example 160 grams, is placed in the sand specimen container (Fig. 13.2) and rammed with three drops of the rammer weight. The next operation is to swing the indicator pointer over on the rammer rod. The greater the percentage of moisture, the shorter the specimen; thus the lower the rammer rod which will cause the pointer to read, the greater moisture percentage on the moisture indicator scale.

GREEN CORE HARDNESS

The hardness to which a green core is rammed will greatly influence the green strength, amount of sagging, permeability, baked strength, and surface finish of the casting on the cored section. Many of the defects such as rough surface and penetration may be charged to low hardness of the core in the green condition before baking.

The hardness to which cores are rammed by the coremakers may be measured accurately with a green core hardness tester as shown in Fig. 13.12. This tester has a ½-in. diameter ball which is loaded with a spring load of 330 grams at a hardness reading of 100. At a reading of 50 hardness the load is 175 grams.

BAKING TEST SPECIMENS

In control testing, core test specimens may be baked with production cores in the plant core oven.

For general plant work, it is impossible to give complete directions for baking which can be taken as

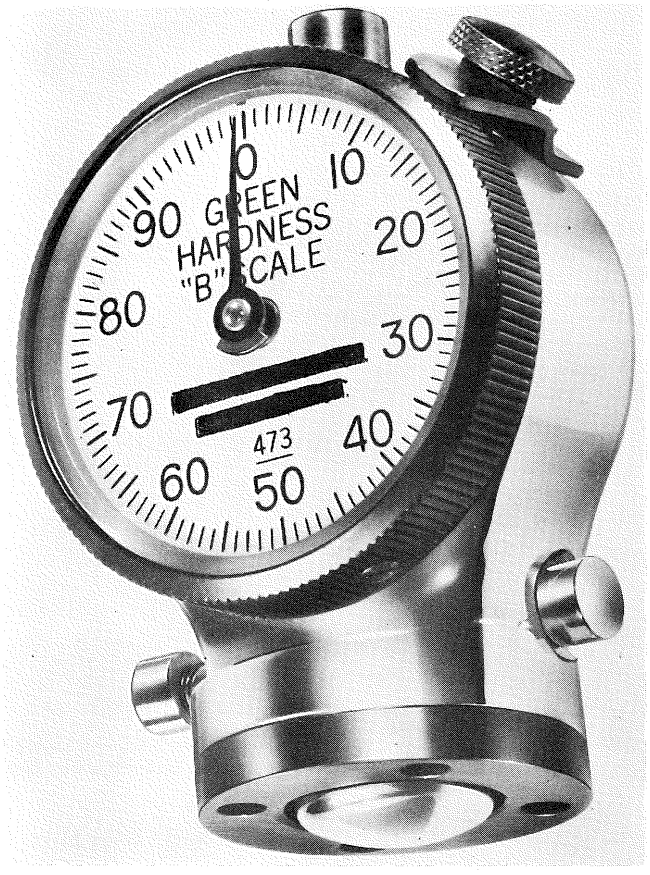


Fig. 13.12 — Green core hardness tester.

standard for all kinds of binders. In cases where core-sand mixtures are to be compared under similar baking conditions, the test cores from the several mixtures should be placed together on the same drying plate and baked. This tends to eliminate a variable which might result from uneven oven temperatures. This system is applicable in comparing core sands and sand mixtures.

When comparing core binders, which may possibly require different baking temperatures or different baking periods, separate plates of test cores, each containing several test cores of each mixture under test, should be baked under different oven conditions as regards time and temperature. The maximum strength thus obtained will indicate the optimum baking conditions.

For test work requiring a high degree of accuracy, a core baking oven, conforming to AFS specifications, should be used to bake the test specimens. The AFS specifications, which follow, require a uniform baking temperature with an indirect source of heat.

Temperature Control

The oven shall be equipped with some form of automatic regulator to maintain an even and uniform oven temperature, with a variation in temperature no greater than ± 5 F (2.7 C) and a thermometer for indicating the temperature inside the oven.

The input of heat must be such that, after putting in the charge, the oven shall recuperate to baking temperature in 10 min.

The thermometer bulb shall be located above the cores and within one in. of them.

Shelf Construction

The oven shall be equipped with a revolving shelf which is made to rotate at about 3 to 4 rpm, this rotation being secured by means of suitable reduction gear drive and motor. The shelf shall be a perforated metal plate, the perforations being approximately one-fifteenth of the total area of the shelf surface. The metal surface shall be strong enough to resist warping when loaded with cores and drier plates.

Circulating Fan

The oven shall be provided with a circulating fan to supply the baking chamber with proper circulation of air for proper oxidation of oils during baking period and maintenance of uniform temperature throughout all parts of the oven.

Number of Air Changes

The oven shall be equipped with sufficient vents of such size and location as to allow five to eight changes of air per hour.

Some openings shall be provided through which baked cores may be removed at different time periods, when testing for baking time, without interference with oven temperature.

Oven

An oven built to the specifications given herein is shown in detail in Fig. 13.13.

CORE PERMEABILITY

The permeability of baked cores may be determined by baking AFS test specimens of core mixtures in a plant core oven or in a laboratory baking oven of accepted design. The test specimen is rammed with three blows of the sand rammer, Fig. 13.2. The specimen may be formed in the standard container or in the special split specimen container, Fig. 13.4. It is a good plan to strip the test specimen on drier discs of 2 in. diameter for ease of handling.

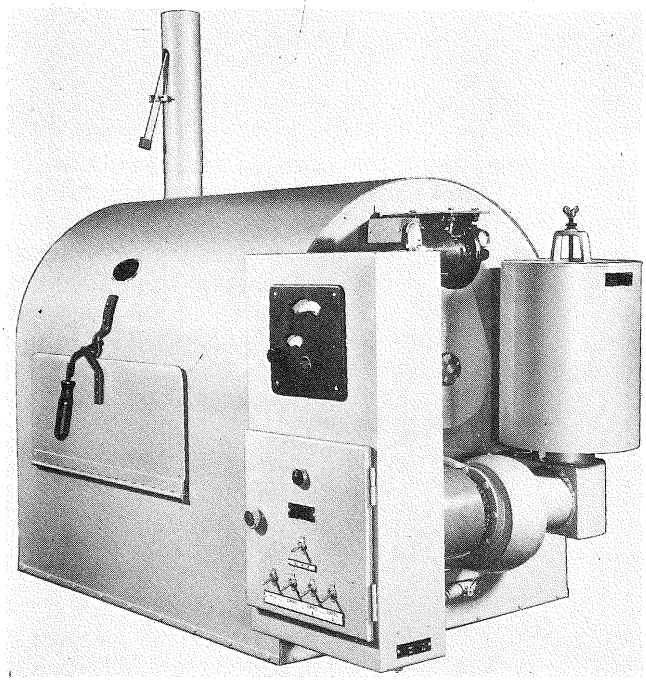


Fig. 13.13 — Core baking oven built to AFS specifications.



Fig. 13.14 — Core permeability specimen container.

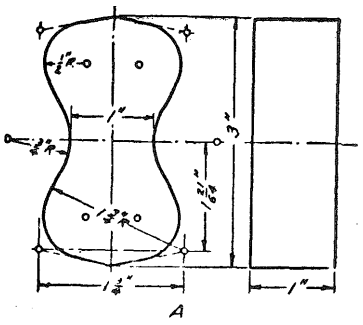


Fig. 13.15 — (Right) Dimensions of briquet for testing tensile strength of core and mixtures.

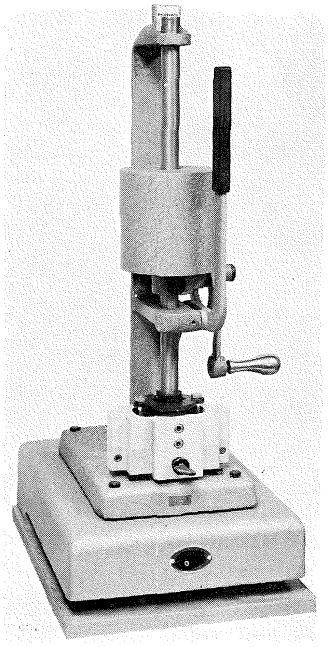


Fig. 13.16 — (Left) Sand rammer with core box for tensile test core specimen.

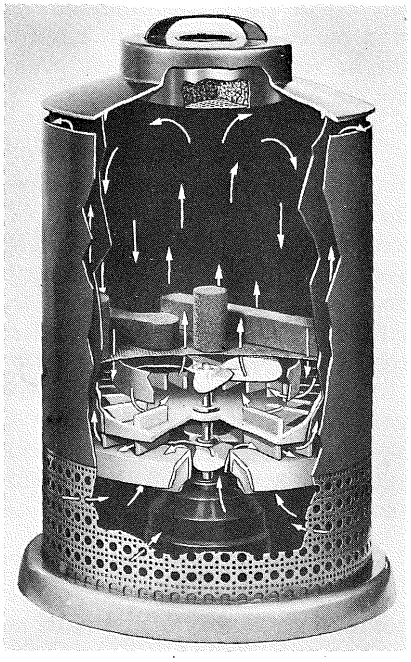


Fig. 13.17 — (Right) Fan-cooled desiccator for rapidly cooling hot test core specimens.

The test specimen is allowed to cool to room temperature in a desiccator and then inserted in the core permeability tube, Fig. 13.14. The core specimen is clamped tight on the rubber gasket and the space between specimen *E* and core permeability tube *G*, designated as *O* in Fig. 13.4 is filled with mercury.

The next operation is to place the core permeability tube in the mercury well of a permeability meter, Fig. 13.16, to determine the quantity of air that the core specimen will pass which is expressed in permeability units. See Chapter 17, *Maintenance of Testing Equipment*, AFS Foundry Sand Handbook (1963 Ed.) for further details.

BAKED CORE STRENGTH

The strength of baked core specimens is determined at the present time by tensile, transverse and compression tests. The American Foundrymen's Society has tentative standard test procedures for the tensile and transverse tests.

Length of air drying of green rammed core test specimens before baking may cause a wide variation in test results. This is particularly true for certain fast air drying binders.

It is good practice to place the green core specimens, immediately after removing each one from the core box, under a humidor. Place all cores in the core oven at the same time after the last core made has set in the humidor for a period of 20 min.

A humidor may be constructed of sheet metal to form a cover for the green cores. The interior surface of the humidor is wet with water. Wet humidor surface and turn over jolting twice on the table top to jar excess water from the interior surface. The green cores are then placed under the humidor.

Tensile Test

The AFS defines tensile strength as the maximum tensile stress which a sand mixture is capable of developing. Tensile strength of a baked core sand is the tensile stress necessary to rupture a test briquette of the standard dimensions shown in Fig. 13.15. The tensile strength is expressed in psi. The test core is rammed in the core box with a sand rammer as illustrated in Fig. 13.16.

The procedure is to place a predetermined weight

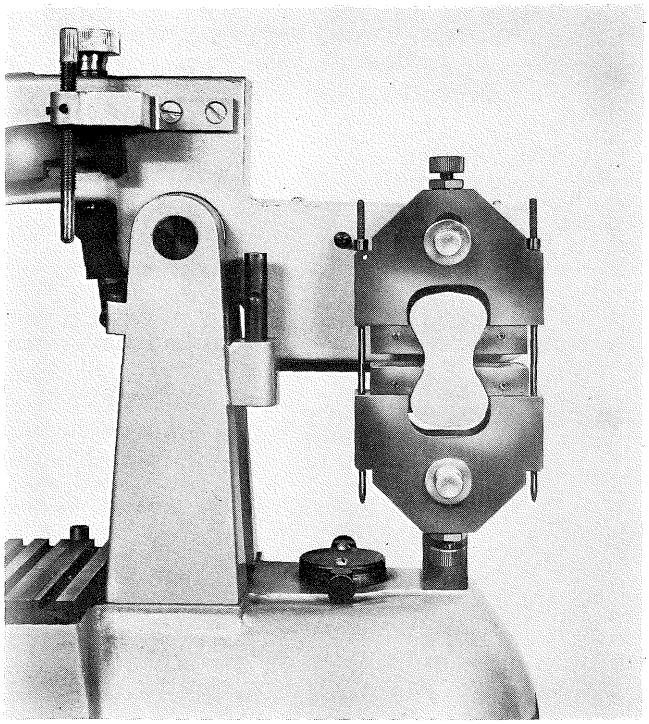


Fig. 13.18 — Sand strength machine equipped with grips for making tensile strength test on core sand mixtures.

of sand in the box and hopper, the amount being such that when the core is rammed (standard method) the height of the core will be one in. (2.54 cm) with a tolerance of $\pm 1/64$ in. (0.039 cm). Sand is then leveled off.

Lower the rammer head (Fig. 13.16) upon the sand. Place the entire assembly under the rammer head and ram with three blows. Remove the assembly from under the rammer. Remove the core box from the core, leaving the core on the plate for baking.

After baking, allow cores to cool to room temperature in desiccator. For fast cooling, an air-cooled desiccator as illustrated in Fig. 13.17 may be used. After the cores cool to room temperature, inspect them for size and defects such as cracks, foreign inclusions or poorly rammed sections. Any test specimen showing any imperfection in the neck should be rejected. Each test core should be calipered for both dimensions at the neck. If either dimension is more than 5 per cent off, reject the test specimen. The specimen shall be tested immediately after having reached room temperature following removal from the oven.

Fit the test cores into the jaws of the tensile machine in such a manner that they will be gripped uniformly along the lateral surfaces and so that the load will be applied along a line through their axes.

Apply the load gradually and uniformly at a rate not exceeding 50 psi per min, with a leeway of 10 psi per min in either direction.

Record the breaking strength in pounds and calculate to tensile strength in psi.

Test at least five briquettes. Briquettes that are manifestly faulty, or give strengths differing more than 15 per cent from the average value of all the test cores made from the same sample and broken at the same period, shall not be considered in determining the tensile strength. The average of the acceptable values shall be reported as the tensile strength of the group. A view of a testing machine equipped with AFS standard tensile core grips is shown in Fig. 13.18.

Transverse Strength Test

According to AFS, the transverse strength of a core mixture is the stress required to break a bar of baked core sand of the dimensions 1 x 1 x 8 in. long when a stress is applied midway between the ends of the bar and when the bar is supported on supports 6 in. apart.

The test specimen, according to AFS specifications, is prepared on the coremaking machine or sand rammer equipped core box, Figs. 13.19 and 13.20. The core sand is rammed with 10 drops of the core box assembly. The excess sand above 1 in. height is cut off with a knife. The test core specimen is removed from the box to a plate. After baking, cool core to room temperature and immediately break core on a transverse bar tester as illustrated, Fig. 13.21. This machinery may be equipped with a deflection gage to deter-

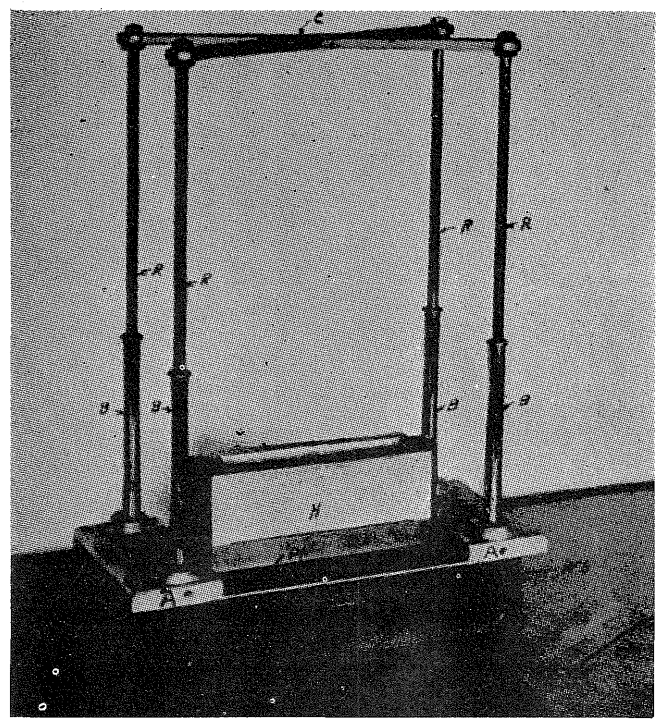


Fig. 13.19 — Apparatus for ramming bar test specimen for determining transverse strength of core sand mixtures.

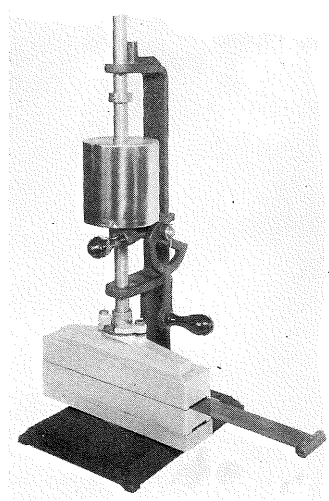


Fig. 13.20 — Sand rammer equipped with apparatus for ramming transverse test bar.

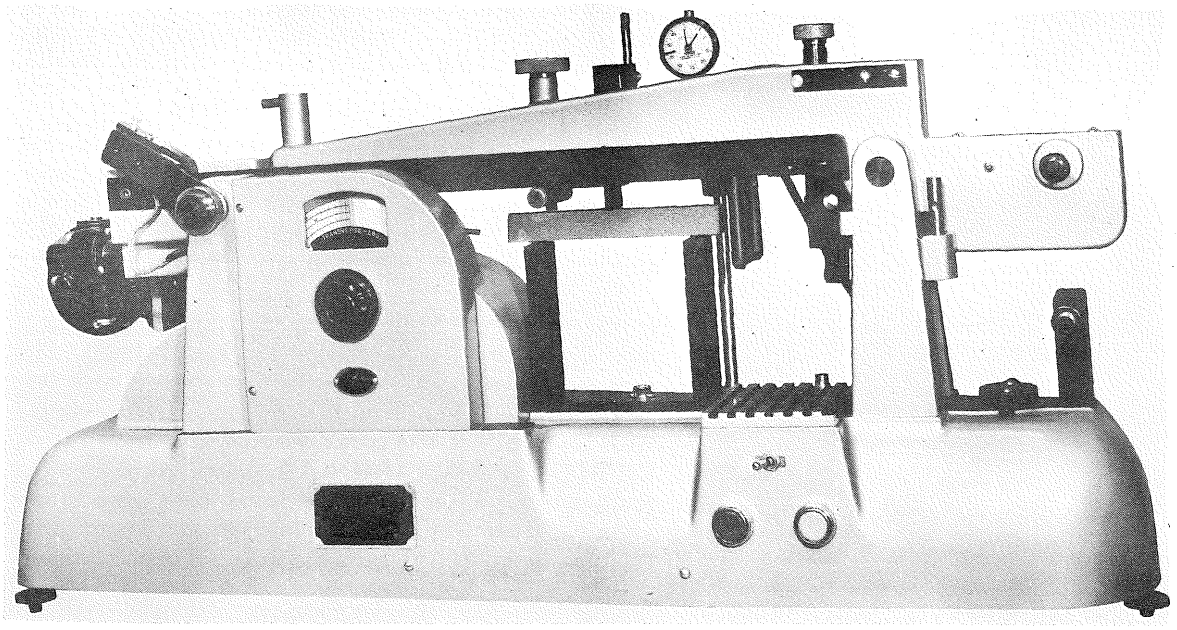


Fig. 13.21 — Universal sand strength machine equipped with transverse core strength accessory and deflection indicator.

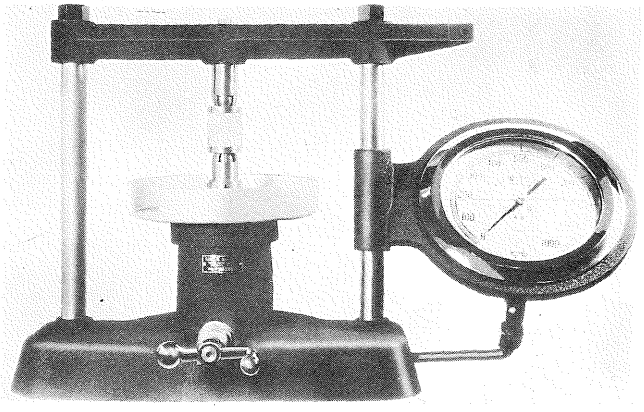


Fig. 13.22 — Compressive test machine for baked cores.

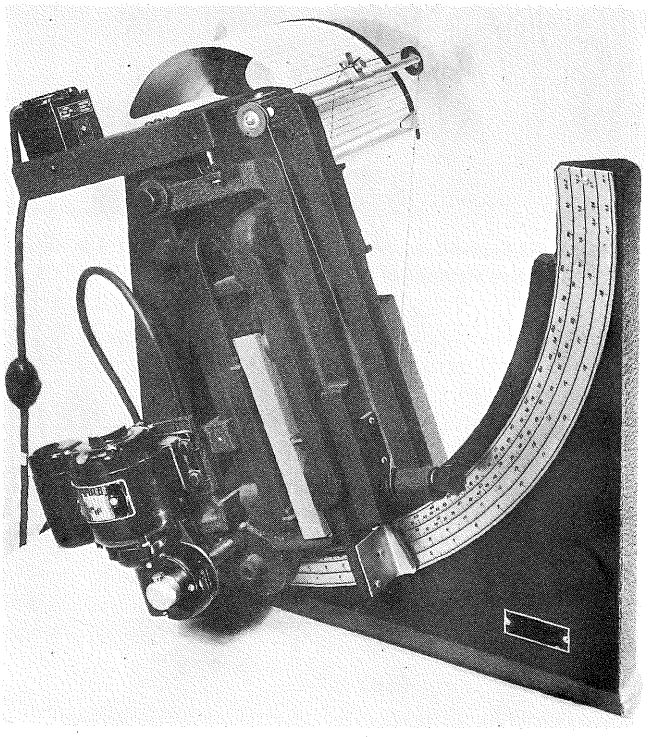


Fig. 13.23 — Strength machine equipped with transverse core strength testing accessory and deflection recorder.

mine the amount of deflection that the core specimen possesses at time of failure.

Compressive Strength Test

The compressive strength of baked cores has received limited attention by foundrymen. Some believe that the compression test is a good index for measuring the resistance that a core offers to shrinkage of a casting on cooling. This would be particularly true providing the test was made at elevated temperatures.

A compressive strength machine, Fig. 13.22, is available to measure the compressive strength of baked core specimens 2 in. in length and 2 in. in diameter. The compressive strength of cores at elevated temperatures will be discussed fully in succeeding paragraphs dealing with hot strength.

DEFLECTION TEST

The deflection test of cores is a very useful test since breakage of cores in a plant depends greatly on the deflection of a core in addition to its strength. A core may have ample strength yet break easily, due to its brittle structure, or conversely, the core may possess excess deflection and be very flexible or raggy.

The deflection of a core is also useful as an index to determine why a core cracks in a drier. The test data, as tabulated in the table, shows cold and warm transverse strength and deflection of laboratory and production oven-baked cores. Cores made with binder *A* do not show any cracks when removed from drier, while cores made with binders *B* and *C* do show cracks. All of the cores have practically the same strength. However, core *A* has a relatively high deflection, while cores *B* and *C* have a lower deflection. It may thus be said that a core should possess a certain amount of deflection to avoid being cracked in intricate driers.

The deflection of a core may be measured by attaching a strength deformation recorder to the core strength testing machine. One such application is shown in Fig. 13.23. The deflection of a core when loaded on center and on supports 6 in. apart is a

COLD AND WARM STRENGTH AND DEFLECTION OF CORES USED IN AN AUTOMOTIVE FOUNDRY

	Laboratory Oven			Production Oven	
Binder	Cold Strength	Cold Deflection, in.	Warm Strength	Cold Strength	Cold Deflection, in.
A	64 lb, 7 oz	0.0153	7 lb, 13 oz	62 lb, 9 oz	0.0133
B	58 lb, 14 oz	0.0065	10 lb, 12 oz	60 lb, 8 oz	0.0088
C	58 lb, 3 oz	0.0100	8 lb, 5 oz	62 lb, 0 oz	0.0074

useful measure of whether a core is brittle and will easily crack on handling. A deflection reading of 0.015 in. or less may be termed low and indicates that a core is brittle. A deflection of 0.018 to 0.025 in. is indicative of a good core while a deflection of 0.030 in. or more describes a core which is too raggy.

Warm Strength Test

Breakage of cores on being removed from the drier while still warm, which is practiced in many foundries. has focused attention on the warm strength of a core.

The warm strength of a core may be defined as the strength that a core possesses at temperature in the range of 150–300 F (66–149 C). The temperature of the core at the time of testing should be designated with the data. The method of determining the warm strength is identical to that described in preceding paragraphs with the exception that the core specimen is tested immediately on removal from the core oven. The strength test may be made either in tensile, transverse or compression. The deflection test may also be made while the core is warm.

The warm strength of a core is not related to the cold strength. The test data, as shown in the table on p. 151, well illustrates this point. For example, core *A* possesses a warm strength of 7 lb 13 oz, while core *B* has a warm strength of 10 lb 12 oz, even though core *A* has a much higher cold strength than core *B*.

CORE HARDNESS

The hardness test of cores is of much importance to foundrymen in that it gives a means of correctly expressing the surface hardness of a core in figures. The surface hardness of a core largely determines how a core will withstand stocking and handling. It also is a property of a core that defines the amount of loose sand that is on the core surface.

The core hardness may be measured by means of a scratch test with degree of hardness being designated by depth of scratch measured in inches subtracted from 0.100 in. Fig. 13.24 shows an instrument for determining baked core hardness.

The plow is spring loaded so that, when a static load of 1,100 grams is applied to the plow, it protrudes 0.100 in. through the plate. A load of 2,000 grams will cause the plow to become flush with the surface of the plate.

The position of the plow in reference to surface of the plate is indicated by the reading in increments of 0.001 in. When the plow is flush with surface of the plate the indicator reads 100 and when the plow protrudes 0.100 in. beyond the plate, it reads zero. The indicator is set to read zero when the point of the plow is flush with the surface of the hardened plate.

The core hardness reading is determined by slowly pulling the instrument across the face of a core. The instrument is pressed with sufficient force against the core to insure that the hardened plate firmly contacts the surface of the core. The reading recorded as the core hardness is to be the average of three tests, as obtained when the instrument is drawn over a core for a distance of not less than one inch.

TESTING CORES MADE WITH CORE BLOWING EQUIPMENT

In practice one is always concerned with the efficiency with which a core mixture will blow. When a means is available which will allow one to express the efficiency of blowability in abstract number, one can then definitely evaluate the ease with which different sands, different compositions and different moisture percentage core mixtures may be blown.

Blowability testing equipment is illustrated in Figs. 13.25 and 13.26. The equipment consists of a steel plate forming the bottom of the core box; an aluminum core box, ½-in. deep, 1½-in. wide and 5 in. long;

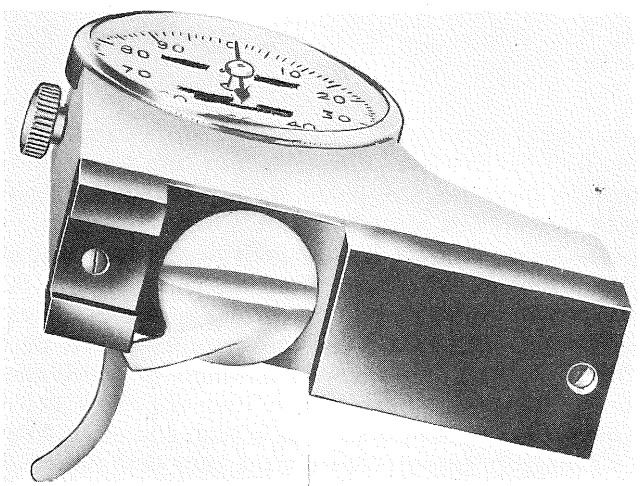


Fig. 13.24 — Baked core hardness tester.

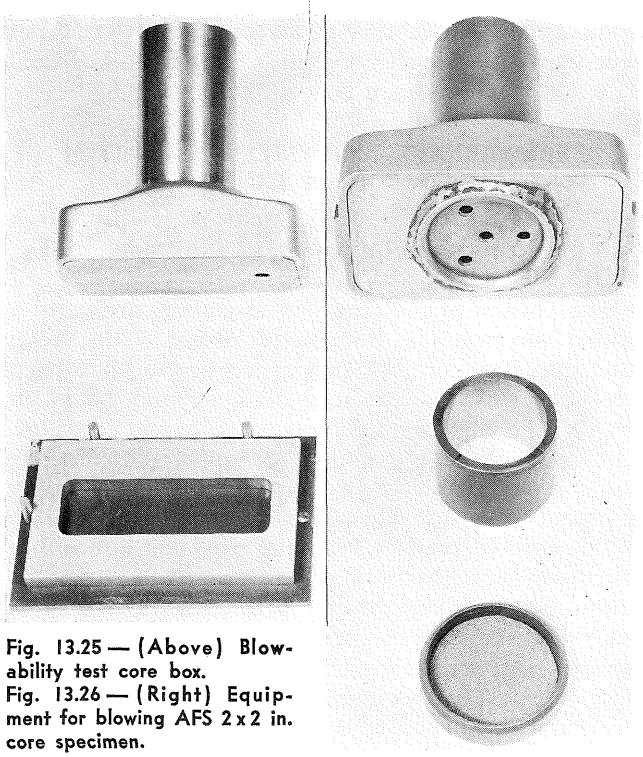


Fig. 13.25 — (Above) Blowability test core box.
Fig. 13.26 — (Right) Equipment for blowing AFS 2x2 in. core specimen.



Fig. 13.27 — Measuring green core hardness of blown core in blowability test.

and a sand cartridge in which is placed the sand to be tested. This sand cartridge contains one blow hole, 3/8-in. in diameter. On the opposite end from the blow hole, the core box contains one vent 0.005 by 0.50 in.

The assembled core box with sand cartridge is placed under a core blower and the core is blown in the usual manner. The sand cartridge is removed from the blown core and a green core hardness tester, Fig. 13.27, is used to measure the hardness to which the core is blown on opposite end from the blow hole. The green core hardness of the bottom end of an AFS 2 x 2 in. green core specimen of the same sand rammed with the AFS sand rammer is measured.

The blowability is expressed as the percentage of blown core hardness to AFS specimen hardness. For example: the blowability of a core mixture is 50 per cent when the blown core has a hardness of 40 and AFS 2 x 2 in. specimen has a hardness of 80.

PERMEABILITY AND GREEN STRENGTH OF BLOWN CORES

The AFS 2 x 2 in. specimen may be readily blown by using core box equipment as illustrated in Fig. 13.26.

The bottom of the core box assembly consists of a vented iron pedestal into which is placed a 2 in. metal filter disc. The core box proper is a ground hardened steel tube which is 2.0 in. in diameter and 2.0 in. in length. The sand is placed in a tubular sand cartridge. The sand cartridge is placed on top of the core box and it in turn is placed in the pedestal. This assembly is placed in a core blower as in plant practice.

The core is stripped from the core box and either tested for green strength, roll-out ability, sagging resistance or overhang ability before baking, or it is baked and the 2 x 2 in. specimen is tested for core permeability using core permeability specimen container (Fig. 13.14). The specimen may also be used for determining the baked compressive strength.

TENSILE STRENGTH AND CORE HARDNESS OF BLOWN CORES

The AFS tensile briquette cores may be blown with equipment illustrated in Fig. 13.28.

This equipment consists of a base plate with clamping screw, steel plate forming bottom of core boxes, two AFS tensile core boxes, and a sand cartridge. The equipment is assembled in order named. The sand cartridge is filled with sand to be tested. The upper portion of the sand is packed by hand to prevent piping. The assembly is placed in a core blower and two tensile briquettes are blown at one time. Each tensile briquette core box is placed on a separate drier, and the core box is removed from the green core. The core is then baked in the usual manner.

DETERMINING GAS GENERATED BY CORES

The quantity of gas that is generated within a core during the pouring and solidification of a casting is a practical question. A common practice in the foundry is to provide ample vents in a core to take care of a volume of gas above that expected. Of equal importance to the volume of gas is the rate at which the gas is generated. Thus, in testing a core for gas, both the total volume and rate of gas generation should be measured.

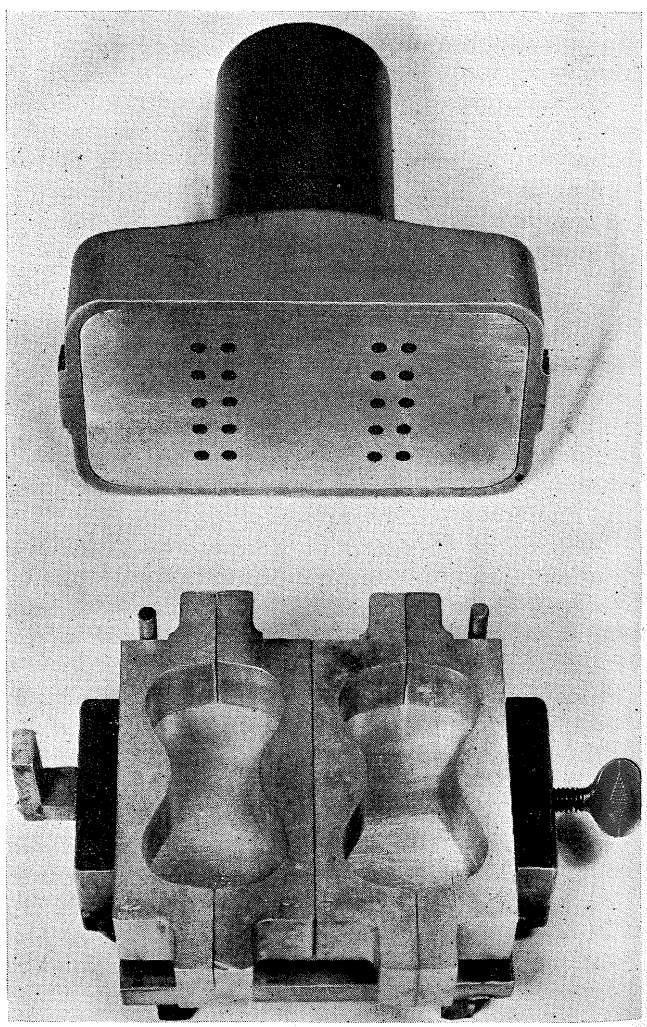


Fig. 13.28 — Equipment for blowing AFS tensile briquette cores.

Apparatus

Equipment for determining the volume of gas and rate of generation is illustrated in Fig. 13.29. This test is made by heating a small sample of core, weighing 5 grams, in a combustion furnace at 1800 F (982 C) for 4 min and measuring the amount of gas evolved.

The combustion tube is 7/8-in. inside diameter and fitted with a magnetic pusher so that the nickel boat with core sample can be sealed in the tube before the boat is pushed into the hot zone of the furnace. Such a device is necessary for, if the boat is placed in the zone before the combustion tube is sealed, the cold boat contracts the hot air, sucking in variable amounts of air and causing erratic results.

Before the boat is pushed into the hot zone, the air in the tube is displaced with carbon dioxide gas or an inert gas, such as nitrogen, introduced through the tube connections. The purpose of the inert gas is to furnish a nonoxidizing atmosphere to the core sample when heated. In the presence of oxygen the gas generated by the core burns forming water, carbon dioxide, and carbon monoxide and some free carbon. The water vapor so produced condenses when it reaches the cool parts of the tube causing inaccurate results. This is quite noticeable for, if the tube is filled with air, the gas contracts rapidly after reaching the maximum volume. Using an inert gas, this contraction due to water vapor is counteracted.

The use of a special atmosphere, as selected, also allows the close reproduction of actual conditions in a mold, for very little air is enclosed in a core in proportion to the volume of core gas given off.

Another arrangement of apparatus used for determining the quantity of gas generated by a core binder is illustrated in Fig. 13.30. It is being used very successfully by a producer of cereal binders. The following is the test procedure for this equipment.

Procedure

Fill bottle and 100 cc graduated gas absorption tube with water maintaining a water level in the bottle sufficient to seal the graduated gas absorption tube. Disconnect pyrex test tube and draw water through capillary tubing which connects with pyrex test tube and close pinch cock. Assemble apparatus, apply flame and open pinch cock.

After filling bottle and absorption tube with water, it is easy to refill tube after each test by closing pinch cock, disconnect cork stopper from pyrex tube and invert bottle and tube. In making the test, two or three blanks should be made to determine the amount of water displaced in the absorption tube by driving out the air in the pyrex test tube. The combustion boat should be placed as near the end of the tube as possible. A uniform flame should be used through all tests and the shield for the flame should be at a fixed point on the tube.

Weigh 0.5 grams of material into a tared combustion boat and proceed as described above. Water will be displaced with gas in the graduated gas absorption tube rather rapidly and in a short period of time remain constant for about a minute or two. When this point is reached, disconnect tube, subtract the blank and record the results on 100 gram basis.

If test is continued beyond this point, decomposition products (tarry substances) and condensate accumulate in test tube and this would discontinue displacement of water in the graduate tube.

Results

	cc Displaced		cc Displaced
Cereal Binder A	68.6	Cereal Binder B	73.2
	68.6		72.2
Average	68.6		72.7
Blank	24.3		24.3
	44.3		48.4

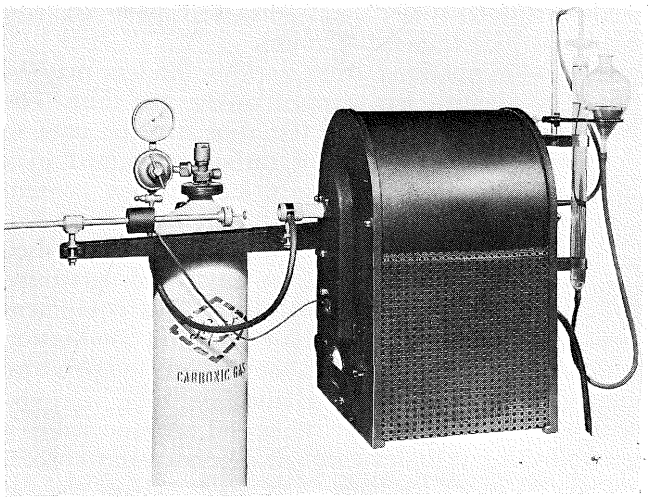


Fig. 13.29 — Apparatus for testing gas generated by a core mixture.

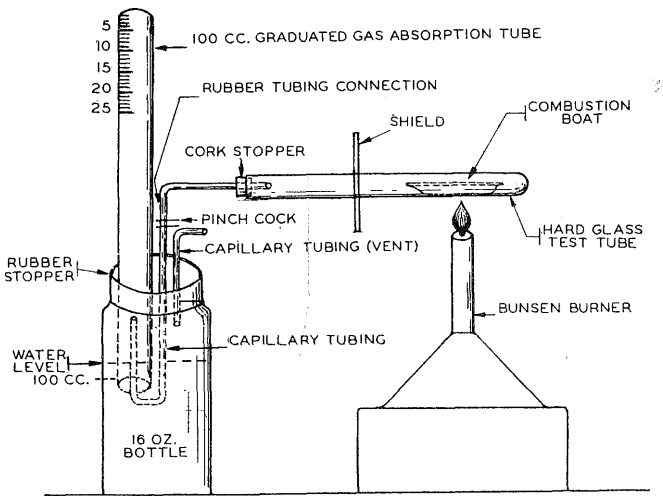


Fig. 13.30 — Another set of apparatus for determining gas evolution in a core mixture.

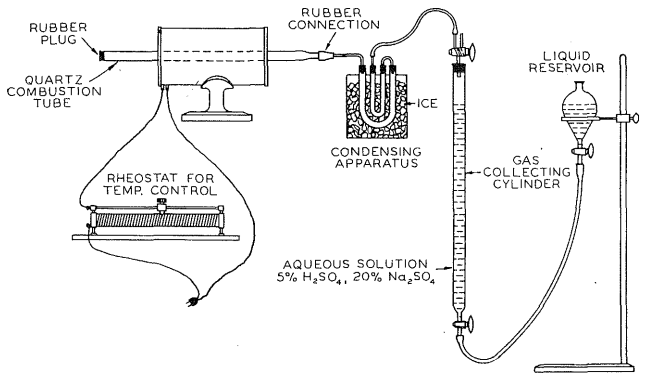


Fig. 13.31 — A third type of apparatus used to determine gas evolution by a core mixture.

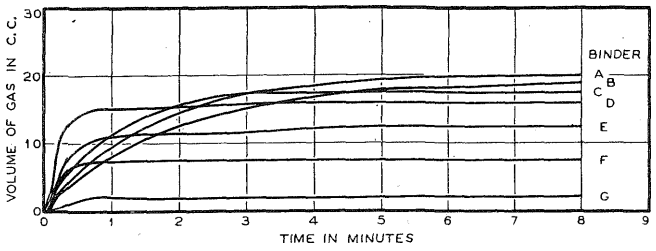


Fig. 13.32 — Rate and gas volume curves as a result of plotting the volume of gas readings against time.

Gas readings × 200 gives binder *A* 8860 cc, and binder *B* 9680 cc per 100 grams.

The odor obtained from various binders may be noted by smelling gas trapped in the test tube. The material remaining in the test tube may be used to determine the percentage of carbon contained in a binder. Cereal binders usually have carbon content around 12 per cent.

A third set of apparatus, shown in Fig. 13.31, is used by a manufacturer of resin core binders to determine the gas evolved by a core mixture. This equipment consists of a quartz combustion tube and combustion furnace equipped with a rheostat for temperature control. One end of the combustion tube is closed with a rubber stopper; the other end is connected to a gas collecting cylinder through a condensing apparatus placed in an ice bath. The lower end of the gas collecting cylinder is attached to a liquid reservoir. The gas collecting cylinder and liquid reservoir are filled with an aqueous solution of 5 per cent sulfuric acid and 20 per cent sodium sulfate.

It has been found that gases such as carbon dioxide and carbon monoxide have a very low solubility in such a solution. By use of the condensing apparatus equipped with an ice bath, the errors introduced in the measurement of the gas evolved through the generation of moisture are eliminated to a large degree.

The procedure is to adjust rheostat to provide a temperature in the combustion tube of 1800 F (982 C). Weigh 10 grams of pulverized foundry core sand into a nickel boat. Raise the liquid reservoir until the liquid level stands at the zero point on the gas collecting cylinder. Open both stop cocks at the upper and lower end of the cylinder to provide for movement of liquids through the lower and gas through the upper. Place the boat containing the pulverized core sand in the cool end of the combustion tube and, by means of a metal rod, move it into the hot zone. Quickly insert the stopper in the end of the combustion tube and adjust the liquid reservoir to balance with the height of the water in the gas collecting cylinder.

Start a stop watch at the time the boat is placed in the hot zone. A few seconds will be required to insert the rubber stopper in the tube. However, generation of gas proceeds very slowly in this short interval. During the next 30 to 60 sec generation of gas proceeds rather rapidly. By taking readings of the volume of gas in the cylinder and comparing with the length of time, a curve can be plotted showing cc of gas evolved versus time.

The test is continued for 7½ min, since after that time interval it has been determined that, with this apparatus, the curve of gas against time flattens out. Run a blank determination with a 10 gram sample of the base core sand in the nickel boat and subtract these results from core mixture gas evolution results.

Results obtained using this equipment are usually reported in terms of cc of gas per gram of sand and the

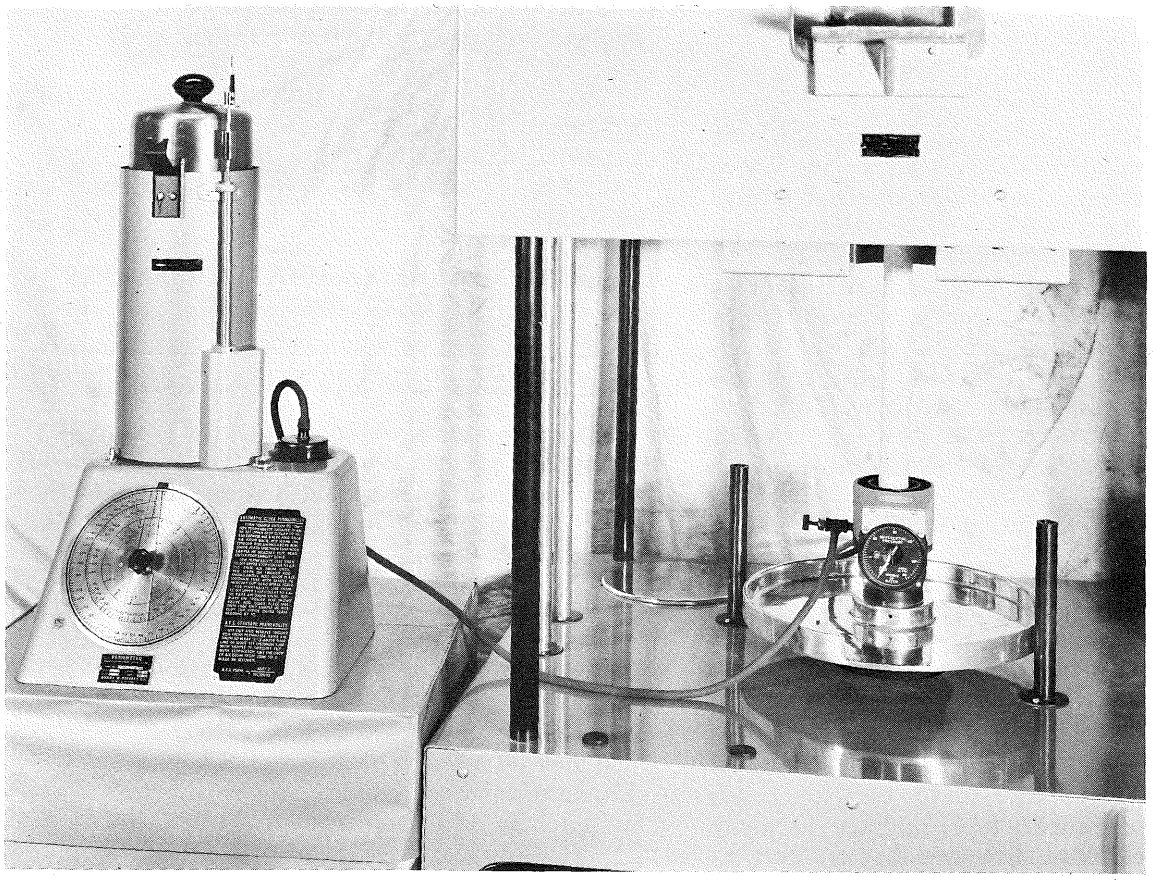


Fig. 13.33 — Equipment for testing for gas volume in cores.

time of the test, 7½-min, is also recorded.

The total volume of gas liberated by a core over a long period of time is not the best index for judging freedom from core gas defects. The better method is to study the rate at which the core gas is liberated. This can be well indexed by using the volume of gas liberated in a relatively short period of time such as one minute. Plotting the volume of gas readings against time result in rate and gas volume curves shown in Fig. 13.32. Referring to Fig. 13.32 it may be noted that the core with binder A has the greatest total gas volume. However, the rate of gas evolution is much slower than in core with binder D. Closing the volume of gas liberated in one minute shows that core binder D gives off 15 cc of gas and core binder A gives off 9.5 cc of gas. Thus core with binder D is preferable.

The gas volume generated by a core may be measured by placing a core specimen, 1⅛-in. in diameter by 2 in. in length, in a closed end quartz tube and then inserting the tube into a furnace. The open end of the quartz tube is connected to a gasometer bell. This bell is floating in a silicone liquid at 220 F (104 C). All of the gas generated by this core is trapped and measured in the gasometer bell. A test set-up for this method of testing for gas volume is illustrated in Fig. 13.33.

GAS PRESSURE CREATED BY A CORE

The rate of gas volume generation within a core is largely a function of the heat input into the core by the molten metal and the type and quantity of core binder.

The hot permeability of the core will endeavor to carry off the gas as it is generated. A gas pressure is built up within the core as the excess gas accumulates within it.

The gas pressure is thus dependent upon the rate of gas volume generation and hot permeability. The gas pressure is an end value of great importance to foundrymen. With light metal and low ferrostatic pressure head the desire is to have low gas pressure. In large molds with great ferrostatic pressure head, gas pressure may actually prove a beneficial aid in combating metal penetration. Gas pressure control is thus a practical item.

A test method of measuring the gas pressure created by a core specimen is illustrated in Fig. 13.34. The core is rammed and baked in a refractory tube 1⅛-in. in inside diameter. The end of the tube containing the core specimen is inserted into a furnace. The gas created may vent out through the free end of the core. The gas not vented will create a pressure and be indicated on a pressure gage.

DETERMINING QUANTITY OF OIL IN A CORE SAND MIXTURE

A 150 gram sample of sand is placed in a cylindrical tube (about 11 x 1 1/16-in. I.D. of approximately 125 cc capacity). This has at the bottom a tapered outlet fitted with a stopper attached to a shorter tube of about the same diameter which is fitted to a 500 cc Erlenmeyer flask with suction. The tapered end of the longer tube contains a filter paper plug upon which

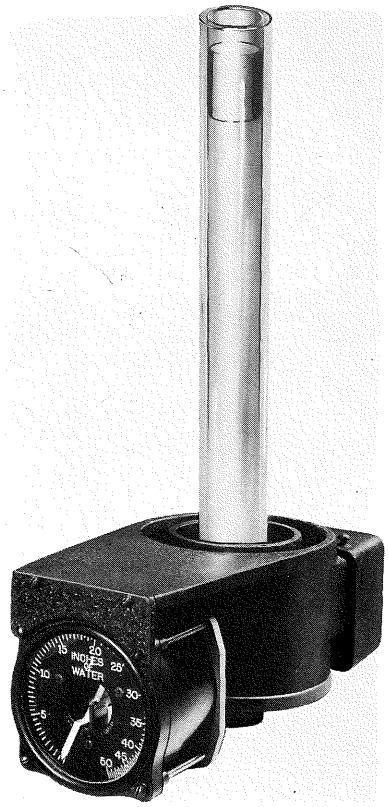


Fig. 13.34 — Equipment for measuring gas pressure in core specimen.

has been rammed about 1 in. of absorbent cotton. The shorter tube contains $CaCl_2$ for removing water.

With the column in readiness and the flask connected to a filter pump, gentle suction is applied and 100 cc of ether is then added in small portions to remove all traces of oil. (A preliminary blank may be run if desired, without the sand, or with a sample of the foundry sand before the addition of the oil.)

Transfer the ether solution to a 100 cc pear-shaped graduated centrifuge tube and evaporate over water bath at 150–212 F (66–100 C). The reading in cc gives percentage oil by volume and divided into 100 gives parts of sand to one part oil.

MOISTURE ABSORPTION TEST

The weakening of cores, due to moisture absorption from the atmosphere during storage or while set in a mold, presents a problem in foundries where cores are stored over a long period, or where molds are not poured soon after the core is set in the mold.

A moisture absorption test proves of practical value in such plants to determine the softening of various binders due to moisture absorption. A suitable test procedure is to place, for a period of 12 hr, either tensile or transverse core test specimens in a vessel containing air saturated with moisture.

Comparing the strength of test core specimens subjected to saturated atmosphere for 12 hours, and the strength of specimens not subject to the humid atmosphere, gives a good index as to how production cores made from a particular binder will be affected by humid weather or moist air in a mold.

The container for the moisture absorption test may be made by having a sheet iron vessel constructed 20 x 6 x 6 in. with a tight fitting cover. The inside of the vessel is lined with canvas. Water is placed within the vessel to 1 in. depth. A screen partition is sup-

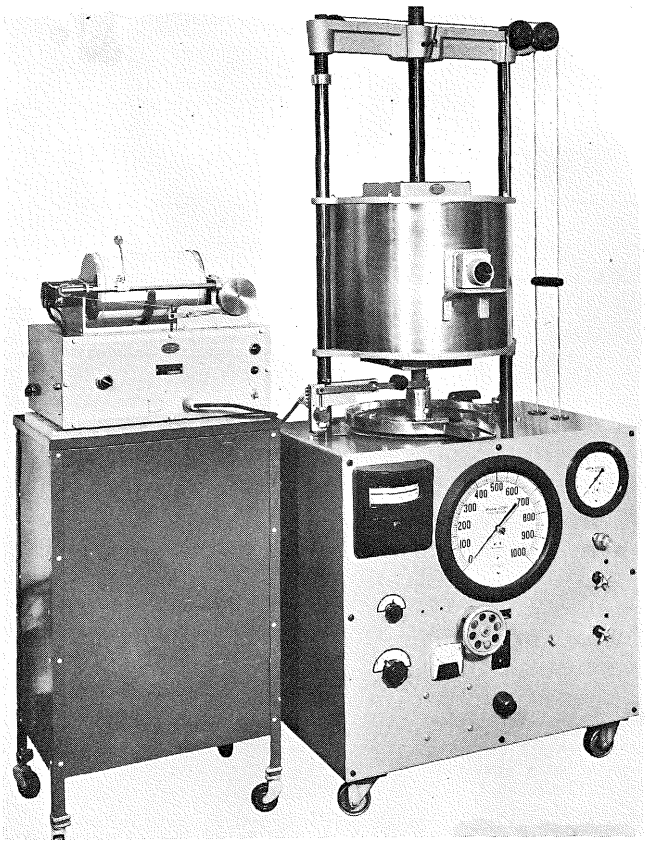


Fig. 13.35 — Thermolab dilatometer with hot deformation and expansion recorder.

ported 3 in. from the bottom of the vessel on which the test core specimens are placed. After the cores are in place, the container is sealed and kept at a temperature between 70–80 F (21–27 C). After a period of 12 hr, the cores are removed from container and immediately tested for strength, core hardness and deflection as desired.

TESTING CORE PROPERTIES AT ELEVATED TEMPERATURES

Core Collapsibility Test

The time required for a core to collapse in a mold is of major interest to a foundryman. When a core collapses too fast, due to a large volume of molten metal laying against a core, and particularly so when the volume of core is small in relation to volume of metal, much trouble is experienced due to metal cutting or penetrating the core.

In order to simulate mold conditions closely in elevated temperature testing of cores, it is advisable to heat the core specimen within a small enclosed chamber so that the gases evolved by the core are trapped and will surround the core specimen under test. A core in a mold must perform its work in an atmosphere which it creates as the heat of the molton metal encounters the core. Should a core containing a combustible core binder be heated to an elevated temperature in a furnace containing air, the core binder will burn rapidly and give a false value as to the life of the core. However, if the gases are trapped around the core as they are in a mold, then the core binder will burn more slowly and then may be tested under conditions similar to that experienced in the mold.

Elevated temperature tests, such as hot strengths and core collapsibility where the specimen is heated within a small confined chamber to trap the gases from the core specimen, are termed as own atmosphere. Own atmosphere may be secured in a furnace by placing a beaker, glass, nickel, ceramic or platinum, over the core specimen or by using an own atmosphere post to which the core specimen is heated.

Should the metal be of such composition to set fast, the core must collapse at a sufficient rate to accommodate the shrinkage of the metal. The collapsibility of a core may be measured by subjecting a core test specimen to a chosen temperature, for example, 2000 F (1093 C), and applying a chosen load, for example, 85 lb. A stop watch is used to determine the time required for the core to collapse. Cores collapsing in periods from 1 to 2 min are fast in collapsing and those collapsing in 8 min are slow. Cores for heavy castings do not collapse under this test, since they possess an appreciable strength at elevated temperatures. Such cores are tested for hot strength.

Hot Strength Test

An excellent test for cores used for heavy castings is the hot strength test made at temperatures of 500, 1000, 1500, 2000 and 2500 F (260, 538, 816, 1093 and 1371 C) preferably in own atmosphere. From prac-

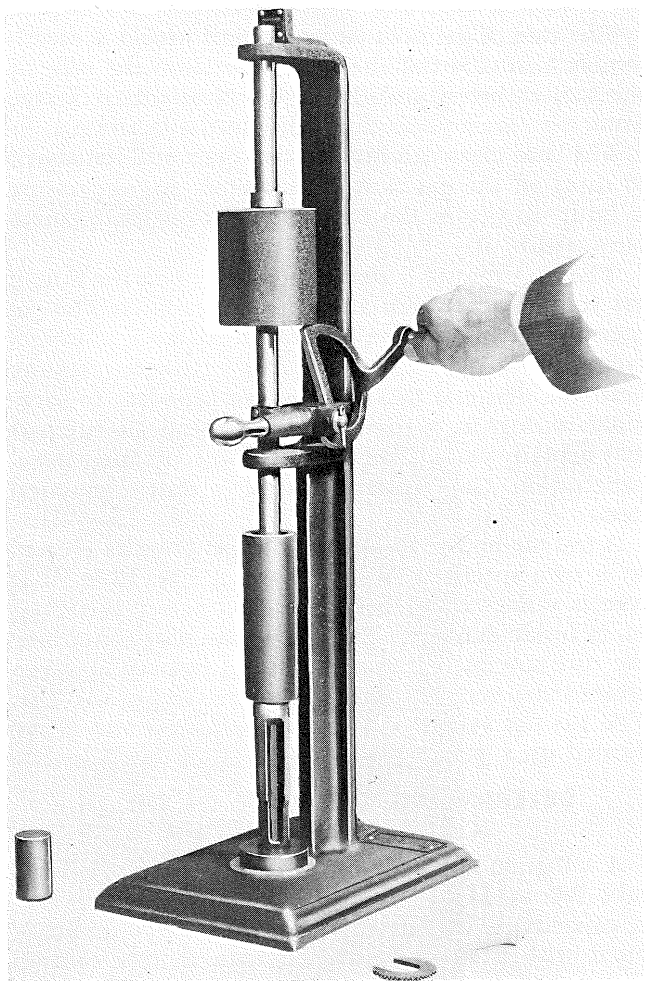


Fig. 13.36 — Special rammer for ramming 1 1/8-inch diameter specimen for high temperature testing.

tice, one determines the proper hot strength that will prevent cracking of castings due to cores and yet not cut, or wash. As an example, it may be found that a core with 60 lb hot strength at 2500 F (1371 C) will cause hot cracks and when the hot strength is reduced to 11 lb, the core will wash. A midway hot strength of 20 lb would be found satisfactory.

Equipment for conducting such tests as collapsibility, hot strength, expansion and contraction of cores is called a thermolab dilatometer, illustrated in Fig. 13.35. The core specimen is rammed with a special double-end ramming apparatus, Fig. 13.36. A test specimen 1⅛-in. in diameter and 2 in. in length has been found quite advantageous mainly due to ease of uniform heating. A specimen 2 in. in diameter by 2 in. in length also is being used to test the strength of core mixtures at elevated temperatures.

A furnace, capable of producing the required temperatures for the test being conducted, forms an important part of a dilatometer. The test specimen is located between a stationary upper post and a movable lower post connected to a hydraulic strength machine. During the test the furnace may be heated to the desired temperature, which may be as high as 3000 F (1649 C), and the core specimen quickly inserted in the furnace, simulating heat applied by pouring a casting. After the core has reached a uniform temperature, usually requiring about 12 min, a load is applied and rupture load is recorded on the gage.

Expansion-Contraction Test

The dilatometer, Fig. 13.35, may be equipped with an indicator gage and quartz or silicon carbide rod or tube, the latter resting on top of the core specimen and actuating the indicator gage. The indicator gage will then show the expansion or contraction of the core. The dilatometer may be equipped with a cathetometer which is sighted on a quartz marker seated on top of the test specimen. The change in specimen height is indicated on the dial indicator. In all of these elevated temperature tests, the same type of specimen is used, either the 1⅛ x 2 in. or 2 x 2 in. specimen. The core specimen may be slowly subjected to a temperature rise by lowering a cool furnace over the specimen and then applying the heat. The practice of subjecting the core specimen to a sudden temperature rise is preferred.

In the expansion-contraction and collapsibility tests, the core specimen is placed on the lower pedestal of the dilatometer. The indicator gage is set to zero and then the dilatometer furnace is heated to 2500 F (1371 C), or to a chosen temperature. Temperature and indicator gage readings are taken at intervals of 15 sec for a period of 12 min. The heat input into the furnace may be so regulated that the furnace temperature will again reach 2500 F (1371 C), or the desired temperature, within 12 min after temperature of the furnace has been slightly lowered by the cooling action of the core specimen.

The expansion of cores may be as high as 0.024 in. per in. of length or as low as a few thousandths. A core may show no contraction reading at a temperature of 2500 F (1371 C), or it may contract as much as 0.070 in. per in., at which time it is considered to have collapsed.

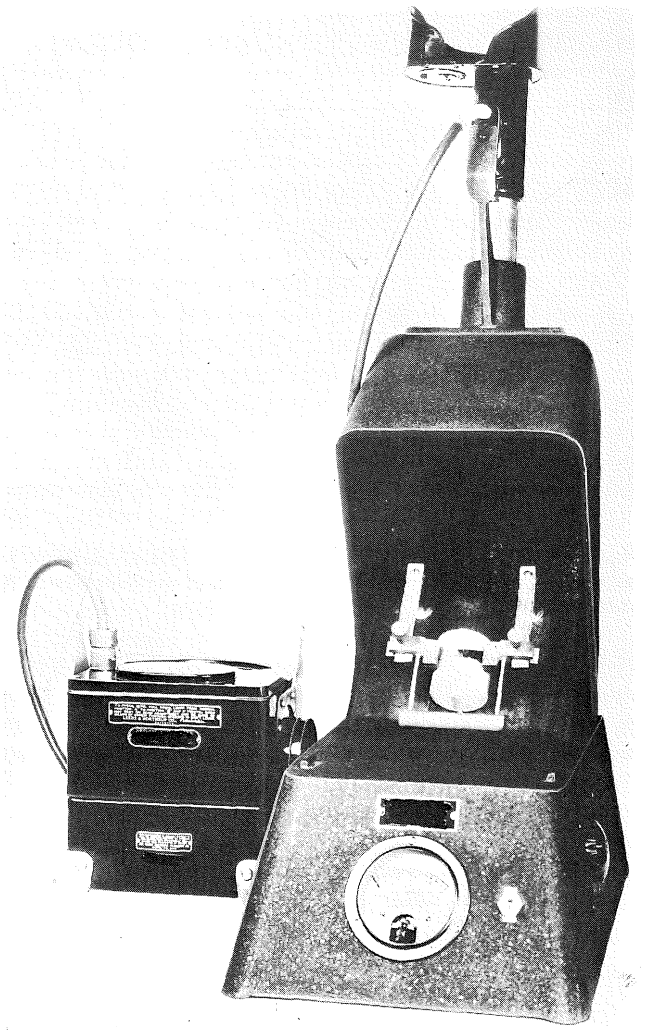


Fig. 13.37 — Sintering test apparatus for determining the refractoriness of core sands.

RETAINED STRENGTH

The ease with which a core will shakeout is measured in the laboratory by a test in which baked core specimens are heated in a dilatometer furnace of the type shown in Fig. 13.35. Usually the test specimen is of 1⅛-in. diameter and 2 in. long. Specimens are heated to 500, 1000, 1500, 2000, and 2500 F (260, 538, 816, 1093 and 1371 C) for a period of 12 min and then allowed to cool to room temperature. The compressive strength of each set of core specimens is determined. These figures are called the retained strength of the core.

A core, made with clean silica sand and bonded with oil, will possess no retained strength after being heated to temperatures above 1000 F (538 C). This indicates that the core will be easy to shakeout from the casting. Cores that possess from 10 to 500 psi retained strength when the core is heated to such temperatures as 1500, 2000 and 2500 F (816, 1093 and 1371 C) are difficult to shakeout.

SINTERING POINT OF CORE SAND MIXTURES

The sand used in a core requires a considerable degree of refractoriness since the volume of a core is usually small compared to the volume of the molten metal surrounding it. A suitable test for refractoriness

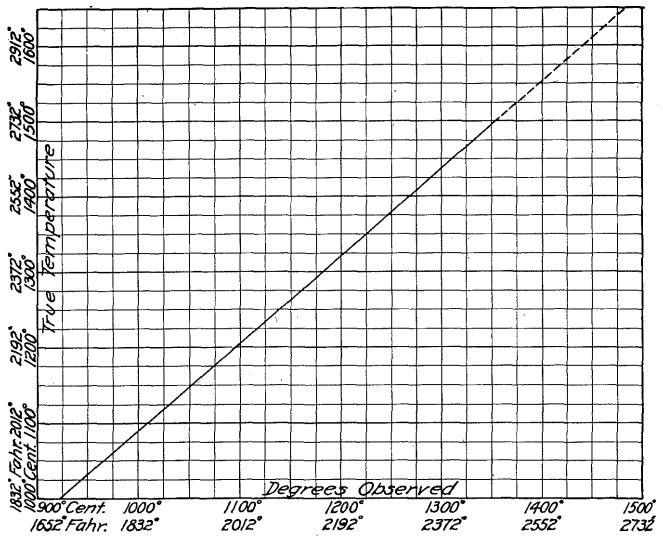


Fig. 13.38 — Temperature corrections for emissivity of platinum to be used in determining correct temperatures of platinum ribbon in sintering test.

of a core sand is the sintering test using the apparatus shown in Fig. 13.37. The sinter meter consists of a platinum ribbon holder, optical pyrometer and an electrical current control unit. The platinum (or platinum-rhodium) ribbon may be heated to the desired temperature by passing the proper amount of current through it. The ribbon is placed in contact with an AFS standard specimen when the sintering point of a core mixture is determined.

Procedure

Place the sand specimen in position in the sintering apparatus under the platinum ribbon. Center the specimen between the platinum ribbon holder terminals and place the platinum ribbon in contact with the rounded surface of the sand specimen, allowing the weight of the platinum ribbon holder unit, which is 170 grams (6 oz), to be the applied load.

Sight the optical pyrometer on the central point of the platinum ribbon and adjust it to read the observed temperature starting with, for example, 1693 F (923 C). Secure the true temperatures by correcting the observed temperatures for the emissivity of platinum by using the chart in Fig. 13.38.

Pass an electric current through the platinum ribbon, and adjust the variable resistance so that the brightness of the platinum ribbon matches the brightness of the filament in the optical pyrometer, which has been set at 1693 F (923 C) observed temperature, 1832 F (1000 C) true temperature.

This accomplished, start an interval timer or stopwatch and allow the heated ribbon to remain in contact with the sand specimen for 4 min. Turn off the electric current and raise the platinum ribbon from the specimen, noting whether or not the ribbon has burned fast to the sand specimen. If the platinum ribbon has not burned fast, rotate the specimen about one inch, and repeat the above procedure, this time increasing the temperature by 45 F (25 C). This corresponds to an observed temperature of 1738 F (948 C) or 1877 F (1025 C) true temperature as shown on the chart.

The lowest true temperature at which the platinum ribbon begins to fuse to the surface of the specimen at the end of the 4 min period is the sintering point.

In testing sands with low dry strength or grain material with no bond, the temperature at which one third of the ribbon at point of contact with the specimen is covered with sand grains is considered as the sintering point.

Precautions

The Subcommittee on Sintering Test, AFS Foundry Sand Research Committee, has made a study of the sintering test with a view to standardizing the procedure in such a manner that results can be checked between laboratories. The following statement is quoted from the report of this subcommittee. "One thing has been established if nothing else. There are few tests on any material that are as sensitive to slight changes in technique as the determination of the sintering point."

This subcommittee has found:

(1) That the time of contact between the platinum ribbon and the specimen shows no difference in sintering point on steel sands bonded with bentonite after 2 min of contact.

(2) That the effect of cooling time, after the power has been shut off, is very important and that best results seem to be obtained when the platinum ribbon is lifted from the specimen exactly 15 sec after the power has been shut off.

(3) That the load on the sand specimen exerted by the platinum ribbon holder has an important influence and a variation in load of as much as 25 grams can lower the sintering point 100 F (55 C) in a sand sensitive to load.

(4) When braided copper leads are used to conduct electricity to the ribbon holder, bending these leads slightly can easily change the load by 15 grams and cause an appreciable variation in the sintering point. Therefore, in conducting tests, the braided leads, if used, should be kept straight.

(5) Ribbon dimensions affect the results obtained materially and the results of the subcommittee's investigation point to the desirability of using a 0.002 in. thick ribbon.

DETERMINING STRENGTH OF CORE PASTE

The tensile core strength test may be used to measure the strength of core paste. The AFS core specimens, Fig. 13.15, are made from a strong oil-sand mixture, for example, with 1:25 oil-sand ratio. The speci-

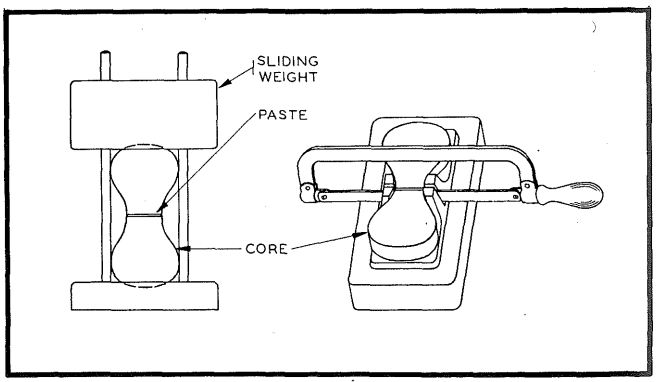


Fig. 13.39 — Method of sawing test specimen and of loading pasted specimen before testing to determine strength of core paste.



Fig. 13.40 — Sand washer used for scrubbing the clay substance from the sand grains.

mens are baked so as to insure that core specimens secured are stronger than the core paste. The core is sawed into halves through the center, as shown in Fig. 13.39. The surfaces of the sawed section are cleaned of any loose sand with a brush.

Prepare the paste, as used in the core room or as recommended by manufacturer. Apply paste and dry specimen in oven or at room temperature, as followed in practice. Allow core specimen to cool to room temperature, if it has been heated. Determine the tensile load that is required to pull the core specimen apart. Report the tensile load as the tensile strength of the core paste, providing the core is pulled apart at the pasted joint.

FINENESS TEST OF CORE SAND

The fineness of a sand used for a core is receiving more attention by foundrymen as time passes, due to the fact that the fineness of the sand affects many properties of a core. For example, the amount of oil binder required to produce a given strength increases as the sand becomes finer; conversely, the casting surface becomes smoother. Many other properties are affected by a change in fineness, such as permeability, rate of core collapsibility, core hardness, rate of baking, retained strength and green strength.

The fineness test data may be reported on the core sand as received, without removing the AFS clay substance, or the test may be reported on the fineness of the sand grains after the clay substance has been removed. In detailing the procedure of the fineness test, it will be assumed that the clay substance is to be reported separately in the fineness data.

The first step is to dry a sample for one hour between 221 and 230 F (105 and 110 C). Cool in a desiccator or covered dish. Weigh 50 grams of sand and place it in a quart fruit jar or a wash bottle. Then add 475 cc of distilled water at room temperature and 25 cc of sodium hydroxide.

Place the jar or wash bottle in a sand washing apparatus, such as is shown in Fig. 13.40. In the washer shown in Fig. 13.40, agitate for 15 min, or if a rotating sand washer is used, for a period of one hour. Then fill jar or bottle with distilled water to a depth of 6 in. Allow to settle for 10 min and then siphon off the water, leaving one in. of water in the jar. Add distilled water again and repeat the 10 min settling time and again siphon. Continue this operation, however, allowing only 5 min settling time for succeeding siphons. When water becomes clear, all of the clay substance has been washed out. Dry the sand grains and weigh. The difference between their weight and that of the original 50 grams, expressed in percentage, represents AFS clay substance. For plant control test, it is permissible to use city tap water in the clay washing procedure after the third washing.

The fineness of the dried grains is determined as follows. Place the weighed, dried sand remaining after removal of AFS clay substance on the uppermost sieve of the series of sieves consisting of National Bureau of Standards sieve Nos. 6, 12, 20, 30, 40, 50, 70, 100, 140, 200, 270 pan and cover. When the fineness test data is reported on the sand, with whatever clay it may contain, the sand is first dried and a 50 gram sample is placed in the uppermost sieve without washing the clay out of the sand.

After placing the sand sample on the uppermost sieve, the set is placed in a sieve shaker, such as those shown in Figs. 13.41 and 13.42, and allowed to shake for a period of 15 min.

Weigh the amount of the sand remaining on each sieve and express in percentage of the original dried sample weight (50 grams). The pan material obtained in the fineness test and the clay substance are reported separately as percentages of total sample (50 grams). In determining the fineness number, the method giv-

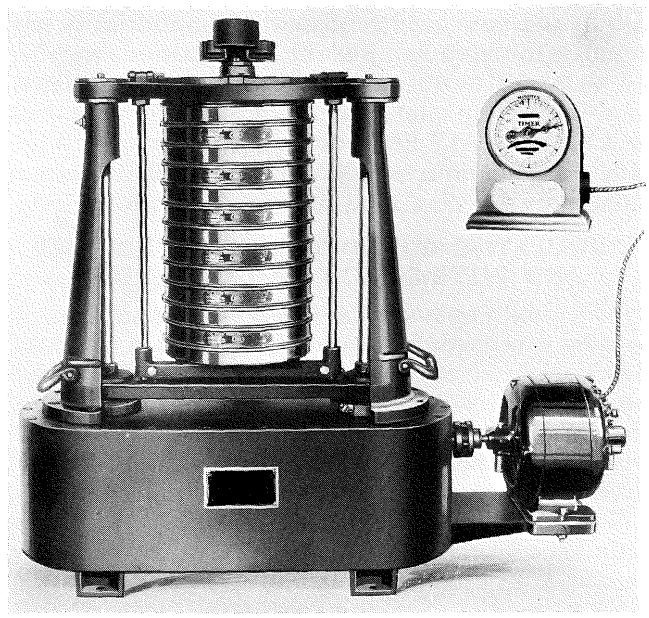


Fig. 13.41 — Sieve shaker.

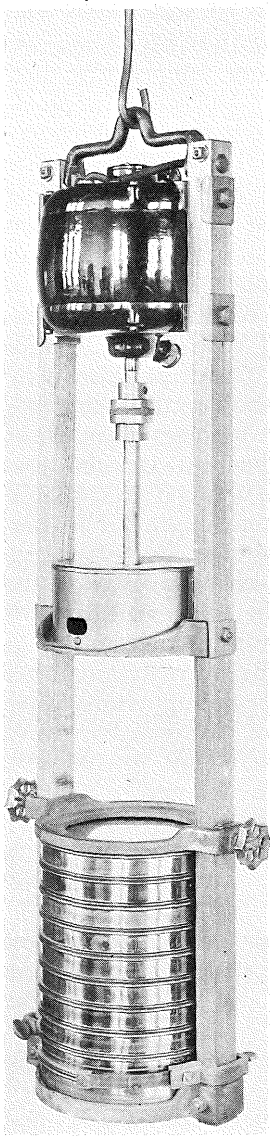


Fig. 13.42 — Gyratory sieve shaker with set of test sieves.

en in Chapter 5, *Methods for Determining Fineness of Foundry Sands,* AFS FOUNDRY SAND HANDBOOK (1963 Ed.), should be used.

Sampling. Sands used for cores are usually very low in clay substance, which allows the sand to easily segregate into coarse and fine size, due to wind, washing by water or by vibration in transportation. Thus, sampling of core sand should receive careful attention. In Chapter 3, AFS FOUNDRY SAND HANDBOOK, full details are given on sampling methods that have proved satisfactory for core sands.

CUMULATIVE CURVE FOR INDICATING SIZE AND DISTRIBUTION OF CORE SANDS

The usual way to obtain data on the size of sands is to pass a representative sample through a series of sieves stacked with the largest sieve at the top and progressing down to the smallest sieve at the bottom. A pan at the bottom of the stack catches the material which passes the finest sieve, and a cover over the top sieve keeps particles from escaping.

The number of sieves may be small or large and the ratio between the openings of consecutive sieves may or may not be the same. In the AFS sieve series the ratio is not the same throughout the series. It will readily be seen, therefore, that the amount of material passing one sieve and retained on the sieve below, has, in itself, little importance. The amount depends on the arbitrary selection of the sieves as well as the material being tested.

Usual Method of Sieve Analysis

A more satisfactory concept of the process may be obtained by considering each sieve separately. When a sample is placed in a sieve and shaken sufficiently, some grains fall through the square openings, while others do not. Those which fall through have a minimum projected area smaller than the square opening in the sieve. Shaking must be continued until the grains near the critical size have several chances to pass an opening by falling on the opening in different positions. When sieving is complete, the sample has been separated into one part which is coarser than the sieve and one part finer than the sieve.

If the weight of sand coarser than the sieve is computed as per cent retained by that sieve, the two fractions may then be mixed and divided by another sieve with a different size opening. In this way a sieve analysis may be made, sieve by sieve, and the results with each sieve are seen to be independent of the size, spacing or selection of the other sieves. The per cent retained by each sieve may be plotted as a function of the size of the openings in that sieve.

To save time, however, sieve analyses usually are made as stated above by means of a set of nesting sieves, the weight of material passing one sieve and retained on the next finer sieve being reported. Usually an effort is made to present this information in the form of a graph which is generally unsatisfactory because the ratio between sieve sizes was not uniform throughout the sieves used.

Satisfactory results may be obtained by weighing the amount retained on any sieve and adding to it the amounts retained on all the coarser sieves. In this way the total amount coarser than the sieve may be found.

Outline of Cumulative Method

Another method which is even more satisfactory is to weigh the amount of material on the coarsest sieve and then to place the material from the next finer sieve on the balance pan with the coarse material and weigh the total. This total is the amount coarser than the second sieve. The material on the third sieve is then added, and so on until the analysis is completed.

This method is called cumulative weighing and, when reduced to percentages, gives the cumulative per cents retained by the various sieves. These data may be plotted as a function of the sieve opening in microns, which usually is found on the nameplate of the sieve.

The use of many types of graph paper over a period of years has indicated that the most satisfactory type is one in which the cumulative per cents retained are plotted as a function of the size of the sieve in microns on a logarithmic or ratio scale. Most materials found in nature, as well as many of those which are processed, as in the washing and sorting of foundry sands, have their particles distributed over such a wide range of sizes that two or three cycles along the logarithmic scale are required to make a graph of the major part of the material.

A good chart paper is No. 3115 or No. 3125, made by the Codex Book Co. This paper has 20 divisions per inch (120 divisions) along one axis, and three 3 in. cycles of ratio or logarithmic ruling along the other axis.

CHEMICAL ANALYSES OF CORE BINDERS

Core Oils

The chemical analysis of oils, used as binders for cores, is of limited interest to foundrymen but it may be used to check core oils to determine whether they meet specified purchasing requirements. The physical properties of a core are not necessarily maintained at a given value by maintaining the chemical specifications within specified tolerances. Where it is desired that physical properties, such as core strength, be maintained, it is preferable to measure this physical property directly.

Iodine Number

Determination: In a 12 or 16 oz glass stoppered bottle, in which the stopper fits closely, place 10 cc of C.P. carbon tetrachloride. The sample of oil is now shaken in its original container and a small amount placed in a dropping bottle fitted with a ground glass stopper. The bottle is wiped clean and placed in the balance case for not less than 15 min.

During the weighing operation, the bottle is handled only with crucible tongs, so that the fingers will not come in contact with the glass and change the weight of the bottle by either depositing upon or absorbing water from its surface.

Weigh very carefully about 0.15 gram of oil. Usually 5 to 7 drops from the bottle will be sufficient. A trial of each bottle will have to be made. When the weight of the dropping bottle and oil is recorded, grip the bottle with the crucible tongs and pour the predetermined number of drops of oil into the bottle containing the solvent. Then reweigh the dropping bottle, handling with tongs all the time. The difference will be the weight of oil taken.

Then add from an accurate burette, 25 cc of the Wijs solution. Wet the stopper with potassium iodide solution sufficient to cover its surface but do not have enough to permit the iodide solution to run down the inside of the bottle. Let stand one hour in the dark, with occasional gentle shaking. Some operators reduce the time to one-half hour.

Now titrate the excess of iodine with the standard sodium thiosulfate solution in the following manner. Shake the bottle, then add 10 cc of potassium iodide solution and shake again. Now add 100 cc distilled water, shake, and run the standard sodium thiosulfate solution in from a burette. When the color fades to a pale straw yellow, add 3 or 4 cc of starch solution, then add the sodium thiosulfate, drop by drop, until the blue color is discharged. It is important to add the reagents in the order and the amounts specified. Near the end of the titration, it is necessary to shake violently in order to free any iodine that is dissolved in the carbon tetrachloride solution.

With each set of determinations, blanks should be run, that is, the operation is carried through exactly as described, except that no oil is placed in the bottle. It is also necessary to use 20 cc of potassium iodide solution and that the Wijs solution and the sodium thiosulfate solution be kept at the same temperature during the time that these solutions are being used. If this is done, the blanks will take care of variations in the temperature from day to day.

Calculation: The calculation of the iodine number from the data obtained is this: Assume the blank required 50 cc of standard sodium thiosulfate, and the oil titration 27 cc. Assume the value of the sodium thiosulfate to be 0.01262 gram iodine per cc and the weight of oil taken to be 0.1528 gram. Deducting 27 cc from 50 cc we have 23 cc as the measure of iodine absorbed, or 0.29026 grams. This number divided by 0.1528 grams, the weight of oil taken, gives 189.9 as the iodine number of this oil. The iodine number expresses the per cent, by weight, of iodine absorbed by the oil.

Solutions: (1) "Wijs' Iodine Chlorine Solution" (method A.O.A.C.), made by Hartman-Leddon Co., Philadelphia, Pa.

(2) Standard sodium thiosulfate solution: Dissolve 25 grams of C.P. sodium thiosulfate in 1000 cc distilled water. To standardize, dissolve 0.2 gram C.P. potassium dichromate in 20 cc of distilled water. Add to this 15 cc potassium iodide solution. Then add 10 cc concentrated C.P. hydrochloric acid and shake. Now add 100 cc distilled water, shake, and run the standard sodium thiosulfate solution in from a burette. When the color fades to a pale straw yellow, add 3 to 4 cc of starch solution. Then add the sodium thiosulfate, drop by drop, until the blue color is discharged. It is important to add the reagents in the order and the amounts specified.

To calculate the strength of the solution, divide 0.5177 gram by the number of cc thiosulfate used. This figure is the weight of iodine that is set free by the 0.2 gram of bichromate of potash used. If, for instance, 41 cc thiosulfate were used, by dividing 0.5177 by 41 we find 0.01262 gram as the amount of iodine to which each cc is equivalent.

(3) Starch solution: Dissolve 1 gram of soluble starch in 100 cc of distilled water (a satisfactory brand of soluble starch is that made by Merck & Co., according to Lintner). The starch is mixed with cold water. The mixture then is warmed and kept in agitation until the solution becomes clear, when it is ready for use.

(4) Potassium iodide solution: To 90 cc distilled water, add 10 grams of C.P. potassium iodide. Shake until solution is complete.

Saponification Number

Determination: Weigh accurately about 5 grams of the sample into a 250–300 cc Erlenmeyer flask. Pipette 50 cc of the alcoholic potassium hydroxide solution into the flask, allowing the pipette to drain for a definite time. Connect the flask with an air condenser and boil until the fat is completely saponified (about 30 min). Cool and titrate with the N/2 hydrochloric acid, using phenolphthalein as an indicator. Always run two blanks with the alcoholic potash.

Calculation: From the difference between the number of cubic centimeters of acid required by the blanks and the determinations, calculate the saponification number (milligrams of potassium hydroxide to one

gram of oil). The saponification number indicates the number of milligrams of potassium hydroxide required for the complete saponification of one gram of an oil.

Solutions: (1) N/2 hydrochloric acid — carefully standardized.

(2) Alcoholic potassium hydroxide solution — Dissolve 40 grams of pure potassium hydroxide in one liter of 95 per cent redistilled alcohol (by volume). The alcohol should be redistilled from potassium hydroxide over which it has been standing for some time, or with which it has been boiled for some time, using a reflex condenser. The solution must be clear and the potassium hydroxide free from carbonates.

Acid Number

Determination: Weigh about 10 grams of the oil into an Erlenmeyer flask. Add about 50 cc of neutral alcohol. Boil for a few minutes, cool and titrate with N/10 sodium, or potassium hydroxide solution, using phenolphthalein as an indicator.

Calculation: Calculate the result in milligrams of KOH required to neutralize one gram of the oil.

Solutions: (1) Neutral 95 per cent ethyl alcohol is generally employed. It should be freshly distilled from sodium hydroxide. However, for routine control work, 95 per cent denatured alcohol, neutralized by the addition of an aqueous solution of caustic soda or potash, can be used. One should be selected, however, which does not change color to an appreciable extent when neutralized.

(2) N/10 sodium or potassium hydroxide.

Fish Oil

Determination: To 15 drops of oil in a test tube, add 12 cc of a 50-50 solution of chloroform and glacial acetic acid. Add bromine water, drop by drop, until it is indicated by color. Keep at 68 F (20 C) and let stand for 15 or more minutes, then place tube in boiling water. If all vegetable oil — solution clears. If fish oil — solution remains cloudy or precipitates due to insoluble bromides.

Solutions: 1. Chloroform.
2. Glacial acetic acid.

References: *Technical Methods of Analysis,* by R. C. Griffin.

Specific Gravity

Determination: Into a hydrometer cylinder of oil sample, place a specific gravity for light liquids at 60 F (16 C) (0.880 to 0.940) hydrometer and a thermometer. Observe specific gravity and temperature and add to it the correction obtained from chart of "Temperature Corrections to Readings of Specific Gravity Hydrometers in American Petroleum Oils at Various Temperatures," of Van Nostrand's Chemical Annual.

Ash Content

Weigh approximately 5 grams of oil into a weighed 50 cc wide form porcelain crucible and thoroughly incinerate, cool and weigh. Weight of ash divided by weight of sample, multiplied by 100 gives the per cent of ash.

Flash Point

Determination: use Cleveland open cup.

Fire Point

Determination: use Cleveland open cup.

Sampling

Place a stoppered quart bottle in the bottom of the container, remove stopper and raise bottle to the top at such a rate so as to have the bottle filled when it reaches the top.

Cereal Binders

Acidity

Weigh 10 grams of the average sample to be tested and transfer to a 600 or 800 cc beaker. Make a paste by adding 50 cc of cold distilled water and stir until all lumps are broken up and a smooth paste obtained. Add from 300 to 500 cc of boiling distilled water, stirring constantly. If more convenient, add hot distilled water and heat to boiling, stirring constantly until completely gelatinized.

This hot solution is titrated with N/19 sodium hydroxide using phenolphthalein as indicator. Take as the end point the first visible pink color. (Calculation): per cent acidity as HCl-titer × 0.0365.

Oil and Fat

The oil or fat is extracted with the regular Soxhlet equipment using a weighed flask, carbon tetrachloride as a solvent, and heating on an electric hot plate.

Procedure used is to dry a clean extraction flask in an oven for an hour, at 230 F (110 C); cool and weigh. Weigh the sample to be analyzed and transfer to the extraction shell, plugging the top of the shell with absorbent cotton. (For starch binders, a 5 gram sample should be taken; for materials high in oil, use 2 grams for extraction.)

Insert shell in siphon tube and connect Soxhlet with the weighed flask, and sufficient carbon tetrachloride to fill the siphon tube twice, allowing the first lot to siphon over into the flask before adding the second amount. Place on the hot plate, connect the condenser and extract for 4 hours. Remove the extraction shell from siphon and continue heating until major part of tetrachloride is condensed in the Soxhlet tube. Disconnect flask and heat flask carefully until the odor of the carbon tetrachloride becomes very faint, using care to not overheat and carbonize the oil which has been deposited in the flask. Transfer to oven and dry for 2 hours at 212 F (100 C), preferably with vacuum, to remove last traces of the tetrachloride. Cool in desiccator and weigh.

Per cent oil is reported on a commercial basis and is determined by the increase in weight of the weighted flask after extraction, and calculation made on the basis of the number of grams used.

When mixture content has been increased above 12 per cent, the sample should be dried above 5 per cent moisture content before making the extraction.

In case foreign material appears in the extraction flask due to faulty extraction thimble or leakage from around the cotton plug, the contents of the flask should be filtered before evaporating and the filter

paper washed with carbon tetrachloride. It is sometimes necessary to use two or three thicknesses of the filter paper, pouring the extracted sample through the paper several times to obtain a clear filtrate.

Protein

Protein is determined by weighing 2 grams of the material to be tested and transferring to an 800 cc Kjeldahl flask. Add 10 grams of potassium sulfate and approximately 0.7 gram of mercuric oxide, rotating flask a few times to thoroughly mix the chemical. Add 25 cc of concentrated C.P. sulfuric acid, 1.84 specific gravity (free from nitrogen), using the acid to wash down any particles of the material that adhere to the sides of the flask or neck.

Place flask in the digestion rack under well-ventilated hood or connected to suction pipe and heat with a low flame over wire gauze for 10 min. Increase heat until acid boils briskly and continue boiling until the mixture is colorless; total digestion time is from 1½ to 2 hours.

Allow the flask to cool, dilute with 200 cc of distilled water, add a small amount of C.P. granulated zinc to prevent bumping, add 25 cc of potassium sulfite solution, which has been prepared by dissolving 40 grams of commercial sulfite in one liter of water. With the flask ready to connect to the distillation apparatus, add sufficient 40 degree Baumé sodium hydroxide, free from carbonates, by pouring it down the side of the flask so that it will not mix at once with the acid solution. A sufficient amount of hydroxide should be used to make the solution in the flask strongly alkaline. Then, without delay, connect the flask by means of the connecting bulb to the distillation apparatus. Mix the contents of the flask by shaking slightly with a rotating motion and distill until all the ammonia has passed over and been condensed into a measured quantity of N/10 acid; in general, 250 cc of distillate is sufficient to contain all the ammonia.

Titrate the excess acid in the receiving flask with N/10 sodium hydroxide using methyl red as the indicator. Deduct this titer from the amount of N/10 acid added to the receiving flask. Each cc of N/10 sulfuric acid neutralized is equivalent to 0.00875 gram protein.

It is necessary to make correction for the nitrogen in the reagents used in the determination by digesting ½ gram of granulated cane sugar using exactly the same amount of reagents added to the regular digestion and distilling into 5 cc of N/10 acid, titrating back the excess of the acid with N/10 sodium hydroxide. As a general rule, the correction of the chemicals is seldom more than 0.30 cc N/10 acid as combining with the reagents.

pH (Hydrogen Ion)

Two methods are used, both of which give complete results: (1) The potentiometer apparatus purchased from Leeds & Northrup Co., Philadelphia, Pa., No. 7654 Quinhydrone pH indicator, No. 7701 Quinhydrone Electrode, and No. 7696 Calomel Electrode Vessel.

(2) If a Leeds & Northrup apparatus is not available, a colorimetric method is used following the instructions given in Clarke's "The Determination of Hydrogen Ions."

Two to 5 grams of the sample are digested with 100 cc of water in a shaking machine for 30 min, then filtered or transferred to a centrifuge and spun for 10 min.

Ten cc of the clear solution are placed in the pH test tube and the proper indicator in accordance with the pH expected is placed in the comparator block and matched to the nearest standard.

Methyl red, brom cresol purple, and brom thymol blue are the three indicators that will cover any range to be found in regular binders or starch.

Method of Determining Solubility

First determine moisture. Take 5 grams, drying at 221 F (105 C) for one hour.

Solubility: Two grams of dextrin are thoroughly mixed with 50 cc distilled water at room temperature. This mixture is then poured into a 200 cc measuring flask, with the addition of about 100 cc more water. This is allowed to stand for one hour with occasional shaking – then is made up to the mark, shaken and filtered through a dry filter, discarding the first few cc of the filtrate. The 100 cc is collected in a measuring flask, evaporated to dryness on the steam bath in a weighed evaporating dish, then dried for an hour at 221 F (105 C) and weighed. Result gives the soluble matter which is then computed on a moisture free basis.

Fluidity: This is determined as the number of cc that runs through a funnel at 70 sec at 70 temperature. The higher the number the thinner the paste.

Viscosity: This is determined as the reverse of fluidity test in that it gives the quantity going through the funnel in a given time.

Chapter 14

CONTROLLING CORE PROPERTIES

INTRODUCTION

Physical tests offer to foundrymen the best means of measuring and specifying the required properties of a core. They offer an exact and definite manner in which a foundryman may describe the type of core that is required. Further, physical tests are useful in the selection and specification of materials used in the core room.

When physical tests become incorporated in the production routine procedure of a core room, then one is at the threshold of a new era in core room practice where the effect of each ingredient and processing treatment is well understood, defined and controlled. Core room practice then may become one of compounding and processing core materials as one does in the case of metals, to obtain a definite product.

The test data presented in this chapter are given as encouraging steps toward incorporating control procedure in the core room.

CORE HARDNESS

In usual foundry practice, the surface hardness of a baked core, as determined in the past by the fingernail scratch test, is used largely to gage the quality of a core. This surface hardness may be readily measured precisely by means of an instrument called a core hardness tester, as illustrated in Fig. 13.24, Chapter 13. It is of practical value to know the many conditions that affect the hardness of a core. With this in view, the material presented in the succeeding paragraphs will show how core hardness is affected when the following conditions are changed.

(1) Baking temperature.
(2) Baking time.
(3) Moisture content of the core sand mixture.
(4) Time that the core was allowed to stand before being placed in the oven.
(5) Cooling time after being baked.
(6) Sand to oil ratio.
(7) Fineness of the core sand.

The author has investigated these variables and presents his results. The test procedure followed and the test equipment used to secure the data, was in accordance with AFS requirements. As a guide to those not experienced in core hardness testing, the range of core hardness readings shown in Table 14.1 will be of value.

The core oil used in the investigation was a commercially compounded core oil of linseed oil base. The core sand used in all tests, with the exception of the grain fineness effect test, was a lake sand mined in the lower western portion of Michigan. A fineness distribution curve of this sand is shown in Fig. 14.1.

TABLE 14.1 — RANGE OF HARDNESS READINGS FOR VARIOUS-TYPE CORES

Type Mold or Core	Hardness
Dried molds, soft	20
Dried molds, hard	40
Baked cores, soft	35
Baked cores, medium	50
Baked cores, hard	75
Baked cores, very hard	90

The temperature and time at which a core is baked will materially affect the core hardness. This is well illustrated in Fig. 14.2, where core hardness values of AFS test cores are shown on contour lines of the graph for a wide range of baking temperature and time in minutes. The area within the 90 core hardness contour lines shows the various selections of baking temperature and baking time in minutes that will produce a core with a hardness above 90.

Effects of Varying Baking Temperature

The temperature at which cores are baked influences both the surface and the interior. The surface

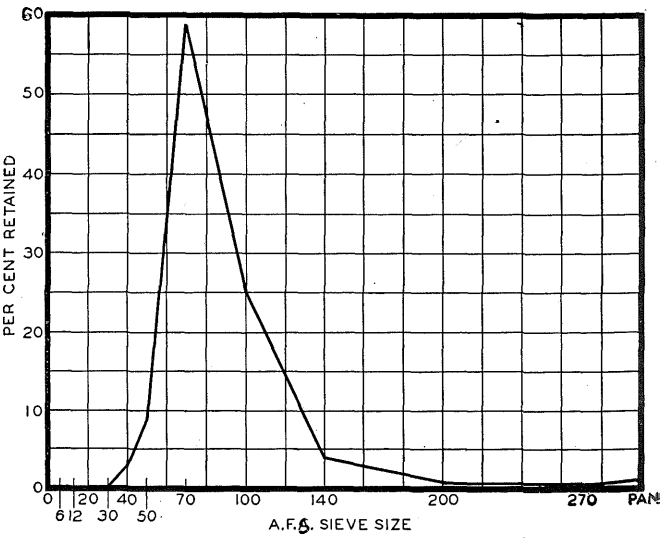


Fig. 14.1 — Grain distribution curve of a lake sand with AFS Fineness No. 56.

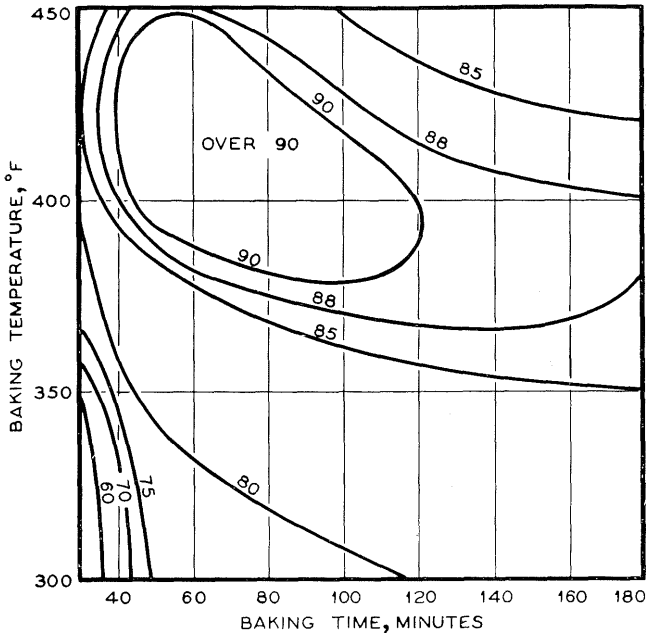


Fig. 14.2 — Relationship between core hardness and baking time and temperature.

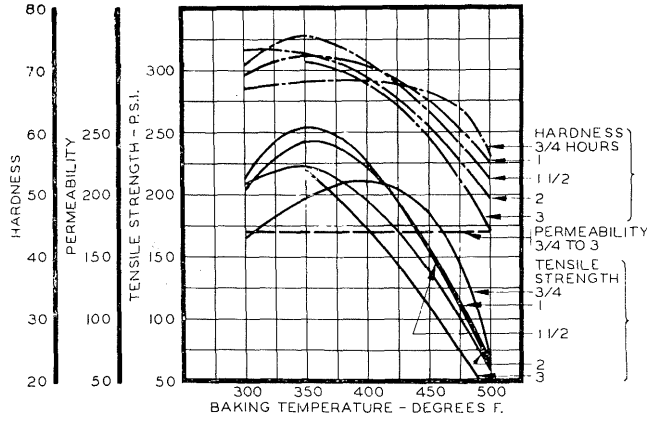


Fig. 14.3 — Effect of varying baking temperature on the tensile strength, permeability and hardness of baked cores. Moisture, 5 per cent; sand to oil ratio, 56-1. Figures on right of chart are baking times.

condition of the core is measured by its hardness, while its tensile strength indicates the condition of the interior. Test cores baked in the core test oven bake more rapidly than cores in production, primarily due to the perfect baking condition obtained in the test oven. Thus to convert test baking time, as shown in succeeding illustrations, one must add additional time to obtain comparable production baking time. The core hardness, tensile strength and permeability of test cores baked at various temperatures under varying baking times are shown graphically in Fig. 14.3. The numbers shown under core property are the baking times in hours. For example, "Hardness-3" indicates the hardness of cores baked for 3 hours in an AFS standard test oven.

A study of the hardness curves, Fig. 14.3, clearly shows that a baking temperature of 350 F (177 C) produced the maximum hardness when the time of baking was 1½-hr. High baking temperatures, in all cases regardless of baking time, produced the lowest core hardness. Baking temperatures below 375 F (191 C) gave best results in producing a firm surface or high core hardness.

The tensile strengths of cores behave in the same manner as core hardness in that temperatures above 400 F (204 C) produced low tensile strength cores regardless of baking time. Strongest cores were obtained at 350 F (177 C) baking temperature with a time of 1½-hr. The permeability of a core is not affected by the baking temperature.

Effects of Varying Baking Time

A very similar set of test curves to that of Fig. 14.3 is obtained when the baking time is varied for different baking temperatures as shown in Fig. 14.4. The hardness of the cores increased as the baking time was increased up to substantially 2 hr, as long as the baking temperature was not above 400 F (204 C). With temperatures above 400 F (204 C), the core hardness shows a decreasing trend, regardless of how short the baking time.

The tensile strength of a core follows the trend of core hardness as the baking time is varied. The advantages of temperatures lower than 400 F (204 C) are clearly shown in Fig. 14.4.

As has been previously stated elsewhere in this volume, and has been demonstrated by the preceding, there is a best baking time and a best temperature for each core mixture. The above test results demonstrate this fact and what is true for one binder in a core mixture also holds true when a combination of binders of different types are used.

This is demonstrated by Fig. 14.5 which shows the results of baking core mixtures at 450 F (232 C) for various lengths of time. Three mixtures were used. One contained core oil only in the ratio of 100-1 with 7.2 per cent moisture; the second, cereal binder only in the ratio of 200-1 with the same moisture; and the third, both cereal, oil, and moisture in the same amounts as had been used previously. The combination of binders increased the tensile strength marked-

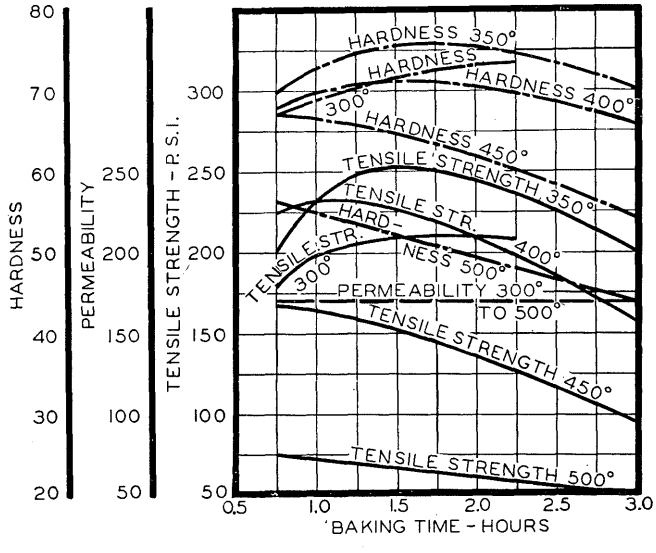


Fig. 14.4 — Effect of varying baking time on the properties of baked cores. Temperatures, F; moisture, 5 per cent; sand to oil ratio, 56-1.

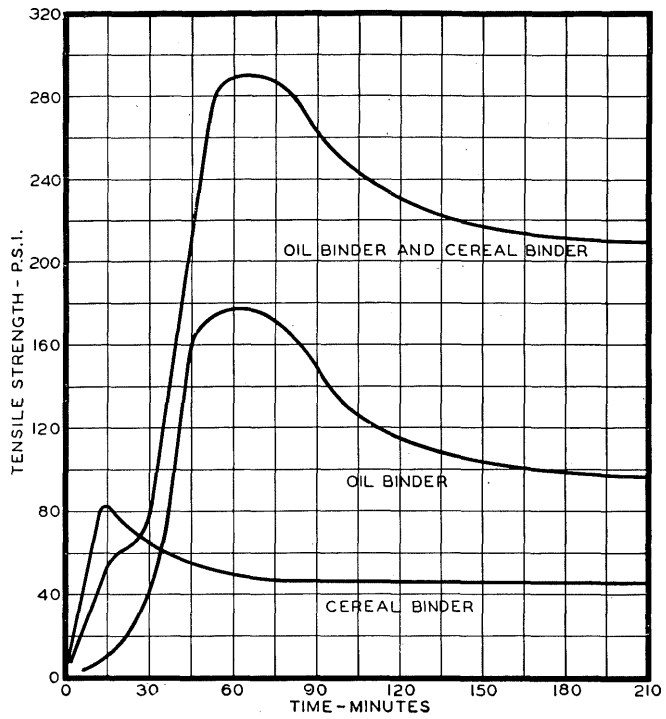


Fig. 14.5 — Effect of a combination of binders on baking time for maximum strength at 450 F (232 C); moisture, 7.2 ±0.2 per cent; oil to sand ratio, 1–100; cereal binder to sand ratio, 1–200.

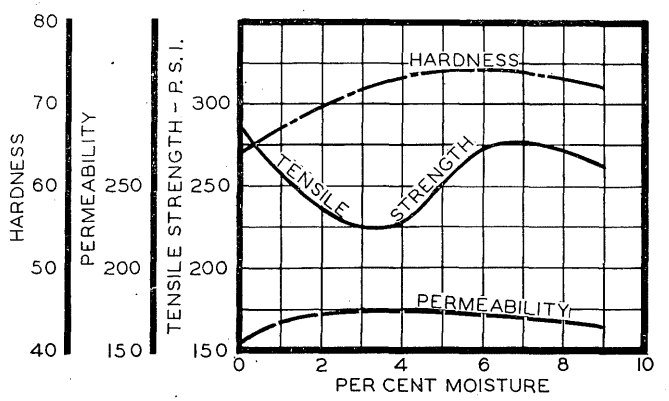


Fig. 14.6 — Effect of varying the moisture content of the core mixture on the properties of baked cores. Baking time, 1½-hr; temperature, 350 F (177 C); sand to oil ratio, 56–1.

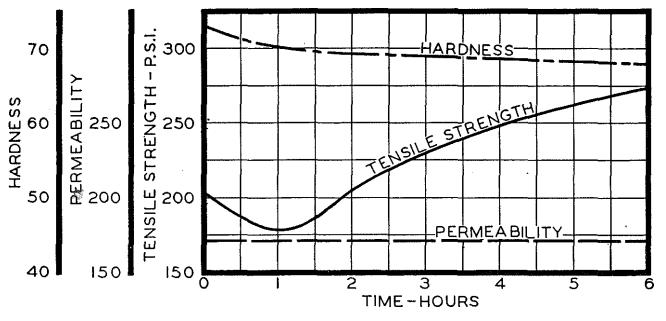


Fig. 14.7 — Effect of allowing green cores to stand in air before baking on the properties of baked cores. Baking time, 1½-hr; temperature, 350 F (177 C); moisture, 5 per cent; sand to oil ratio, 56–1.

ly. The curves were characteristic with the exception of the cereal-binder-only mixture. That curve indicates too high a baking temperature.

Effects of Varying Moisture Content

A baking temperature of 350 F (177 C) with a baking time of 1½-hr was used in studying the effect of moisture in the core mixture. The curves shown in Fig. 14.6 illustrate how the hardness, tensile strength and permeability change with a change of the moisture content in core sand mixtures. The core hardness increased as moisture content increased up to 6 per cent for the lake sand used. When the moisture was increased beyond 6 per cent, the hardness decreased slowly. This indicates the desirability of using moisture control to secure cores of uniform hardness.

The tensile strength curve shows a maximum at zero moisture and a second peak at 6.5 per cent moisture. Core mixtures tempered with insufficient moisture will result in low strength cores. The permeability of a core is slightly affected by moisture content of the mix as shown in Fig. 14.6.

Effects of Standing in Air Before Baking

Rammed specimens were allowed to stand in the air for periods varying from zero to 6 hr before baking. The results from this series of tests are shown in Fig. 14.7. As may be assumed, the core hardness decreases as the length of time increases before cores are placed in the oven. Cores placed in the oven immediately after ramming produced a hardness of 73, while those allowed to stand for 6 hr possessed a hardness of 68.

A marked change in the tensile strength of the cores was noted as the length of standing time was varied. Cores placed in the oven immediately possessed a strength of 200 psi, but if allowed to stand one hour, the strength decreased to 180 psi. As the length of standing time was increased beyond one hour the strength increased. A strength of 270 psi was secured when the standing time was 6 hr. Moisture in the cores was apparently reduced to practically zero, which gave the maximum strength. Cores made with zero moisture (Fig. 14.7) gave a strength of 275 psi.

Effects of Cooling Time

Cores in a foundry are often used while they are still warm. The practical man realizes that the strength and the hardness are much lower when the core is still hot or warm. The relation between the cooling time and the strength and hardness is shown graphically in Figs. 14.8 and 14.9.

The hardness of test cores, after cooling 5 min in a room (temperature 83 F [28 C]), was 56 and after cooling 70 min the hardness was increased to 73.5. The tensile strength for the same range of cooling times increased from 180 psi to 205 psi. The surface temperature of the cores after 5 min cooling was 200 F (93 C), and for 70 min cooling it was 84 F (29 C). The curves of Fig. 14.9 show clearly the relation between the temperature of the core and hardness and strength.

When the temperature drops from 200 to 84 F (93 to 29 C), the strength of the core increases 14.8 per cent and the hardness increases 31 per cent. This increase in both strength and hardness shows the impor-

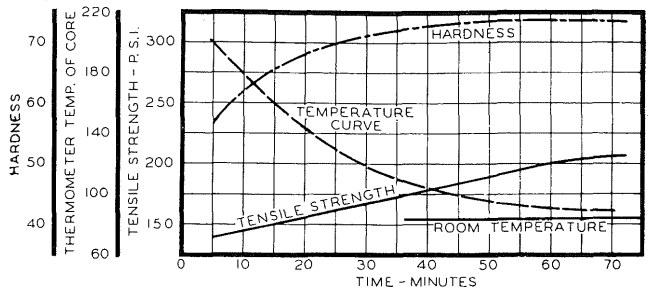


Fig. 14.8 — Relation of core strength and hardness to core cooling time. Baking time, 1½-hr; temperature, 350 F (177 C); moisture, 5 per cent; sand to oil ratio, 56–1.

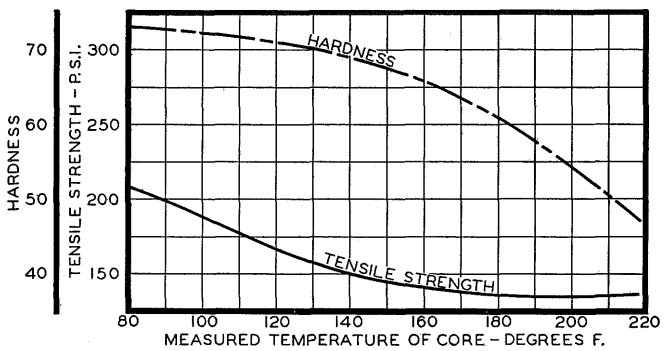


Fig. 14.9 — Development of strength and hardness of baked cores while cooling. Baking time, 1½-hr; temperature, 350 F (177 C); moisture, 5 per cent; sand to oil ratio, 56–1.

tance of allowing the core to cool before handling in order to decrease core breakage.

Relation Between Sand to Oil Ratio and Core Hardness

Increasing the oil in a core sand mixture naturally increases the strength and hardness. The rate at which the strength and hardness increase is shown in Fig. 14.10. The hardness increases in a straight line function, while the strength increases in a parabolic function. In percentage, the strength increases faster than the hardness.

The permeability of a core decreases as the amount of oil is increased. A core made from 70:1 sand to oil ratio by volume showed a permeability of 175; while one made from a 28:1 ratio had a permeability of 155, a decrease of 11.4 per cent. Increasing the amount of oil materially increases the amount of gas generated. Doubling the amount of oil in a core mixture will increase the strength substantially 150 per cent and increase the hardness 50 per cent.

Effect of Sand Grain Size

Core sand that varies in fineness is frequently used. The effect a change in fineness has on the hardness, strength and permeability is shown in Fig. 14.11. Test cores were made from sand which consisted wholly of a certain sieve size, this ranging from 30 mesh to pan material.

It is of particular interest to note in Fig. 14.11 that 100 mesh material gave the hardest and strongest cores. An increase or decrease in grain size resulted in a material decrease of hardness and strength. A core made of 100 mesh material gave a permeability of 107, a hardness of 76 and a tensile strength of 222 psi.

Cores made from 270 mesh and pan material possessed practically no strength or hardness. The most economical core sand from a standpoint of strength and hardness would consist of sand grains ranging from 70 to 140 mesh, preferably all 100 mesh, when the core sand mixture is tempered to 5 per cent moisture and a linseed base core compound is used.

Conclusions

The relations found in this study show that the core hardness is affected by the manner of core treatment before, during and after baking.

Conclusions reached as to conditions influencing core hardness are listed.

(1) A baking temperature of 350 F (177 C) produced the greatest tensile strength for the type of core oil used. Different oils would undoubtedly require different temperatures. It would prove economical to determine the baking temperature which produces the maximum hardness and strength to allow the use of the minimum quantity of core oil.

(2) The maximum hardness and strength were ob-

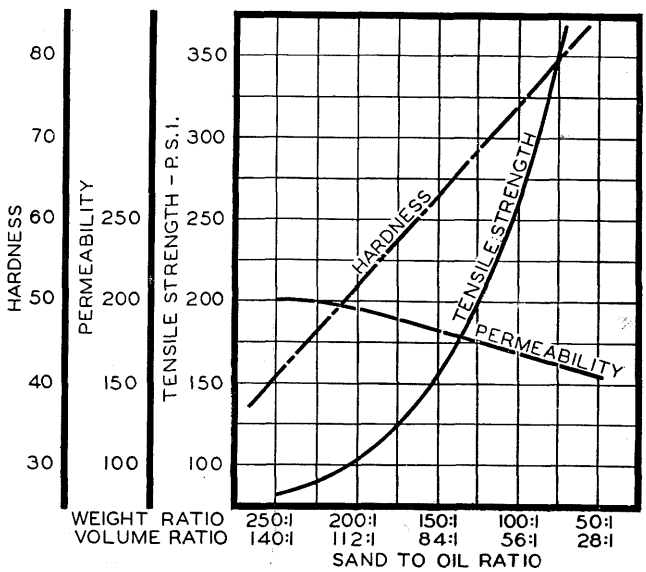


Fig. 14.10 — Variation of properties of baked cores when the sand to oil ratio is varied. Baking time 1½-hr; temperature, 350 F (177 C); sand to oil ratio, 56–1.

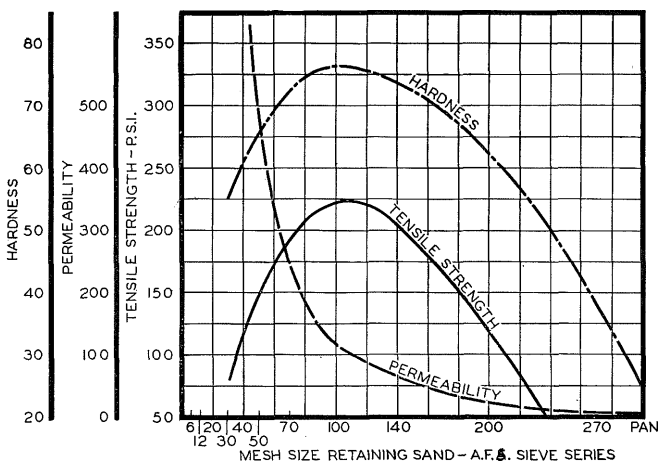


Fig. 14.11 — Variations in properties of baked cores with variation in sand grain size. Baking time, 1½-hr; temperature, 350 F (177 C); moisture, 5 per cent; sand to oil ratio, 56–1.

tained with a baking time of 1½-hr when a temperature of 350 F (177 C) was used. This short baking time cannot be used as a criterion for baking cores in the foundry, since the AFS standard test oven, as used, bakes very fast and efficiently. However, the test shows clearly that the length of baking time materially affects the core hardness.

(3) Temperatures lower than 375 F (191 C), regardless of the baking time, produce the strongest cores.

(4) The permeability of a core is not affected by the baking time or temperature.

(5) A core should be cooled to a temperature near 80 F (27 C) to permit it to reach maximum hardness and strength before handling.

(6) The tensile strength of a core increases at a faster rate than the hardness as the quantity of core oil addition is increased. The permeability of the core decreases under such conditions.

(7) The grains of a core sand, when retained on sieves 70, 100 and 140, preferably 100 mesh sieve, produce a core of maximum hardness and strength. Sand grain size should be changed from this size only as necessitated by finish of core surfaces and availability of sand.

(8) The hardness of a core increases as the moisture content of the core sand mixture is increased.

(9) The strength of a core is maximum when zero moisture is present in the mix. A second high strength point is obtained when using lake sand and the mixture contains between 6 and 8 per cent moisture. Working the sand at low moisture should be avoided in that the strength will be low.

(10) The permeability of a core is lowest when zero water is present in the sand mix, for in this state, the sand grains pack tightly together.

(11) Cores with maximum core hardness are obtained when they are placed in the core oven immediately after making, as this avoids drying of the outer surface of the cores.

(12) Cores of maximum strength are obtained when they are allowed to stand in the core room for a period of 6 hr before baking.

(13) The permeability of cores is not affected by length of time standing in the room before baking.

FINENESS

The grain size, grain shape and grain distribution of core sands receive considerable attention from those that produce such sand and operate efficient plants. A variation in the fineness of core sand may cause the strength, permeability, baking time or gas content to change sufficiently to result in scrap producing cores.

Surface Area vs. Strength

The tensile strength of a core decreases rapidly as the surface area of the core sand increases. As an illustration, note Fig. 14.12. A core made from a sand with a surface area of 10,000 sq mm per gram will give a tensile strength of 268 psi, while a core made from a sand with twice that amount of surface area will have a tensile strength of only 140 psi. The former sand would have an average AFS fineness of approximately 50 mesh, while the latter would have approximately 70 mesh fineness.

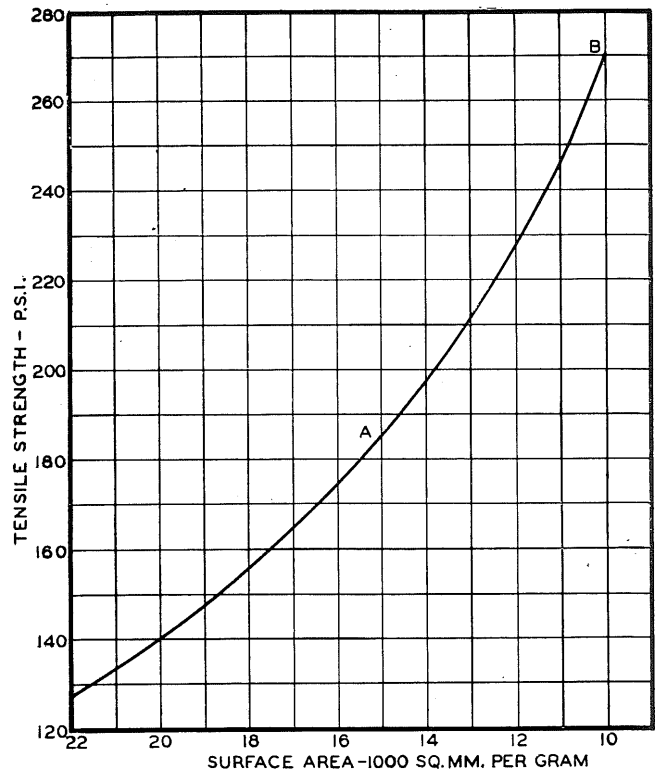


Fig. 14.12 — Relation of surface area of sand grains to tensile strength of cores. Baked at 400 F (204 C); sand to oil ratio 62–1; moisture, 5 per cent.

Grain Shape vs. Strength

The shape of the core sand grains has a great influence on the strength of a core. Round (spherical) shaped sand grains with a 50 mesh average fineness will have approximately 10,000 sq mm surface area per gram, while sharp (angular) sand grains with a 50 mesh average fineness will have approximately 15,000 sq mm surface area. The round sand grains will give a core of 268 psi tensile strength; the sharp sand grains will give a core with a tensile strength of 185 psi when other conditions remain constant. These two points are represented by *A* and *B* respectively in Fig. 14.12.

Baked Permeability vs. Fineness

The baked permeability of cores decreases rapidly as the fineness of the core sand increases. Figure 14.13 illustrates this point clearly.

Baking Time vs. Fineness

The time required to bake cores is definitely related to the fineness of the core sand. Figure 14.14 shows the relation between baking time and fineness of sand for cores bonded with a linseed oil compound. The baking time to secure maximum strength for an open core sand with a 40 mesh average fineness is 1½-hr. When the core sand fineness is increased to 60 mesh, 2¼-hr will be required to secure maximum strength core. An increase of fineness above 60 mesh does not materially affect the baking time.

The fineness of every shipment of core sand should be tested either by a fineness test or by the base permeability method to insure that shipments come within five points of a designated AFS average fineness mesh.

CONTROLLING ELEVATED TEMPERATURE PROPERTIES

Methods of controlling the physical properties of cores at room temperature has received considerable study and attention by foundrymen. At present, foundrymen have only certain beliefs concerning the proper way to control the physical properties and behavior of oil-bonded cores at elevated temperatures.

The author feels that metal can be cast more successfully and better castings produced when definite information is available on how to control the action of a core when exposed to the high temperature of molten metal. As a step in this direction, he presents the following, feeling that it will be of practical value.

When a core is surrounded by molten metal, it is generally conceded that the core first expands or increases in volume due to growth of the silica sand grains. Next, it collapses when the bond is destroyed by the heat. The methods used to control the expansion and collapsibility or breakdown of oil-bonded cores is of interest.

A core at room temperature is judged largely by its strength. One of the best methods of evaluating the strength is by the tensile strength. A second method of evaluating a core at room temperature is by the core hardness which may be determined by a fingernail scratch test or by a core hardness test.

Having these two methods of gaging the desirability of a core, it would be advantageous to know how tensile strength and core hardness may be used to control the expansion of a core at elevated temperatures.

CONTROLLING EXPANSION

The expansion of a core may be measured with the aid of a dilatometer furnace, shown in Fig. 13.35,

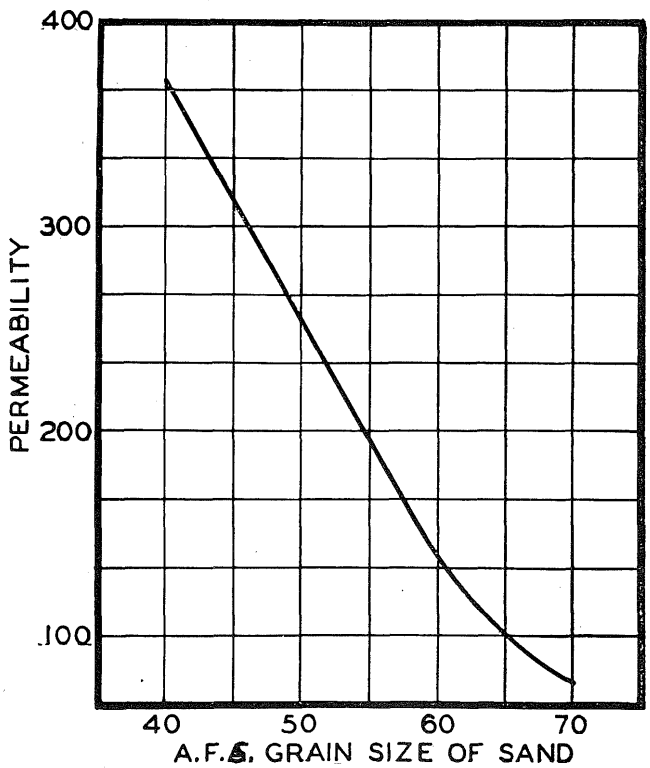


Fig. 14.13 — Permeability of baked cores as affected by sand grain size. Cores baked at 400 F (204 C); sand to oil ratio, 62–1; moisture, 5 per cent.

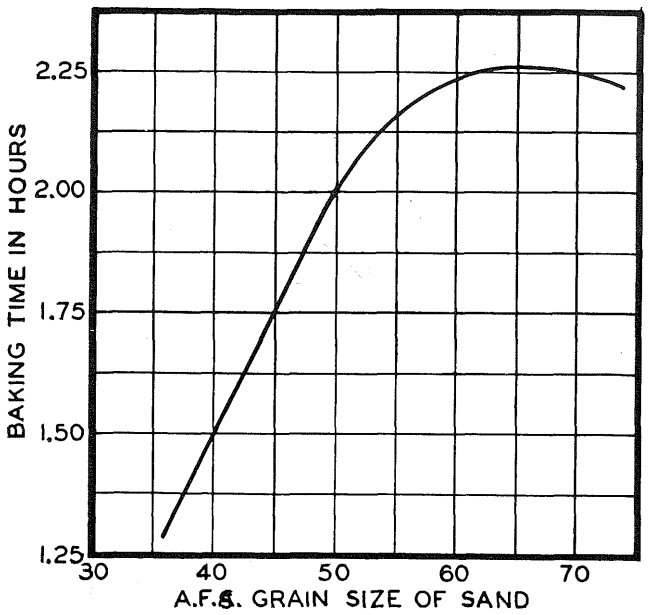


Fig. 14.14 — Baking time for maximum strength as affected by grain size of core sand. Cores baked at 400 F (204 C); sand to oil ratio, 62–1; moisture, 5 per cent.

Chapter 13. The core is placed on a pedestal and the furnace, at the pouring temperature of metal, is lowered around the core specimen. The expansion of the core is shown by a dial indicator located on top of the unit.

The author has conducted tests on core specimens which were baked at 400 F (204 C) and which were prepared from a mixture consisting of lake sand, cereal binder, linseed oil base core compound with sand to oil ratios varying from 1:50 to 1:100 by volume.

Tensile Strength vs. Expansion

The relation between tensile strength and expansion is well illustrated in Fig. 14.15. As the tensile strength of a core decreases, the expansion decreases rapidly. For example, with the mixture under consideration, when the baked tensile strength is 190 psi, the expansion at 2500 F (1371 C) is equal to 0.091 in. per in. of core length. Should the baked tensile strength be decreased to 130 psi, the expansion at 2500 F (1371 C) is reduced to 0.004 in. per in.

Hardness vs. Expansion

When using core hardness as the index, a core hardness of 75 corresponded to an expansion of 0.091 in. per in. Reducing core hardness to 59 reduced the expansion to 0.004 in. per in. To secure the above range of strength, core hardness, and the oil to sand ratio, see Fig. 14.15, which shows the properties of cores in which the sand to oil ratio varies from 1:50 to 1:100.

Thus, the expansion of a core may be controlled by controlling the tensile strength or core hardness. This is a very simple procedure in most cases.

Many imperfections such as "cat whiskers," fins and hot cracks may be held in check by maintaining a definite control over core tensile strength or core hardness so that these two properties will be held to a minimum, thus reducing the expansion and core collapsibility to the safe limits.

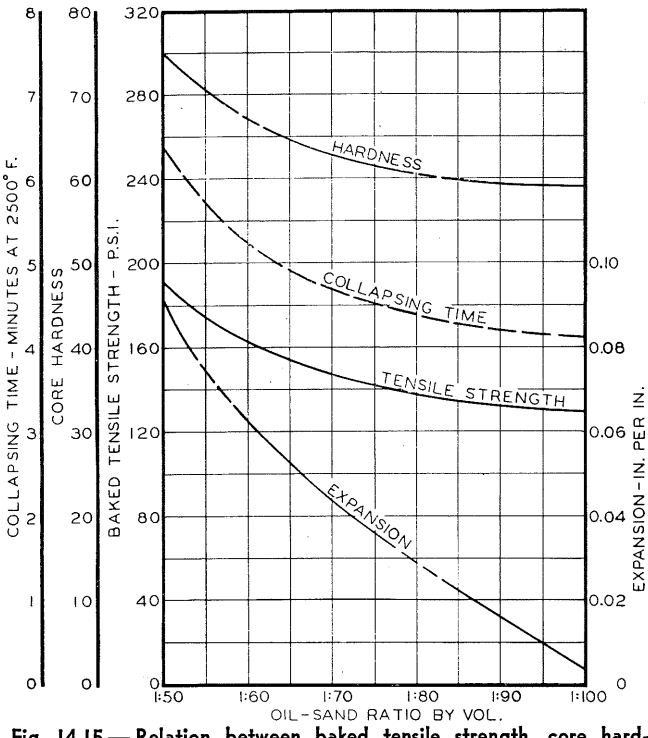


Fig. 14.15 — Relation between baked tensile strength, core hardness, expansion at 2500 F (1371 C), collapsing time, and various sand to oil ratios.

CONTROLLING COLLAPSIBILITY

The rate at which a core collapses should be controlled to obtain the best casting result. When the core collapses too fast, flaws such as dirt, fins, and core washes appear. Should the core collapse too slowly, hot cracks and difficulty in shakeout are experienced.

The time required for a core to collapse also may be measured with the dilatometer furnace shown in Fig. 13.35, Chapter 13. A load of 4 oz per sq in. is applied to the core. The furnace at 2500 F (1371 C) is pulled over the core. The time in minutes required to fully collapse the core specimen or cause a contraction of 0.070 in. per in. is recorded as collapsing time. The collapsing time of baked cores with various sand to oil ratios is shown in Fig. 14.15. Should a core fail to collapse in 12 min in the collapsibility test, a load sufficient to crush the core then is applied to the core. This load in psi is recorded as hot strength at 2500 F (1371 C).

TABLE 14.2 — CORE COLLAPSIBILITY TEST DATA

	Core No. 1	Core No. 2	Core No. 3	Core No. 4
Bentonite, %	Knock-out-sand	1.75	0.70	0.0
Cereal binder, %	0.1	0.23	0.10	0.1
Core permeability	109.0	121.00	190.00	250.0
Time of collapsing, min.	8.0	4.80	3.25	2.5

Tensile Strength vs. Collapsibility

It may be noted that strong cores with a tensile strength of 190 psi, which corresponds to a core hardness of 75 for the mixture under discussion, produces a core that collapses slowly; that is, it requires 6.3 min to collapse. A core with a moderate strength of 130 psi, possessing a medium hardness of 59, collapses fairly rapidly in 4.1 min.

One method of controlling the rate at which a core collapses is to control the strength and hardness for a given mixture.

Collapsibility vs. Permeability and Clay Content

The rate at which a core collapses as it is heated by molten metal may be varied not only by the strength of the core but also by the core permeability and clay content of the mixture. As an example, the author prepared and tested a group of four cores with physical properties as shown in Table 14.2.

Core No. 4, Table 14.2, which did not contain any clay bond, required 2.5 min to collapse. Core No. 2, with 1.75 per cent bentonite, required 4.8 min to collapse. Core No. 1, containing knockout sand which carried considerable clay substance, required 8 min to collapse. This illustrates how the collapsibility of a core may be retarded by increasing the clay substance in the core mixture.

Comparing the core permeability of the four cores under discussion, it may be noted that core No. 4, with 250 permeability, collapses fast, in 2.5 min, while core No. 1, with a permeability of 109, collapses slowly, in 8 min. Thus, as the core sand becomes finer, the core will collapse more slowly and it will require more effort to shakeout.

IRON OXIDE ADDITIONS ON CORES

Effect on Collapsibility

A method has been found to control the rate of collapsibility of a core and has enabled foundrymen to eliminate or reduce blemishes, such as fissures or fins on cored surfaces of castings. The practice consists of adding from 1 to 2 per cent iron oxide (Fe_2O_3) to the core mixture.

However, the time required to collapse at 2500 F (1371 C) is increased from 3 min 14 sec to 5 min 30 sec by the addition of 2 per cent iron oxide.

Effect on Tensile Strength

The effect of adding iron oxide to oil-sand core mixtures is illustrated in Table 14.3, which shows that the tensile strength of the core is reduced from 177.5 to 105 psi by adding 2 per cent iron oxide.

TABLE 14.3 — EFFECT OF 2 PER CENT IRON OXIDE ADDITION TO A CORE MIXTURE*

Properties	Baking Time† Hr	No Iron Oxide	2 Per Cent Iron Oxide
Tensile strength, psi	1	172.5	102.5
Tensile strength, psi	1½	177.5	105.0
Tensile strength, psi	2	170.0	102.5
Tensile strength, psi	2½	150.0	95.0
Expansion, in. per in.	—	0.009	0.010
Collapsibility	—	3 min 14 sec	5 min 30 sec
Sintering point, F	—	2900	2940
Sintering point, C	—	1593	1616

*Mixture consisted of lake sand of 55 AFS Grain Fineness No.; Sand to oil ratio of 100 to 1; 5.5 per cent moisture.
†Baking temperature, 400 F (204 C).

Effect on Expansion

The expansion at 2500 F (1371 C) is identical for all practical purposes.

Explanation of Behavior

This reduction in the core collapsibility undoubtedly explains why the addition of Fe_2O_3 proves helpful in reducing fin core deformities on castings. The ferric oxide may retard core collapsibility, due to the fact that it adds to the fines in the sand which will be mixed with the oil binder between the sand grains. The oil binder is protected from the heat by the fines in a sand. For example, the addition of silica flour to a core sand mixture acts in the same manner as does ferric oxide.

Another possible explanation is that the atmosphere in a core is reducing, which will change the Fe_2O_3 to Fe_3O_4. The Fe_3O_4 immediately reacts with the silica sand and forms a glass in the form of a stable silicate. This silicate will act as a binder and help to hold the core together.

Effect on Refractoriness

The refractoriness of a core sand is not reduced by an addition of red iron oxide. For example, the sintering temperature of a certain sand without Fe_2O_3 is 2900 F (1593 C) and when 2 per cent Fe_2O_3 is added, the sintering temperature is raised to 2940 F (1616 C).

EFFECT OF CEREAL BINDERS ON HOT STRENGTH

Foundrymen frequently resort to the addition of cereal binders to core mixtures for the purpose of preventing hot cracks or tears in castings. The cereal binder also is added to impart green strength to a core mixture.

Data given in Table 14.4 show how the addition of 1.0 per cent cereal binder will affect the green compression and hot strength of a core for steel castings.

TABLE 14.4 — EFFECT OF CEREAL BINDER ADDITIONS ON GREEN AND HOT STRENGTHS

Core Mixture	A	B
Sand, %	92.7	91.7
Core oil, %	0.9	0.9
Bentonite, %	0.3	0.3
Resin binder, %	1.1	1.1
Silica flour, %	5.0	5.0
Cereal binder, %	0.0	1.0
Test Results		
Green compression, psi	0.65	1.5
Tensile strength, psi	128	198
Baked permeability	200	146
Core hardness	70	76
Hot strength, psi	42	28

The green compressive strength is increased from 0.65 to 1.5 psi by the addition of one per cent cereal binder. A green strength of 1.5 psi for core mixtures in steel foundries is a satisfactory value.

The hot strength of the core at 2500 F (1371 C) is decreased from 42 to 28 psi by the addition of 1.0 per cent cereal binder. A hot strength of 42 psi at 2500 F (1371 C) will cause hot tears in many steel castings. A hot strength of 28 psi at 2500 F (1371 C) is satisfactory for cores used in steel castings where the metal thickness averages ¾ to 1 in. Where the hot strength at 2500 F (1371 C) is in the low range of 6 psi, the core usually will cut for many steel castings.

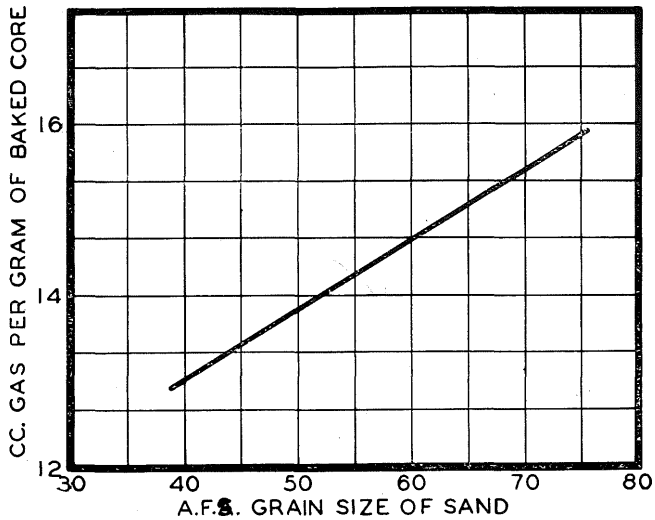


Fig. 14.16 — Effect of sand grain size on amount of core gas generated during pouring. Cores baked at 400 F (204 C); sand to oil ratio, 62–1; moisture, 5 per cent.

From the above, it will be seen that one way to reduce the hot strength of a core or molding sand is by the addition of a proper amount of cereal binder. A few trial castings, made with cores of different hot strengths, quickly enable one to determine the proper hot strength to use for the particular type casting.

METHODS OF REDUCING CORE GAS

A reduction of the amount and the rate of liberation of gas given off by a core when a casting is poured is an ever present desire of foundrymen. The gas given off by a core, under such conditions, is undesirable both from the viewpoint of casting quality and pollution of the foundry air.

Effect of Sand Fineness

There are a number of ways in which the gas given off by cores during pouring may be held to a minimum. One may assume off hand that the fineness of the sand need not be considered. However, the fineness of the sand does enter into the problem. The coarser the sand, the greater the permeability of the core. The greater the permeability of the sand, the better the core will be baked. This means that the binder has absorbed a maximum amount of oxygen and will produce less gas on pouring. A graphical illustration of how the quantity of gas in a core is reduced as the fineness of the core sand is changed from 75 to 40 AFS Fineness No. is shown in Fig. 14.16. Thus, the total amount of gas may be reduced by using a coarser sand.

One other factor must be considered in connection with the fineness of the sand, namely: as the core sand becomes coarser, the permeability of the core increases, which causes the heat to travel through the core faster on pouring. This, in turn, causes the core to burn up faster, creating a fast rate of generation for the quantity of gas contained in the core. This often limits coarseness of a sand to conservative fineness to avoid a too rapid gas generation or core collapse.

Effect of Quantity of Binder

It is easy to understand that the quantity of binder added to a core mixture will influence the total quan-

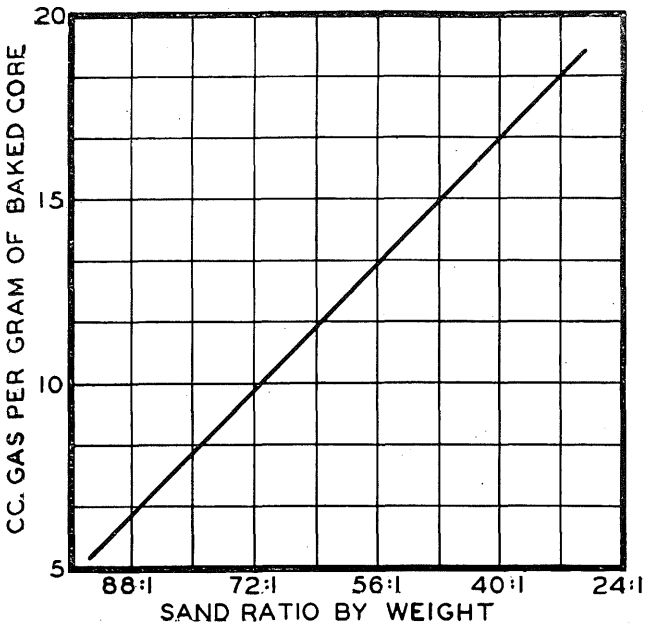


Fig. 14.17 — Effect of sand to oil ratio on amount of core gas generated during pouring.

tity of gas contained in a core. A good illustration of this fact is shown in Fig. 14.17. The gas content of a core made with a sand to oil ratio of 98:1 is 6.9 cc per gram of core and 17 cc per gram when the sand to oil ratio is 40:1. The greater the quantity of binder used in the core mixture, the greater the volume of gas generated by the core on pouring. Thus, through the use of a minimum quantity of binder and through the use of a strong binder, the volume of core gas may be kept to a minimum.

Effect of Baking Temperature

The gas content of a core may be reduced by baking the core at a high temperature, with some sacrifice in the baked strength of the core. A study of curves in Fig. 14.18 is instructive, since it shows how the gas content is quickly reduced by baking a core at higher temperatures. Table 14.5 gives figures showing the gas

TABLE 14.5 — CORE GAS CONTENT AS RELATED TO BAKING TEMPERATURE

Baking temperature, F	350 F	400 F	450 F
Baking temperature, (C)	(177 C)	(205 C)	(232 C)
Gas at max. tensile strength, cc	17.8	15.2	15.8
Tensile strength, max., psi ...	267	255	235
Gas at end of bake, cc	17.0	13.4	12.8
Tensile strength at end of bake, psi	237	230	177

content and tensile strength for cores baked at 350, 400 and 450 F (177, 205 and 232 C). Should one bake the cores at a chosen temperature to give maximum strength, little reduction in gas would be obtained by selecting a high baking temperature. However, by selecting a high temperature, and slightly overbaking the core, a substantial reduction in volume of gas may be obtained. For example, a core baked at 450 F (232 C) will show a gas content of 12.8 cc per gram of core as compared to 17.0 cc per gram when baked at 350 F (177 C). The sacrifice in tensile strength is from 237 psi at 350 F (177 C) to 177 psi at 450 F (232 C). Where the design of the casting is such that venting of the core is limited, it may be found expedient to bake the core at a high temperature and for a sufficient length of time to slightly overbake.

Importance of Liberation Rate

The rate at which the gas in a core is liberated may be as important as the total volume of gas. For example, two cores, one which generates 7.0 cc of gas per gram of core gives off the gas very fast while the other core which generates 10 cc of gas per gram gives off the gas only half as fast as the first mentioned core. The core with the greatest amount of gas would vent more freely.

The curve in Fig. 14.19 illustrates the rate at which gas generation is affected by two different core mixtures. In these cores, the rate is identical for the first minute when the core is subjected to a temperature of 1800 F (982 C). However, the rate varies greatly as the time of immersion increases. The total volume of core gas for these two cores is quite different.

EFFECT OF SILICA FLOUR ON HOT STRENGTH

In some foundries, silica flour is added to cores, bonded with a linseed base core oil, to enable the cores to withstand the heat from heavy sections of metal. The silica flour closes the pores of the core so as to reduce the penetration of the metal. It also retards

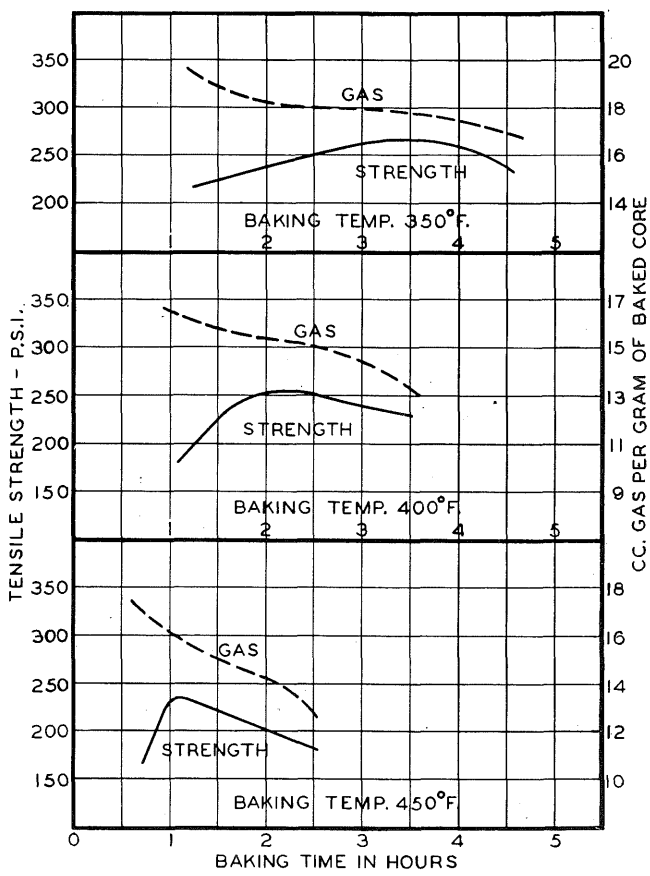


Fig. 14.18 — Effect of baking temperature on tensile strength and gas generating capacity of cores.

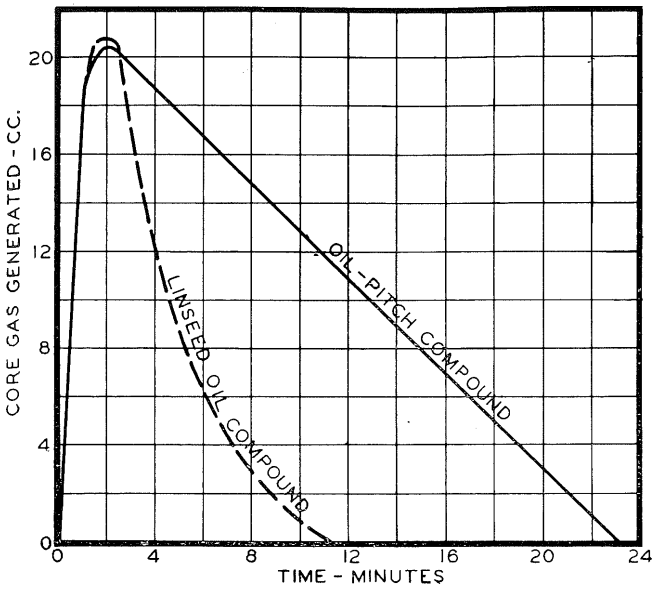


Fig. 14.19 — Diagram illustrating the different gas generating capacities and the rates of gas generation in two core mixtures.

the collapsibility of the core and imparts hot strength to the core at elevated temperatures.

The effect of silica flour on the physical properties of an oil-bonded core is well illustrated in the data in Table 14.6. The amount of oil required to maintain a definite tensile strength of the baked core increases from a ratio of oil to sand of 1:100 when no silica flour is added; to 1:64 when 10 per cent silica flour is added to this mixture.

The green compressive strength of the core mixture increases from 0.37 to 0.62 psi when silica flour is increased from 0 to 10 per cent at the expense of much additional core oil.

The core permeability decreases from 193 to 117 as silica flour increases from 0 to 10 per cent. This, undoubtedly, explains why a silica flour addition decreases penetration so effectively. The core becomes more dense with silica flour which increases the core hardness from 73 to 89 as the silica flour addition increases from 0 to 10 per cent when the tensile strength of the core is maintained at a constant value.

This increase in density of the core sand grain structure by the addition of silica flour, from 0 to 10 per cent, also causes the core to increase in expansion from 0.008 to 0.017 in. per in.

The time required to burn up a core 1⅛-in. in diameter at 2500 F (1371 C) is increased with silica flour additions. For example, with no silica flour addition, the core burns up or collapses in 2.27 min, while when 10 per cent silica flour is present, then it fails to collapse or burn up in 12 min under a load of 4 oz per sq. in. A load is then applied, showing a hot strength of 17 psi, as shown in Table 14.6. The oil-bonded core containing 10 per cent silica flour is the only one that possessed any hot strength at temperatures of 1500, 2000 and 2500 F (816, 1093 and 1371 C). For oil-bonded cores, substantially 10 per cent silica flour is required to impart sufficient hot strength to this type of core to make it suitable for large gray iron and steel castings.

The amount of compressive strength that the oil-bonded core possesses after being heated for ½-hr at elevated temperatures and then allowed to cool to room temperature, is termed "retained strength" in Table 14.6. The greater the retained strength, the greater the shakeout effort required. The retained strength of the oil-bonded cores, Table 14.6, shows an increase of retained strength from 107 to 255 psi when silica flour is increased from 0 to 10 per cent. However, no retained strength for temperatures 1000, 1500 and 2000 F (538, 816 and 1093 C) is obtained for cores containing from 0 to 10 per cent silica flour, except that the cores made with 10 per cent silica flour show a 12.5 psi retained strength for 2000 F (1093 C).

The cores with 2, 4, and 10 per cent silica flour show a high retained strength for 2500 F (1371 C). This retained strength is really the sintered strength and would represent a thin outer layer of the core.

For cores made with 0 to 4 per cent silica flour, no appreciable difference in shakeout effort would be experienced for oil-bonded cores containing no bentonite. When 10 per cent silica flour is added, a little more shakeout effort would be required as compared to cores containing from 0 to 4 per cent silica flour.

TABLE 14.6 — INFLUENCE OF SILICA FLOUR ON THE PROPERTIES OF OIL-BONDED CORES

Core sand, per cent	100	98	96	90
Silica flour, per cent	0	2	4	10
Ratio by volume, oil to sand	1-100	1-85	1-70	1-64
Moisture, per cent	5	5	5	5
Green compression strength, psi	0.37	0.41	0.45	0.62
Core permeability	193	201	160	117
Core hardness	73	74	80	89
Tensile strength, psi	171	165	178	178
Core strength loss in humidor 24 hr, per cent	60	53	66	35
Expansion at 2500 F (1371 C), in. per in.	0.008	0.013	0.014	0.017
Collapsibility time, min	2.27	2.18	3.50	*
Hot strength at 500 F (260 C), psi	72	165	205	255
Hot strength at 1000 F (538 C), psi	0	0	1	4
Hot strength at 1500 F (816 C), psi	0	0	0	5
Hot strength at 2000 F (1093 C), psi	0	0	0	9
Hot strength at 2500 F (1371 C), psi	0	0	0	17
Retained strength heated to 500 F (260 C), psi	107	105	102	255
Retained strength heated to 1000 F (538 C), psi	0	0	0	0
Retained strength heated to 1500 F (816 C), psi	0	0	0	0
Retained strength heated to 2000 F (1093 C), psi	0	0	0	12.5
Retained strength heated to 2500 F (1371 C), psi	0	117	152	185

*Failed to collapse.

TABLE 14.7 — EFFECT OF VARIOUS INGREDIENTS IN A CORE MIXTURE

Sand Mixture No.		No. 1			No. 2		No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Baking time, min	20	60	180	20	60	180	60	60	60	60	60	60	Air Set
Michigan City sand, lb	1950	1950	1950				1950	1950					
Washed silica sand, lb				1950	1950	1950			1950	1950	1950	1950	1950
Oil to sand ratio, vol	1:60	1:60	1:60	1:60	1:60	1:60	1:60	1:30	1:60	1:60	1:96		
Wheat flour to sand ratio, vol	1:25	1:25	1:25	1:25	1:25	1:25			1:25	1:25	1:64		
Silica flour, per cent									5	15	7.5		
Bentonite to sand ratio, vol							1:63	1:63			1:128	1:80	1:13.3
Resin to sand ratio, vol											1:24	1:27	
Dextrin to sand ratio, vol													1:43
Iron oxide to sand ratio, vol											1:96		
Corn flour to sand ratio, vol												1:54	
Green compression strength, psi		0.3			0.2		1.2	1.05	0.75	0.2	2.3	1.50	5.0
Moisture, per cent	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	5.5		4.5	4.5
Core permeability		219			226		243						
Baked tensile strength, psi	37.5	150	120		200		25	243	105	61			219
Baked transverse strength, lb					48			45	185	125	135	135	40
Hardness	28	60	50		72		7	12	75	79	73	58	35
Expansion, in. per in.		.0085		.0045	.0085	.018	.018	.019	.019	.0195	.018	.010	.024
Contraction, in. per in.									+.009	+.014			+.013
Collapsibility, min	2.7	2.7	2.7	2.0	2	2	2.7	6.2	*	*	*	3.5	*
Hot strength at 2500 F (1371 C), lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12	36	215	0.0	4

*Failed to collapse.

The beneficial effect of the 10 per cent silica flour is to keep the oil-bonded cores for heavy castings from collapsing too fast.

EFFECT OF VARIOUS INGREDIENTS IN A CORE MIXTURE

Physical properties of cores bonded with different ingredients are shown in Table 14.7. The ratio of binder to sand is given in ratio of volume. For silica flour, the quantity added to the sand mixture is shown in percentage by weight. All cores were baked in a core test baking oven conforming to AFS standards.

Sand Mixtures 1 and 2 show comparison of cores made with a Michigan City core sand, and washed and dried silica sand, respectively. The cores of Sand Mixture 1 have a little greater green compressive strength and a lower baked tensile strength than cores of Sand Mixture 2.

The cores made from Sand Mixture 3, containing bentonite to sand ratio of 1:63, show a high green compression with a very low baked tensile strength of 25 psi.

In Sand Mixture 4, the oil to sand ratio is 1:30, in place of 1:60, as used in Sand Mixture 3. The cores made from the Sand Mixture 3, with 1:30 oil to sand ratio and bentonite to sand ratio 1:63, show a baked tensile of 45 psi and a green compression of 1.05 psi.

Sand Mixtures 5, 6 and 7 contain, respectively, 5, 15 and 7.5 per cent silica flour. Mixture 7 contains bentonite, resin and iron oxide, which give cores with very high hot strength. Whenever bentonite or clay is present in a mixture, the hot strength and also the retained strength is increased rapidly by small additions of silica flour. When the mixture does not contain any clay substance, the hot or retained strength increases slowly with silica flour additions.

The cores made from Sand Mixture 8 are bonded with bentonite, resin and corn flour and possess very good collapsibility.

Sand Mixture 9 is for cores that are hardened by air drying in a room. The binders are bentonite and dextrin, producing a low strength core with good hot strength value for steel castings.

Chapter 15

CORE SETTING

INTRODUCTION

The accuracy with which a core is set and held in proper position materially affects casting losses and accuracy of metal thickness. A core may set in its proper position and little is gained unless suitable means are provided for holding the core in the exact position as set. Core prints, bolts, and chaplets are used to hold a core in position within a mold.

CORE SETTING AIDS

Gages

Mechanical aid for correctly setting a core is a worthwhile provision. Mechanical aids may be simple and yet productive tools. As an example, the core setter may be supplied with a set of thickness gages which may be inserted between the surface of the core and the mold to check the opening that will form the thickness of the casting section.

Reducing Manual Effort

A reduction in manual effort required to set a core in the mold will yield efficiency in production and in correctness of core positioning. Supervisors are justified in asking for greater accuracy of work from core setters when core setting fatigue is reduced. An excellent example of reducing manual effort in core setting is illustrated in Fig. 15.1. The weight of the core is supported by an overhead crane, thus relieving core setters from heavy lifting. Their duty is to guide the core and set it correctly in the mold. To accomplish this, the core is strapped to two iron pipes by canvas bands. After the core is set in position, the canvas bands are withdrawn.

Use of Ram-Up Cores

Small cores, set in the pattern and accurately located by it, are used in many cases to aid in setting a core correctly. These small cores are called ram-up core prints, since the molding sand is rammed over and around them, thus holding them securely in position. They remain in the mold when it is stripped from the pattern. Ram-up cores usually are employed only in the drag and that portion of core print which was inserted in pattern protrudes beyond the face of the mold surface and is tapered. This tapered portion of the core print enters a correspondingly shaped hole in the main body core and guides the main core into correct position in the mold.

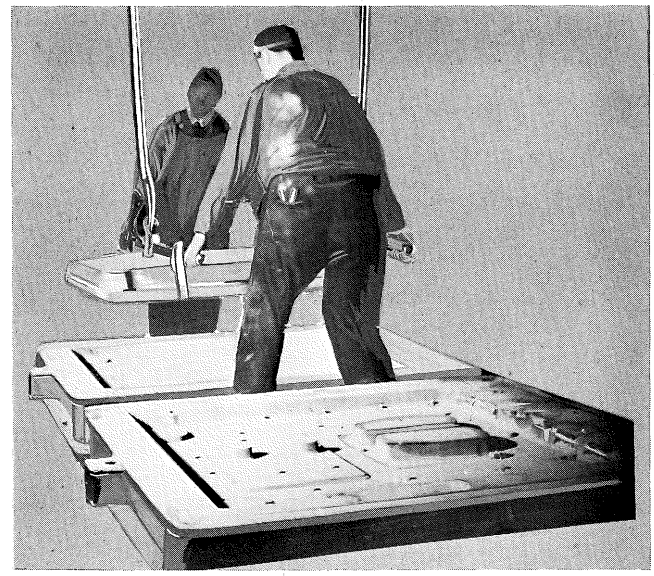


Fig. 15.1 — Setting a core with an overhead crane.

Fixtures

In high production foundries, core setting fixtures of elaborate design are employed to insure that the core is set exactly in its proper position in the mold. Basically, core setting fixtures consist of an aluminum frame or box which grips the cope section of the body core. Handles or trunnions for slings are provided to lift the core and lower it into the mold. As the fixture with the core enters the drag of the mold, the fixture is guided into proper position by flask closing pins and, since these same pins are used in guiding the cope into position, the core is located correctly.

Frequently core setting fixtures also are used as a core assembly fixture. This practice is followed in the foundry of at least one large automobile manufacturer. Figure 15.2 shows the core for an engine block being assembled in a core setting fixture. After the various core parts have been assembled in fixture, the assembly is lifted and transported to the drag mold by an air lift hoist. The fixture is revolved one-half revolution and lowered on the drag mold, as shown in Fig. 15.3. The guide pins of the drag mold will locate the fixture so that the core is positioned correctly in the mold. The fixture clamping device is loosened, allowing the fixture to be raised and core remaining in the mold.

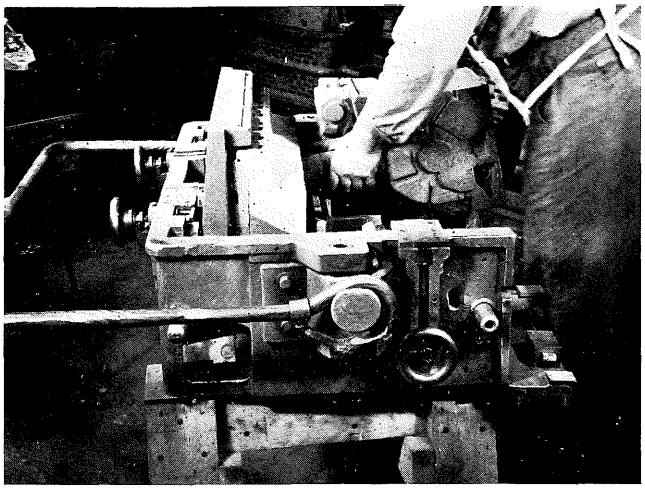


Fig. 15.2 — Assembling cores for a 6-cylinder engine block. This fixture also is used to set the core accurately in the mold.

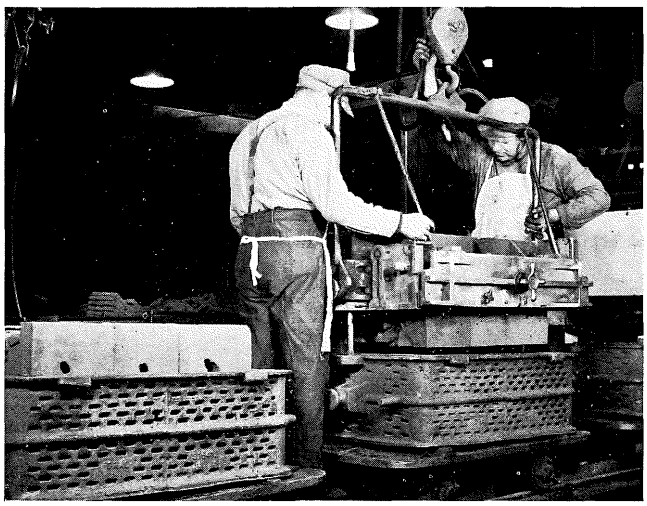


Fig. 15.3 — Setting a 6-cylinder engine block core with the aid of the core assembly fixture.

HOLDING THE CORE IN THE MOLD

It is apparent that little is gained if the core is correctly set and improper provisions are made to hold the core in its position during the pouring and solidification of the metal. To hold cores in their selected position, foundrymen use core prints, metal arbors, bolts, and chaplets.

Core Prints

Core prints are used universally to aid in holding a core in position. There are four main types of core prints, namely, ram-up, set, extended, and surface. The ram-up print is described in the first part of this chapter under core setting. A ram-up core print may be used both to guide and to help hold a core in position.

Set Core Prints

A set core print is a small core set into the mold so that it protrudes from the face of the mold a distance equal to the thickness of metal desired. The main body core rests on top of the core print. This is illustrated in Fig. 15.1. Note the first drag mold showing both core prints and chaplets.

Extended Core Prints

An extended core print is a section of a core which extends into a recess in the mold. The cope of the mold is set on this core print, thus anchoring the core in place.

Surface Core Prints

A surface core print frequently is permissible when the casting design is such that a portion of the main body core is not covered with metal. In such cases, the rammed molding sand may bear directly on the core and hold it in place.

Chaplets

In a majority of cases, a core is held directly in position by frictional grip between the prints or by chaplets in the drag and cope. Chaplets are metallic supports or spacers used in molds to maintain cores, or parts of the mold which are not self-supporting, in their proper position during the casting process. It is important that the height of the core above the face of the drag be held accurately. Figure 15.4 shows a chaplet height gage being used to check the height of chaplet above the face of the drag. Should the height be insufficient, the chaplet is shimmed up by inserting thin tins on top of the chaplet. When chaplet is too high, it may be rubbed into the core slightly, or, better yet, the core should be removed and filed or ground to proper height.

Requirements for Chaplet Performance

The parts of the chaplets in contact with the molten metal are required to form a sufficient union with the metal to become an integral part of the finished casting. If all conditions have been carefully considered, a welding or burning in action takes place, which actually unites the chaplet with the metal in the casting. Under other conditions, while there may be no actual welding action, the chaplet may be so firmly gripped by the surrounding metal that it is steam and water tight, and the resulting casting performs satisfactorily in service.

The requirements of a chaplet for use in any particular casting are: (1) that it be of the right size and

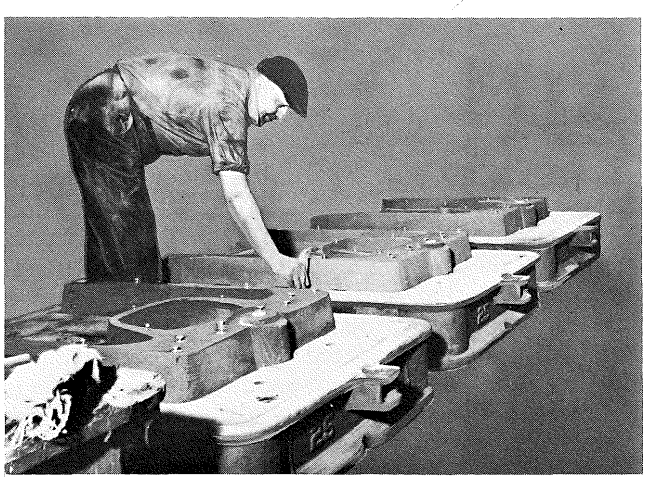


Fig. 15.4 — Gaging the height of chaplets.

shape, and (2) that it be made of a material similar to the casting or of such material that its presence in the casting will not be harmful. Steel chaplets are commonly used in ferrous metals and copper chaplets in brass castings. The strength of a chaplet should be sufficient to carry the load required, even when the temperature of the chaplet approaches that of the molten metal surrounding it, but it should not be heavier than absolutely necessary. The cold metal of a too heavy chaplet will chill the molten metal to such an extent that it will not close in around the chaplet and form a good union.

For hot metal to close in tightly around a chaplet, the latter must be clean and dry. Any spot of rust on an iron chaplet will cause the metal to spit and sputter. In steel castings, the best results seem to be obtained with freshly sand blasted chaplets, but, as it is not possible to keep these from rusting for any length of time, it is customary to use chaplets that are hot tinned, electrotinned or copperplated. These coatings prevent rusting, which otherwise occurs very rapidly in most foundries because of the steam and gas formed when pouring. Copperplating, if fresh and clean, is believed by some to cause a better union of the chaplet in the casting than tinning, but the copperplating seems to be affected by the atmosphere so that it turns dark and becomes ineffective after a few months storage in the foundry, while the tinning stays good for a long time.

When cold chaplets are put in a mold of warm, damp sand, there is very likely to be a condensation of moisture on them. This turns to steam when hot metal strikes it so the chaplet must be of such a shape that any steam, gas or volatized material will not be trapped and can escape readily.

An investigation was conducted by Taylor and Rominski,* U.S. Naval Research Laboratory, Washington, D.C., who studied the use of chaplets in the manufacture of steel castings. While these authors devoted their efforts to steel castings, some of their observations appear to be applicable to all cast metals and the following material on factors affecting chaplet reactions, effect of chaplet volume on fusion, effect of shape, effect of material, effect of surface preparation, coatings, cleanliness, and effect of molding operations are from their paper.

Factors Affecting Chaplet Reactions

Some of the factors affecting chaplet reactions are listed.

(1) Diameter of chaplet supporting rod.

(2) Temperature of the cast metal surrounding the chaplet.

(3) Design of chaplet, especially the supporting rod.

(4) Material of the chaplet.

(5) Composition and quality of plated, dipped, or alloyed exterior chaplet covering.

(6) Cleanliness of surface both before and after cleaning.

(7) Mold conditions.

*Taylor, H. F., and Rominski, E. A., *"Chaplets in Steel Castings,"* AFS Transactions, vol. 48, pp. 481-517 (1940).

Effect of Chaplet Volume on Fusion

It is common among practical foundrymen to regard strength and rigidity as chief criteria in choosing chaplet material for a certain job. As a result, many types are employed which are unnecessarily large for the weight of the core supported, and which are too large to be properly fused with the cast metal at normal pouring temperatures. The ratio of cold chaplet volume to the available heat content of the molten metal surrounding it is often so large as to preclude any possibility of fusion. This would indicate that a certain rather critical chaplet diameter might exist for a particular metal temperature, but it appears that a fairly large latitude prevails. It would be illusory to attempt to prescribe specific metal temperatures for any particular application, since control is not normally practiced within very close limits.

However, many castings have been noticed in which not only were chaplets unfused, but large open gaps were present for a radius of 2 or 3 in. around the chaplet stem. This could only result from too low pouring temperatures or because metal had to run too far in the mold. With present improvements in fluidity tests, and optical and photoelectric pyrometers, it should be a simple matter to correct these conditions. Thin walled castings are the chief offenders in this regard, and, from the standpoint of proper fusion, the mass of metal surrounding the chaplet must be considered as well as metal temperatures. When it is known that metal temperatures will be unavoidably low, a chaplet should be chosen which has a lower fusion point than those normally provided, such as the silicon impregnated variety.

It oftens happens that chaplets are chosen with a stem too small for the weight of core supported and the temperature of metal poured. This causes premature melting and complete fusion to the extent that the core shifts before the metal has solidified enough to support it. This occurs with less frequency than the selection of an oversize type because of the desire of a molder to be on the safer side. Certain low melting point chaplets might give trouble if used with the same judgment as plain low carbon steel types. Core supporting properties, from the standpoint of rigidity alone, might be equal in each case, or even better in the alloyed chaplets, but the lowered melting point of the one would cause trouble unless it was used with care.

Effect of Shape

There seems to be a definite trend toward making chaplet stems in some form of corrugated, rather than plain, surfaces. No doubt this is done with the expectation that the roughened or irregular surfaces are an aid to fusion, and to a certain extent, are more appealing to a buyer. It is logical to assume that sharp points and patterns in relief may fuse more readily than a plain surface, but experimental evidence does not always bear this out. What advantage might be gained in promoted fusion may be nullified by the formation of gas pockets in the sharp corners and depressed sections.

Effect of Material

Chaplets ordinarily are made of low carbon steel with the stems stamped, rolled, or machined into the desired shape, the end pieces being stamped, placed on the stem, and pressed into a tight fit or spot welded to make a rigid assembly. The relatively high melting point of the low carbon steel prevents too rapid melting and is cheap, conveniently shaped, and easily made.

Some high alloy chaplets are on the market in which fusion results in an alloying action in the cast metal for a considerable distance around the chaplet cast metal interface. This would affect the properties of this region according to the nature of the element and might be advantageous in some cases and bad in others.

Effect of Surface Preparation

In regard to special preparation of chaplet surfaces, many different methods have been tried. Special treatment is necessary for a variety of reasons. If the plain, low carbon chaplets were left exposed to the air without any protective covering, they would rust and accumulate moisture. Upon use in a casting, excessive porosity would result at the fusion zone and for considerable distances into the body of the metal. This would be caused by the reaction between the carbon of the metal and the iron oxide of the scale, with the formation of carbon monoxide. Also any moisture present as such in the scale, or on the surface of the chaplet, would cause defects and retard satisfactory fusion. The surfaces of uncoated chaplets could be cleaned in acid or sand blasted immediately prior to use, but this would be both inconvenient and subject to lack of care. To prevent this, chaplets are coated and prepared in several ways.

Coatings

Electroplated surfaces include nickel, copper and cadmium in thicknesses from 0.0005 to 0.01 in. In a series of tests conducted by cooperating industrial foundries, the copper plate was found to give the most consistently good results of any tried. Included in the work was a tin dipped series, but none of the silicon impregnated variety. What type or how extensive the investigation was is not known.

So-called dipped chaplets are prepared by dipping the cold pieces into a bath of molten metal, such as tin, and allowing a thin layer to adhere, after which they are removed and cooled. Opinion varies greatly among foundrymen as to the relative merits of this.

Silicon impregnated chaplets can be prepared by a patented process, the chief function of which is to cause silicon to alloy with iron by diffusion at some temperature below the melting point of either one.

By the process of silicon impregnation, cases from 0.005 to 0.01 in. can be obtained. The silicon-rich iron case, containing as much as 14 per cent silicon, has a relatively low melting point and would fuse, or perhaps completely melt, very readily. Such being the case, fusion would result at a specific temperature with considerably larger impregnated chaplets than plated or dipped types.

Cleanliness

Cleanliness of chaplet surface, both before and after coating, merits much greater consideration than it is commonly given. Any scale or dirt present prior to coating will be covered up by a thin layer of deposited metal and is a potential source of porosity in the casting. Also a very thin or loose layer, or at worse, none at all, might adhere in the vicinity of the scale, allowing more oxide to collect. In impregnated varieties, this is not so important and the corrosion resistance of this type is excellent.

Rust is only one of many forms of uncleanliness that may lead to poor chaplet fusion. Any oil or moisture present would cause porosity, the former being spilled accidentally or rubbed from the hands of any person handling the material. Moisture could result from water spilled over the chaplet or by condensation from the atmosphere before or after being put into the mold. Fine dust often collects in irregularities or even on smooth surfaces, if chaplets are stored in open containers on the foundry floor, and this may account for some porosity and much of the slag sometimes noticed in unfused specimens.

Effect of Molding Conditions

Conditions of molding have an important influence on the satisfactory functioning of chaplets. If a green sand mold containing chaplets is allowed to stand for a long interval before pouring, moisture from the humid atmosphere of the mold condenses on the cold metallic surface and either remains as water or promotes rusting, each capable of causing faulty castings. In cases where green sand molds are oven dried with cores in place, very favorable conditions for rusting are presented, and any spot of porous or discontinuous coating would be readily attacked. The flaky nature of the silicon impregnated chaplets tested present good possibilities for the absorption of moisture and the collection of dust.

Types of Chaplets

Chaplets are made in a wide variety of sizes and shapes. Some of these are given in the following together with some typical applications.

Double Head. Double head chaplets are one of the most commonly used types. Several are shown in Fig. 15.5. The stems are usually nicked, grooved or distorted in some manner so that they will make a better union with the casting. Double head chaplets in the smaller sizes usually are made without the distorted

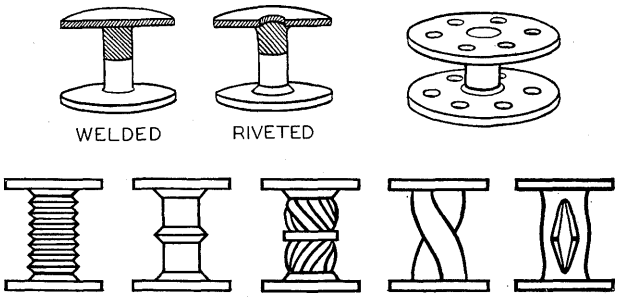


Fig. 15.5 — Double head chaplets showing construction at top left and center, and one with perforated heads at top right. The bottom illustration shows various types of distorted stems used for such chaplets.

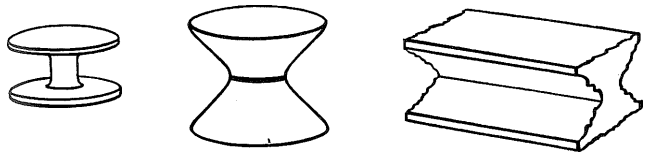


Fig. 15.6 — Types of cast chaplets.

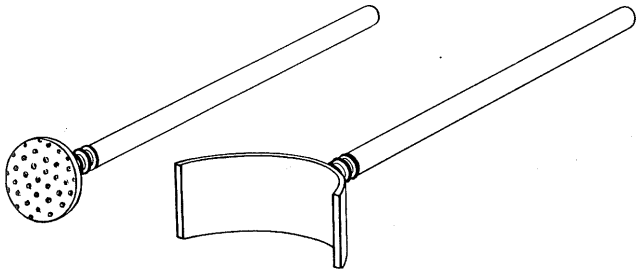


Fig. 15.7 — Stem chaplets. The type on the left is sometimes termed forged head, and that on the right, fitted head stem chaplet.

stem and are known as motor chaplets. Heads are sometimes made with several holes pierced as shown at the top right in Fig. 15.5 to give entrapped gas a chance to escape.

Cast chaplets, as shown in Fig. 15.6, have been used to some extent but in most production work the riveted or welded chaplets seem to be preferred.

Double head chaplets with one or both heads upset from the metal of the stem, like the head of a nail or rivet, have been made but, except for boiler chaplets, they are not used extensively. Boiler chaplets are chaplets with one small round head and a larger square head. The small head is used against the core and the larger head against the green sand of the mold or against a metal chaplet seat. Double head chaplets are available in practically any size.

Stem Chaplets. Stem or single head chaplets are used to hold down large cores. Stem chaplets, sometimes called forged head or fitted head chaplets, depending on how they are made, are rods with a head on one end to bear against the core. Figure 15.7 shows on the left, a forged head, and on the right, a fitted head stem chaplet. Either forged or fitted head chaplets are furnished with distorted stems to anchor them in the casting, and the surface of the forged chaplet usually is made with knobs to grip the core and prevent it from moving sideways. Both kinds are regularly supplied in the tin-coated form.

In use, the stem of the chaplet projects up through the cope and a bar is clamped across the flask at such a height that wedges may be slipped between the bar and the chaplet or, if the flask is weighted, the wedges are placed between the chaplet and the weights. On the casting, the projecting chaplet stems are cut off in the cleaning operation. Stem chaplets are available in many sizes.

Radiator Chaplets. Radiator chaplets, shown in Fig. 15.8, are largely used on light castings, particularly where the mark left by some other chaplet would be unsightly.

In use, the points of these chaplets are placed in holes provided in the pattern, leaving the heads projecting. The sand is then rammed in the mold, squeezing around the heads and anchoring them so that when the mold is rolled over and the pattern drawn, the stems project into the mold the distance that they originally entered the pattern. These projecting stems form the supports of the core. After the casting is made, the stems and heads of the chaplets are left protruding from it, and are broken off during the cleaning operation, the stem being nicked at the proper place so that a clean break occurs.

Light cores may rest directly on the ends of the stems, but for heavier cores or where greater accuracy is required, metal plates are used on the core. These plates may be placed in recesses in the core box and baked on the cores, the core binder causing them to adhere, or they may be used on top of the core only, being laid in position before the mold is closed.

As will be noted from Fig. 15.8, radiator chaplets are made with coiled heads, both plain and flattened, and plate heads, square and notched. The notching is to allow the sand to squeeze around the head better and not leave a soft spot under it. Any of these chaplets may require a little squeeze from the molder's fingers to be sure the sand is tucked tightly under the head, especially if a short chaplet is used, bringing the head close to the pattern.

Radiator chaplets are made with and without a shoulder. The purpose of the shoulder is to properly regulate the distance the chaplet drops into the pattern. The hole into which the chaplet drops is made sufficiently deep so that any sand or dirt that gets into it does not affect the setting of the chaplet. Unless the pattern is counterbored for the shoulder, it is left projecting as a small lump or knob when the stem breaks off. On castings where a smooth, unblemished surface is required, radiator chaplets without a shoulder are used, the proper location of the chaplet being regulated by the depth of the hole in the pattern. These chaplets have the break-off nicks carefully located so that they break off flush with the surface and leave practically no trace of their presence.

Most radiator chaplets are made with two or four knitting nicks in the part of the chaplet which stays in the casting to enable the metal to grip the chaplet better. The forming of these nicks should not enlarge or bulge the stem to cause it to stick in the pattern.

Radiator chaplets are regularly made from various sizes of wire, No. 13 being the most common, with heads ½, ¾, 1 or 1¼-in. square or coiled heads approximately these sizes. The overall length is usually 1¾-in. with the shoulder distance to suit the casting. They are available with several different coatings and for both ferrous and nonferrous castings.

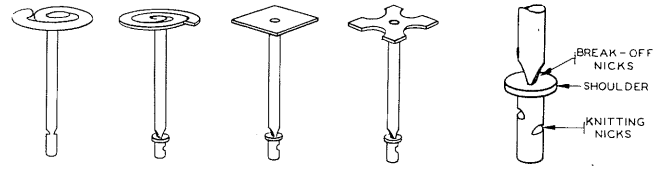


Fig. 15.8 — Radiator chaplets. The illustration at the right shows how the stems are nicked above the shoulder so that the stem breaks off properly, and below the shoulder to enable the metal to grip the stem better.

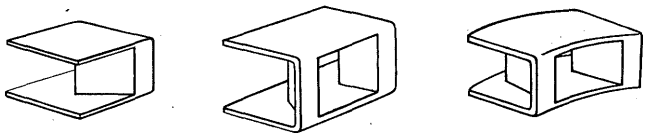
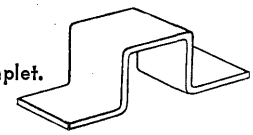


Fig. 15.9 — Angle stem sheet metal chaplets. (Left) Plain angle; (center) double angle; (right) curved double angle.

Fig. 15.10 — Bridge chaplet.



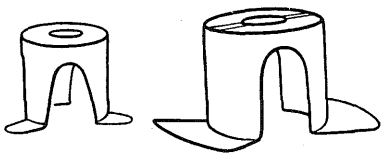


Fig. 15.11 — Shell chaplets; (right) three prong; (left) two prong.

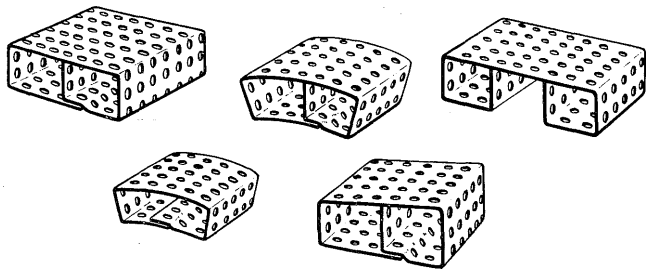


Fig. 15.12 — Various perforated chaplets.

Sheet Metal Chaplets. Sheet metal chaplets are used extensively on light castings. In general, they are economical, give free passage to any gas that forms in the mold and, being of a uniform thin section, they unite well with the casting. They are available in any metal that can be cut and formed.

Angle stem chaplets, Fig. 15.9, are one of the heavier types of sheet metal chaplets. They are made in thicknesses from $\frac{3}{16}$ to 2 in., the width and length increasing with the thickness, and in four gages of metal, 14, 16, 18 and 20. One of their advantages is that they can be supplied with curved surfaces.

Bridge chaplets, Fig. 15.10, are used to some extent, but they are not considered as safe as some of the others.

Tin shell chaplets are made with two and three prongs, as shown in Fig. 15.11. Their design gives them exceptional strength, but they should be set on dry sand cores if possible, as their bearing is small. Tin plates are sometimes used instead of a core to increase the bearing area. Their venting qualities are not all that might be desired, although a good sized hole in the top and a depressed channel give gas a chance to escape. They are made in diameters from $\frac{1}{4}$ to $1\frac{1}{4}$-in. and in thicknesses up to 1 in. or sometimes more.

Perforated chaplets are formed from perforated sheet metal and are made in a large variety of shapes and sizes, as shown in Fig. 15.12. Their strength is not as great as some of the other chaplets but, under ordinary conditions, they will carry all that can be safely applied to the green sand surface on which they are used. The fact that, in addition to being made flat, they can be supplied to any desired curvature or of any variety of shape, makes them very useful. Similar chaplets are made of sheet metal, not perforated, and are known variously as pipe, box and burner chaplets.

Ventilated chaplets, Fig. 15.13, are pressed from sheet metal and are made both flat and curved in many sizes. The diameter of the core that they are made to fit is determined by the die in which they are formed, so that special curvatures are not easily produced. It is claimed that the chaplets with continuous strips depressed do not tangle as badly as those with the separate prongs, but both kinds have been used for years with very satisfactory results. Another chaplet of the sheet metal type is the chaplet shown in Fig. 15.13 at the right. These are made in double "Z" shape in flat only, for metal thicknesses up to 1 in.

Spurred Chaplets. To facilitate setting, chaplets are sometimes attached to cores. Spurred double head chaplets are made for this purpose with one large and one small head and a projecting spur, as shown in Fig. 15.14, left. A recess is made in the core box to receive the smaller head and is counter-bored slightly to let the larger head drop in flush, the spur extending inwardly. The core is rammed and dried with the chaplet anchored on it by the spur and can be set in place with a minimum of molder's time.

A tin chaplet for use in this manner is known as a two-story chaplet and is shown in Fig. 15.14 right. It is made only for light cores with $\frac{3}{16}$ and $\frac{1}{4}$-in. metal thickness.

Forces Chaplets Must Resist

To determine what chaplets are required for a given job, the foundryman should understand something about the forces that act on a core in a mold.

In all metals, except aluminum and the lighter alloys, a sand core tends to float or be buoyed up with a force greater than its own weight. This force is not

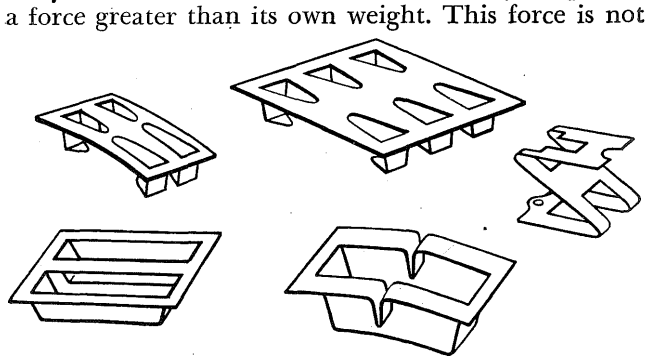


Fig. 15.13 — Ventilated chaplets. On the right is shown the so-called reeder chaplet.

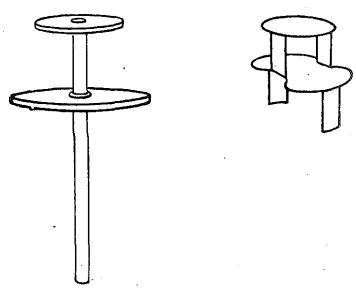


Fig. 15.14 — (Left) Spur chaplet; (right) two story chaplet.

caused by the height of the sprue or risers, like the force tending to lift the cope, but by the difference in weight between the core and the metal it displaces. That is, it is buoyed up by a force equal to the weight of the liquid displaced. Assume a sand core in the form of a cube measuring one foot on each edge and containing one cubic foot of sand. Such a cube will weigh about 100 lb. If placed in molten cast iron, it will sink until it has displaced 100 lb. of iron, and then it will float. If we apply pressure to its upper surface until it is entirely submerged, it will displace one cubic foot of iron, weighing about 450 lb, and be buoyed up with a force of that amount. As the core weighs 100 lb, however, the pressure to keep it submerged will be 450 less 100, or 350 lb.

Once the core is submerged, the pressure to keep it down is practically the same whether it is just under the surface or at the bottom of the ladle, which means that increasing the head of metal in a mold does not increase the lifting effect of the core, although it does increase the pressure on the surface of the mold.

The ratio of 100 lb (the weight of the core) to 350 lb (the pressure to keep it submerged) or 1 to 3½ will hold good for cores of any size, so we can make the rule that, roughly, the lift of a sand core in molten cast iron is 3½ times its weight. Table 15.1 gives the ratio of the weight of a core to its lifting effort in various metals.

From the table, it may be seen that for all metals except aluminum, the lift is greater than the weight of the core, and stronger means will have to be provided to hold the core down than to support it.

TABLE 15.1 — RATIO OF LIFTING FORCE TO WEIGHT OF CORE

Material	Ratio
Aluminum	0.66
Brass	4.25
Copper	4.50
Gray Iron	3.50
Steel	3.90

However, a core seldom is surrounded completely by metal, but the approximate lift can be calculated by considering the parts that are nearly surrounded. The core can be weighed or the weight can be figured by assuming a weight of 0.06 lb per cu in. for the sand. This weight, multiplied by the factor from Table 15.1 gives the lift.

Load Sustained by Chaplets. By trial, it has been found that on green sand molds, rammed as in ordinary practice, a load of 5 psi is all that can be applied to the surface without sinking into it an appreciable amount. Dry sand cores have considerable strength until acted on by the hot metal, when they disintegrate rapidly. Tests have shown that, on oil sand cores, chaplet heads loaded up to 75 psi of area do not cut into the core to any extent in molds for gray iron, poured hot, with a 1 in. thickness of metal where the chaplet is set. Heavier loads on the chaplet may push it into the core, and a thicker section of metal may be so slow in cooling that the core softens and gives way under the chaplet.

Load Sustained by Core Prints. There usually are prints or points where the core bears on the green sand. As green sand, rammed as in ordinary gray iron practice, will withstand a pressure of about 5 psi without being indented appreciably, these prints can be considered as being able to carry a load of that amount. If they are not sufficient in area or properly located to carry the load, chaplets will have to be used. Under the core, the only support necessary is for the weight of the core itself when it is set in place. Above the core, provision must be made to take care of the lift.

Type of Chaplets to Use

Light sheet metal chaplets are intended to be used with the side of largest bearing area against green sand, and can be counted on to carry about 5 psi load. The area of the head of radiator chaplets should also be figured to carry about 5 psi load.

TABLE 15.2 — LOAD SAFELY SUSTAINED BY CHAPLETS IN MOLTEN CAST IRON

	Double Head		Stem Chaplet		
				Safe Load	
Stem Dia.	Head (Square)	Safe Load	Head (Round)	Thin Metal	Thick Metal
1/16	3/8	5	—	—	—
1/8	1/2	20	1/2	20	10
3/16	3/4	45	3/4	45	22
1/4	1	80	7/8	80	40
3/8	1 1/2	180	1 1/4	180	90
1/2	2	320	1 1/2	320	160
5/8	2 1/2	500	1 3/4	500	250

In an effort to determine what might be the safe load for various sizes of steel double head chaplets in gray iron, a series of tests was made in which a mold was arranged with the chaplet between two cores, the upper of which protruded through the cope and was arranged with a lever by which a measured pressure could be applied to it. As the mold was filled with iron, pressure was applied until the chaplet failed. Although these tests were not elaborate or conclusive, the results indicated that the values given in Table 15.2 are approximately correct. There was no opportunity to make tests in steel, but undoubtedly the chaplets would lose further strength because of the higher temperature. Chaplets located near a gate, where considerable hot metal washes past, will be heated to a higher temperature and lose more of their strength than chaplets in more remote parts of the mold.

The size of heads on double head chaplets is limited by the fact that, if they are too large, gas is liable to pocket in the chaplets. As ordinarily made, the heads give sufficient bearing on a dry sand core surface, but are not large enough to carry all the load that the stem will stand when set against a green sand surface. A chaplet with a ¼-in. diameter stem, which would normally have a 1 or 1¼-in. head, is listed in Table 15.2 as being able to carry 80 lb in thin metal. This force would press the chaplet into the sand, and, for this reason, slabs of core are usually rammed up against the pattern at the point where the chaplets are to be placed. In the case of the chaplet mentioned, the slab should be about 4 in. square. This is found by dividing 80 lb (the greatest permissible load on the chaplet) by 5 lb (the maximum load per sq in. on the

green sand surface) which gives 16 sq in. or a 4 in. square.

Perforated, ventilated and most of the other types of chaplets, as ordinarily made, placed with the side of greatest area to the green sand, will carry in molten gray iron about all that can be safely put on the sand surface, that is, about 5 psi.

Shell chaplets are about twice as strong as other forms of tin chaplets of corresponding size, but are lacking in bearing surface. For this reason, it is recommended that they, as well as the so-called double head chaplets, be set on ram-up cores.

Chaplets for Steel Castings

Taylor and Rominski conducted tests on stem type chaplets of various types for steel castings as obtained from four manufacturers in the condition received. They also studied copperplated, tin-dipped and silicon-impregnated chaplets of the coarse thread and so-called superstem designs. Their results indicated that the chaplets investigated were not entirely fused into the casting. From their investigation, it did not appear that threaded stemmed chaplets gave any greater assurance of fusion than the superstem type. The authors felt that a plain type chaplet with a smoooth fillet in the juncture of the stem and plate might be superior to any of the types investigated. They did not attempt to correlate stem diameter and section size particularly.

Their investigation of coatings showed that the copperplated series, differing only in thickness of coating, indicated no constant difference in fusion. The tin-dipped series showed very good fusion and little porosity. The silicon-impregnated chaplets showed satisfactory fusion but also a slight amount of porosity. The above tests were conducted on chaplets as received from manufacturers.

These authors also conducted tests on specially prepared chaplets to study the effect of various type coatings. The chaplets were coated with: (1) silver plate, (2) silver plus cadmium plate, (3) cadmium plate, (4) copper plate, (5) nickel plate, (6) tin-dipped, (7) aluminum-impregnated, and (8) aluminum-dipped. Some were sandblasted before being electro-cleaned and coated and were placed in a desiccator to be free from dust before use. Others were treated in the same manner but left on the foundry floor to accumulate dust and moisture. In one instance, a superstemmed style chaplet was treated as before and placed in a desiccator until required and then placed in a washed, green sand mold prior to drying and cast in a high silicon steel.

In discussing the results of experiments, it was stated, "There seems to be a trend in favor of the specimen being sandblasted before coating. Whether this is the influence of the metal scale or some film built up during forming the chaplet stock which is not removed by electric cleaning is not known, but it is certain that there exists a very noticeable difference in the appearance of the two surfaces" (sandblasted and unsandblasted).

In comparing chaplets kept ideally clean with others similarly prepared but exposed to the conditions of foundry storage, it is stated, "It must be noted that these conditions were not nearly as aggravated as those usually encountered in the average foundry, since they stood exposed only for a matter of three weeks and the foundry was not extremely dusty. However, there seems to be enough difference to indicate that cleanliness and care in storage are matters for attention. Several of the chaplets tarnished very noticeably in the time allowed."

To check the corrosion resisting characteristics of various coatings, the authors placed specimens outside the window and subjected them to changing climatic conditions of wind, rain, snow and sun. With regard to the result of this investigation, the authors stated "In general, and only from visual estimation, it can be said that the ability of the various coatings to prevent corrosion is about as indicated in the electromotive series of metals. That is, in the order of decreasing resistance, they could be placed: aluminum, cadmium, tin, nickel and copper with silicon impregnation in some position near the top of the list."

In the case where chaplets were placed in a green sand mold painted heavily with a mold wash and the whole dried slowly in a core oven, the conditions for chaplet corrosion were aggravated. Every porous spot in the coating of a chaplet rusts badly and certain of the specimens were completely covered. In this condition, the mold was poured with a high silicon steel. "In spite of the apparently bad surface condition of the chaplets, nearly every one fused satisfactorily. It appears that silicon has diffused from the base metal into the chaplet stem."

In studying the effects of design, Taylor and Rominski found that under the conditions of the tests recorded, there was very little difference noticeable between the plain and threaded stem type chaplets. They found that in the plain stem type there was a tendency for the porous spots to localize at the junction of the stem and head of the chaplet, whereas, while the same tendency usually was shown in all cases, there generally appeared to be an increased number of holes near the base of the "V" in the coarse-threaded type.

In their investigations of the particular type coating best suited to chaplets for steel castings, they stated as follows: "While the present work does not clear this issue entirely, the results do show very definitely in favor of certain ones or others. For example, it can be seen readily that the silver-coated chaplets function very well under all test conditions. It might not, however, be enough better than copper, nickel, or aluminum to merit its extra cost. This coating was tried on the basis of the absorbing power of silver for gases. It was thought that perhaps the coating would absorb such gases as seemed to be quite generally present at cast metal chaplet interfaces. It is seen that a silver-plated chaplet would function properly and would certainly present no problem by solution into the base metal.

"In the interest of increased corrosion resistance, a specimen was tried with a layer of silver covered by a layer of cadmium, the latter having excellent corrosion resistance. This would permit advantage to be taken of the gas absorbing power of silver and at the same time provide a very corrosion-resistant coating. This type was not satisfactory because of the influence of the cadmium, which has a high vapor pressure and

produces extensive blowholes as a result of its volatilization. In four of the tests, this type was quite good but was not dependable, as two cases were unsatisfactory.

"From these tests, it appears that cadmium is not suitable as a chaplet or internal chill covering.

"The copperplated series proved very satisfactory in all tests, except the one employing the specimens which had been kept on the foundry floor to collect dust and moisture. From the standpoint of convenience and economy, this type, or the nickelplated type, would be the best choice. Copperplated surfaces, if not carefully stored, will oxidize to a considerable extent and often, because of the porous nature of the coating as plated, some iron oxide will build up. However, with reasonable care in handling, this should provide a satisfactory chaplet.

"Like copper, nickel seems to give consistent and fully satisfactory results. The choice of chaplet material and cleanliness of surface, as well as stem diameter, no doubt accounts for the failure of some nickel-flashed internal chills to fuse properly. Perhaps a certain amount can be laid to the condition of the steel.

"Contrary to the results of the work on the commercially plated specimens, the tin-dipped chaplets were not consistently satisfactory. There is some reticence on the part of many foundrymen to use tin since they believe it to be deleterious to the steel. Lacking any definite data on the subject, it is impossible to say what the exact influence might be but, on the basis of general observations, one is led to believe that what small amount would be washed from the chaplets would not seriously affect the physical properties of the casting. In trials at various foundries, tin was not found as suitable for a coating as copper in regard to fusion characteristics.

"Aluminum-dipped and aluminum-impregnated chaplets were not sufficiently good to merit the extra expense in preparing. Aluminum dipping is not an easy matter and such a process has not been commercially developed. It would seem that the aluminum-impregnated chaplet would fuse rather readily in the manner of the silicon-impregnated variety. However, such was not the case but the layer of aluminum-rich iron was extremely thin. Further work on the aluminum-impregnated variety will no doubt prove of value.

"Aluminum-sprayed chaplets were prepared by thoroughly sandblasting and spraying with a metallizing gun. It is imperative, in this instance, that the base material be perfectly free of dirt or grease or the sprayed layer will not adhere. A trial was made with chaplets as received and not sandblasted but the sprayed metal would not stick. While expensive and troublesome to prepare, this type may yet prove of practical importance. Because of its value as a powerful deoxidizer, this type would no doubt function equally as well in steels which were not so fully killed. This type has excellent corrosion-resisting properties as well."

The conclusions which were the result of Taylor and Rominski's work are stated as follows.

"The conclusions which can be formed from this work will vary considerably with the individual viewpoint regarding the importance of the issue. However, assuming that the smallest detail merits consideration in a field far too little investigated, the following observations are made.

(1) Many generally ignored factors operate jointly or individually to cause the unsatisfactory operation of chaplets.

(2) Threaded stem chaplets do not present any added assurance of satisfactory fusion and may, in some cases, be deleterious by presenting spaces at the bottom of threads for the accumulation and localization of dust, moisture and subsequent gases. Threaded stem types do promote a keying action by fusion at the points of the threads. This may be an aid in passing a qualifying test, but without complete fusion at the base as well as the point, the casting may fail in service. Perhaps the square stem type twisted torsionally might give this desired keying action at the same time being stronger and obviating the sharp V's.

(3) More consideration should be given to the storage and handling of chaplets.

(4) Too heavily alloyed chaplet material fuses readily but may sometimes melt too easily for suitable core support. A properly chosen thinly-impregnated case would promote the necessary fusion and yet the base material would probably not melt too readily.

(5) A good grade of low carbon steel is well chosen for chaplet material to be used in steel castings.

(6) Fusion is aided greatly by carbon diffusion from the higher carbon base metal into the chaplet material at the interface. This diffusion lowers the melting point of the chaplet and promotes satisfactory fusion at a clean surface.

(7) Silicon-impregnated chaplets fuse readily. A certain amount of grain coarsening results in the casting for a small distance around the imbedded chaplet. Perhaps this type would operate more satisfactorily with a thinner case than used in the present tests, as mentioned in (4).

(8) While the tin-dipped variety proved good in the investigation of chaplets as received from the manufacturer, further tests did not bear this out consistently.

(9) Copper- and nickel-plated chaplets proved satisfactory when prepared properly and kept clean.

(10) Silver-plated chaplets were the most consistently satisfactory of any series tried. Silver-cadmium and cadmium coatings proved unsatisfactory because of the high vapor pressure of cadmium.

(11) Aluminum-sprayed chaplets are thought to be very good but too little actual data was collected on this type to allow an accurate statement to be made. More work on the impregnated and dipped types might prove of great value.

(12) So-called streamlining of chaplets would obviate the tendency of gases to form and localize in indented areas.

(13) The duplication of test results indicate the suitability of the testing procedure used."

Mechanism of Chaplet Fusion

It is commonly believed that fusion between chaplet and cast metal is a case of simple melting, enough superheat existing in the melt to raise the temperature of the chaplet above its melting point. This is a fair belief, since most steel is poured at relatively high temperatures. However, cases are known where cast iron has fused soundly with low carbon steel chaplets, the temperature never reaching the fusion point of the latter. This leads to the necessity for considering some other phenomenon than that of simple melting.

Considering the case of cast iron and turning to the iron-carbon diagram, it is obvious that chaplet metal containing 0.10 per cent carbon, and no other alloying elements, would have a melting point higher than that normally reached by the cast iron poured around it. For fusion to result, some means must be provided for a lowering of the fusion point. When immersed in molten cast iron, it is known that chaplet material will absorb carbon by diffusion and the carbon content of the surface will rise progressively to a high figure. This carburization will go on until the melting point of the chaplet surface has been lowered to correspond to the temperature of the surrounding cast metal. It is obvious that unless some such mechanism exists, fusion in the above instance would be impossible unless the cast iron were held at the fusion point of iron containing 0.05 to 0.15 per cent carbon, i.e., 2714–2732 F (1490–1500 C) a temperature too high for the production of sound iron castings. It is known that satisfactory fusion has resulted in cases such as the above and a micrographic examination revealed a very definite carburization for a considerable distance into the body of the chaplet.

Since the above mechanism prevails in the case of cast iron, it is logical to expect that a similar phenomenon exists in the operation of chaplets in steel castings. Steel is poured with enough superheat to melt a low carbon chaplet material but in cases of thin sections, or when the metal is forced to run long distances, a large amount of this heat is dissipated to the sand. As a result, many borderline cases exist where temperatures are possibly too low to effect satisfactory fusion, unless some carburization operates jointly to raise the surface carbon content of the chaplet material. That a certain amount of carbon penetration does take place is shown in the paper by Taylor and Rominski to which previous reference has been made. A composite photograph shows the polished and etched surface from the center of a chaplet outward into the body of cast metal.

The increasing amount of pearlite from the center of the chaplet to the interface is an indication of the carbon penetration, as is the increasing ferrite noticed from the unaffected cast metal toward the fusion line. The carburization in the present case is of a low order and the difference in melting point between the original compositions of chaplet and casting is slight. In cases of low or medium carbon steel castings, little advantage from the standpoint of a lowered melting point would result. In higher carbon castings, however, it is probable that the influence of carburization would operate to advantage.

Determining Number of Chaplets Needed

A general rule for figuring chaplets is to first get the weight of the part of the core which is nearly surrounded by metal, either by weighing a sample or by estimating the weight at the rate of 100 lb per cu ft or 0.06 lb per cu in. The lift is then found by multiplying this figure by the ratio given in Table 15.1. Any prints or points where the core cuts through on the top or bottom can be figured as carrying 5 psi of projected area. The remainder of the force exerted by the core will have to be carried by chaplets. Where one end of a relatively long core is well anchored in the mold, about half the load will have to be carried by chaplets, placed toward the unsupported end.

The selection of the best and most economical type of chaplet for any particular job is a matter of judgment. It usually is better to use several light chaplets than fewer heavy ones. Tin chaplets, which can be used without having to be placed on ram-up cores, are a saving if they will carry the load without having to be used in too large numbers.

As an example of how to figure chaplets for a particular case, assume a gray iron casting as shown in Fig. 15.15. From the previous discussion, we know that

Volume of Sand in Core (cu in.) × 0.06 psi (wt per cu in.) × Ratio (Table 15.1) = Lift of Core (lb).

Projected Area of Core Prints (sq in.) × 5 lb (support supplied per sq in. of projected core print area) = Lb Support Given by Core Print.

Lift of Core — Support of Core Print = Load on Chaplets.

$$\frac{\text{Load on Chaplets}}{\text{5 lb (Load Carrying Capacity per sq in. of Chaplet Area)}} = \text{Chaplet Area Necessary}$$

The calculation would be as follows:

The sand contained in the main body and neck sections of the core would be figured by the formula $\frac{\pi d^2}{4} l$ or $0.7854d^2l$.

Hence,

$0.7854 \times 3 \times 3 \times 12 = 84.8$ cu in. (main part of core)
$0.7854 \times 1\frac{1}{2} \times 1\frac{1}{2} \times 3 = 5.3$ cu in. (neck)
90.1 cu in. (total sand in core)
$90 \times 0.06 = 5.4$ lb (wt of core)
$5.4 \times 3.5 = 18.9$ lb (lift)
$1\frac{1}{2} \times 1\frac{1}{2} = 2.25$ sq in. (projected area of core print)
$2.25 \times 5 = 11.2$ lb (load print will safely carry)
$18.9 - 11.2 = 7.7$ lb (load to be carried by chaplets)
$\frac{5}{7.7} = 1.54$ sq in. (necessary chaplet area)

From the above it is seen that, underneath the core a chaplet will be required to carry about half the weight of the core, or say 3 lb. The area should be about ½-sq in. and a choice can be made of any one of several types of chaplets.

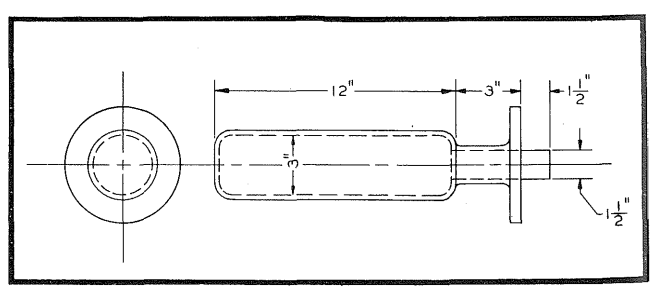


Fig. 15.15 — Casting for which formula for chaplet requirements are given.

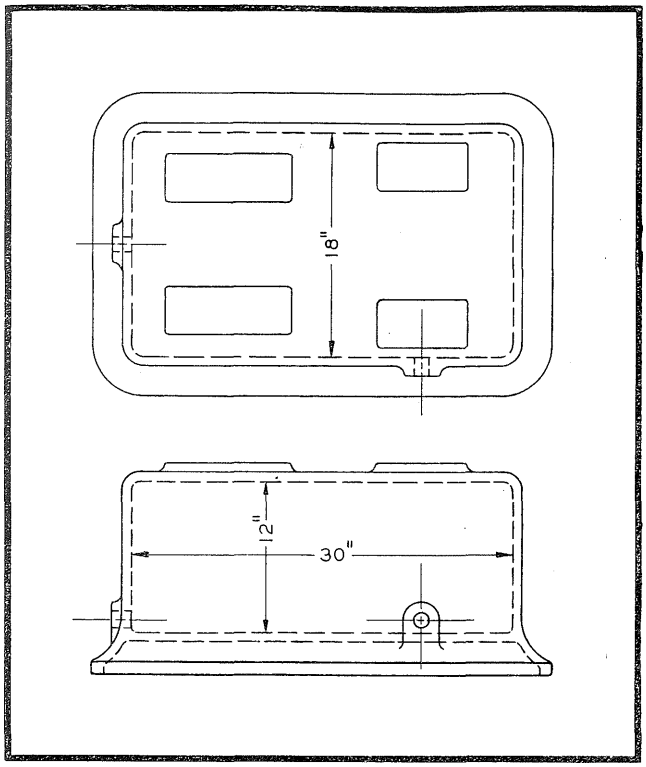


Fig. 15.16 — Centrifugal pump base casting.

On the cope side about 8 lb of lift has to be spread over about 1½-sq in. of chaplet area. Two ⅞-in. square, ventilated chaplets would do nicely, placed well to the unsupported end of the core; or two 1 x 1 in. perforated chaplets; or radiator chaplets of the required head area could be used.

As another example, take the centrifugal pump base casting shown in Fig. 15.16, which is cored out to serve as a reservoir. The inlet and outlet are so small that they furnish almost no support for the core and should be disregarded. The mold is green sand with a dry sand core.

The core would contain 1 x 1½ x 2½ or 3¾-cu ft of sand weighing about 375 lb. The lift in gray iron would be 375 x 3½ or 1312 lb. By referring to Table 15.2, we see that, for the drag side, five double head chaplets with ¼-in. stems, each capable of carrying 80 lb, would furnish sufficient support, provided they are set on ram-up cores. The area of each of these cores should be 80 lb divided by 5 lb, which is the permissible bearing pressure per square inch for green sand, or at least 16 sq in. to insure its not being pressed into the sand when the heavy core is set upon it.

On the cope side, double head chaplets might be used, but the load is so great that it is better to use stem chaplets and take the force outside the mold than to try to prepare a mold surface that will carry it. In this case, the metal would be considered a thin section and, from Table 15.2 it is seen that four ½-in. stem chaplets, each capable of carrying 320 lb, would give practically the required support.

Unless the prints where the core cuts through are sufficient to locate it and prevent it from shifting sideways in the mold, light double head or perforated chaplets should be used at the sides, hung in place with wires, and it would be best to provide ram-up cores for them to bear against. This would also prevent marring the face of the mold in getting them in place.

Stem chaplets are seldom, if ever, used on the drag side of a core. They are pushed up through the cope and after the mold is closed, a bar is rigged and clamped across the flask to take the thrust.

Design vs. Chaplets

When a casting requiring cores is being designed, the method of anchoring the cores should be carefully considered. If it is possible to avoid use of chaplets, even with some change of design, it is usually better to do so, as chaplets leave an unsightly mark in the casting, and, if leaks or blows occur, it is quite likely that they will be around the chaplet. When chaplets are necessary, they should be as small and light as will safely serve the purpose.

Chapter 16

CORE KNOCKOUT

INTRODUCTION

Much thought and effort is being placed on the speedy removal of cores within castings with the least amount of atmospheric pollution and labor. There are six methods of approach to obtaining a solution to efficient removal of cores.

(1) Design of casting.
(2) Selection of the core sand.
(3) Selection of the binder.
(4) Baking.
(5) Time casting is left in the mold.
(6) Selection of knockout equipment.

EFFECT OF DESIGN

When cast parts are being designed, the designer or patternmaker should provide ample size openings from which the cores may be removed from the casting. The expense of core knockout is increased continually by failure to provide ample size openings properly located to facilitate the removal of sand.

SELECTION OF SAND

Through the selection of the core sand with reference to fineness and clay content, a foundryman can improve the degree that the core burns or collapses after the casting is poured. The coarser the sand, the greater the quantity of heat that will flow through the core during pouring and cooling of the casting; consequently, the coarser the core sand, the quicker it will disintegrate completely, thus causing easier knockout.

EFFECT OF BINDER

An increase of clay content in a core will retard the rate of core collapsibility, thus increasing the amount of knockout effort required to remove the core from the casting.

A wide variety of binders is used in cores. Certain binders, for example, such as oil and cereal binders, burn easily within a hot casting, thus reducing amount of work required to knockout a core.

The ease with which a core may be removed from a casting is influenced not only by the selection of binder, but also by the amount used. The greater the quantity of binder used, the harder the core, which makes it more difficult to remove.

EFFECT OF BAKING

The degree of baking of a core also will influence the collapsibility of a core. An underbaked core is more difficult to remove than a well baked core.

EFFECT OF TIME IN MOLD

Wherever it is practical, a casting should remain within the mold a sufficient length of time to allow it to cool to a reasonably low temperature. Following this practice will give castings of minimum strain and cores will be more completely burned than when castings are removed quickly after the mold is poured.

TYPES OF KNOCKOUT EQUIPMENT

Through the proper selection of knockout equipment, much may be accomplished in obtaining efficient, speedy, clean and thorough core knockout. Every mechanical aid provided in the knockout operation is a step forward.

Mechanical tools used in the knockout operation may be divided into two groups: hand tools and mechanical knockout units. The hand tool group includes pointed bars, hammers, malls and pneumatic chisels. In the mechanical knockout units, there are vibrators, bumpers, hydraulic jets, jolters and tumbling barrels.

Hand Method

The hand tools, as previously enumerated, all employ manual labor to operate them, placing the man

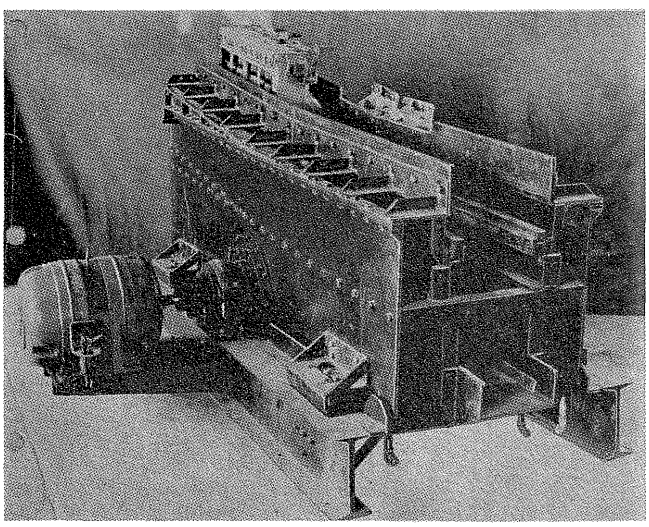


Fig. 16.1 — Mechanical vibrator unit removing cores from motor block castings.

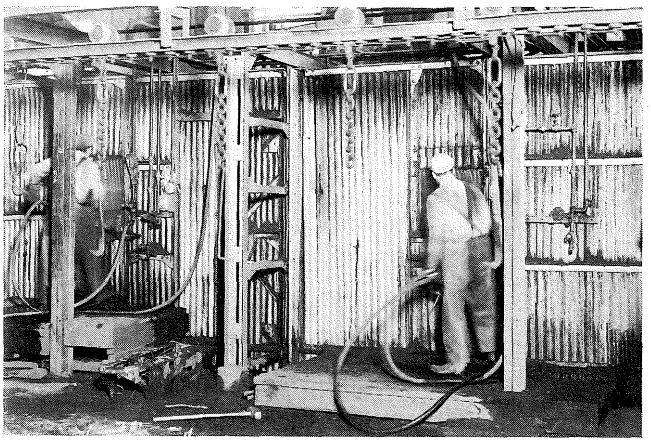


Fig. 16.2 — Installation of wet method of knocking out cores in a large steel foundry. In this installation the operators are outside the blast room and the castings pass the operators on a conveyor from which they are suspended.

in position where he may be subjected to a polluted atmosphere. The pneumatic chisel finds a large application in removal of black cores of large castings. Mechanical knockout units find their largest application in foundries making small and medium size castings, with exception of the hydraulic jet, which is used for the removal of cores in large castings.

Vibrator Mechanical Knockouts

Vibrator core knockout units may be divided into two classes, namely, air vibrator type and mechanical vibrator type. The air vibrator type may hook onto a casting or the casting may be clamped pneumatically within the frame of the vibrator. The casting receives a rapid series of raps or vibrations from the air hammer of the vibrator. This action loosens the core sand, causing it to pour from the casting.

The mechanical vibrator is essentially a metal frame, or cradle, which is caused to vibrate rapidly by having the frame mounted on an eccentric shaft. The shaft is driven by an electric motor. A good illustration of this type of unit is shown in Fig. 16.1.

Castings may be swung against metal or rubber cushioned bumpers by hand to jar the cores loose. This same principle is employed in some knockout units where the castings are hooked on a conveyor and pulled across a series of steps or bars, causing castings to be jolted, which allows the core sand to pour out of a hole in bottom of the casting.

Tumbling Barrels as Knockouts

The cores in many small castings are removed by placing the castings in a tumbling barrel. The cores, during the tumbling operation, are jolted loose, causing the sand to run out of the casting interior.

Wet Methods of Core Removal

Wet methods of core removal are practiced either with or without a system for sand recovery. In general, these systems fall into two categories.

(1) A hydraulic method, employing a relatively large water gallonage at a pressure between 250 and 450 psi.

(2) The discharge of relatively small quantities of water in which sand is entrained at a pressure of 1200 psi. The latter system may be used as a sandblast in certain types of work in the same operation as knockout.

In the first instance, the water is in general reused, being repumped through a centrifugal pump. In the second system it is impracticable to use water containing any percentage of fine material because of the extremely high pressure, and the water is generally wasted.

The two systems are adaptable to different types of castings; the first being the most successfully applied in open castings with relatively soft cores, while the latter may be applied most successfully to more complicated castings having relatively harder cores.

Figure 16.2 shows cores being removed from castings in a large installation where the operators are outside the blast room. Figure 16.3 is a diagram of wet core knockout system, and Fig. 16.4 shows an installation where the operator is inside the blast room. Note protective clothing used by operator in Fig. 16.4.

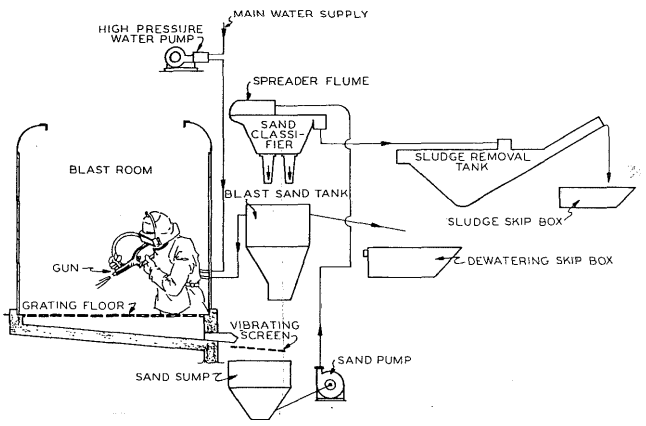


Fig. 16.3 — Flow diagram of wet knockout method.

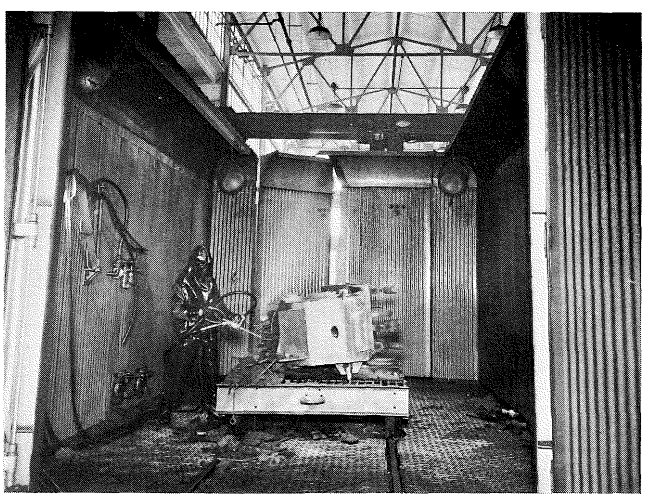


Fig. 16.4 — Installation where operator is inside blast room. Note protective clothing used by operator.

DIFFICULT CORE KNOCKOUT

The effort to knockout a core from a casting may be reduced in the following ways.

(1) Reducing retained strength of a core. The retained strength is the compressive strength of a core at room temperature after it has been heated to an elevated temperature in own atmosphere.

The retained strength is a good laboratory measure for predetermining the core knockout effort of various core mixtures. When the test cores are heated at 800 F (427 C) for 12 min in own atmosphere the better test results are obtained for light to medium weight iron castings.

The retained strength of a core may be reduced by increasing the grain size of the core sand by proper selection of ingredients and by reducing baked strength of the cores.

(2) A reduction of the hot strength of a core. The hot strength of a core may be reduced by grain size increase, proper selection of ingredients, and reduction of fines.

(3) Increasing size of vents in core to increase the flow of hot gases through the core.

(4) Increasing the time the casting is left in the mold.

Chapter 17

CORE SAND RECLAMATION

INTRODUCTION

Core sand which is removed from a casting usually is contaminated with molding sand that adheres to the casting, metal shot, fines, and carbon and ash from the burned core binder. In addition, the outer layer of each sand grain is covered with a coating of hard, carbonaceous material from the binder. Thus, it is quite evident that work must be done on the used core sand if it is to be utilized again as a clean core sand.

The amount of processing to which used core sand must be subjected to be put into condition so that it can be worked again depends largely upon the type of core binder in the cores. When binders are used, such as oil, which is readily absorbed by any molding sand present, the sand should be thoroughly cleaned. Other binders such as pitch or resin and cereal binders are not adversely affected by the presence of molding sand.

Another point in core sand reclamation is the refractoriness of the reclaimed sand. Impurities such as dust, metal and molding sand will reduce the sintering temperature or refractoriness. Where a core must possess high refractoriness and reclaimed core sand is used in the mixture, it is necessary to clean the used sand thoroughly.

There are three methods of reclaiming used core sand, namely, the thermal, dry and wet processes.

THERMAL RECLAMATION

In the thermal process, the used core sand is fed into a rotating kiln and fired at 1500 F (816 C) or more for a period not less than 15 min. A thermal reclamation unit consists of a crusher for crushing any core butts, screening equipment for removal of gaggers and core rods, a second crusher to break up any remaining lumps, a grain size classifier, a magnetic separator, and a horizontal or vertical kiln operating at 1400 F (760 C) or above. The carbon coat around the sand grains is burned off and any clay substance is dehydrated. The sand then passes through a rotary cooler with removal of fines by air current. Labor and fuel cost for reclaiming core sand has been shown to be less than one dollar per ton. See Fig. 17.1.

DRY RECLAMATION

The dry process of reclaiming used core sand consists of crushing core lumps in a crusher. The sand then is screened to remove grains that are too coarse or too fine. The dust is removed by suction and the tramp metal by means of a magnetic separator.

Figure 17.2 shows a sketch of a dry reclaiming system installed in a steel foundry. In this installation, the sand, as knocked from the castings, has a temperature of approximately 200 F (93 C). During the travel of the sand from the shakeout through the reclaiming system, all rods and chills are removed by magnetic separator and core lumps are bypassed to a roll crusher. The sand from the crusher then returns to be conditioned through an aerator and 50 mesh screens along with the remainder of sand knocked from the castings. The sand, in traveling from the shakeout through the aerator, loses considerable temperature and moisture. It then enters the screening part of this system where fines are removed and the fineness number of the sand and clay content are reduced. As an illustration, in this installation, the sand enters the

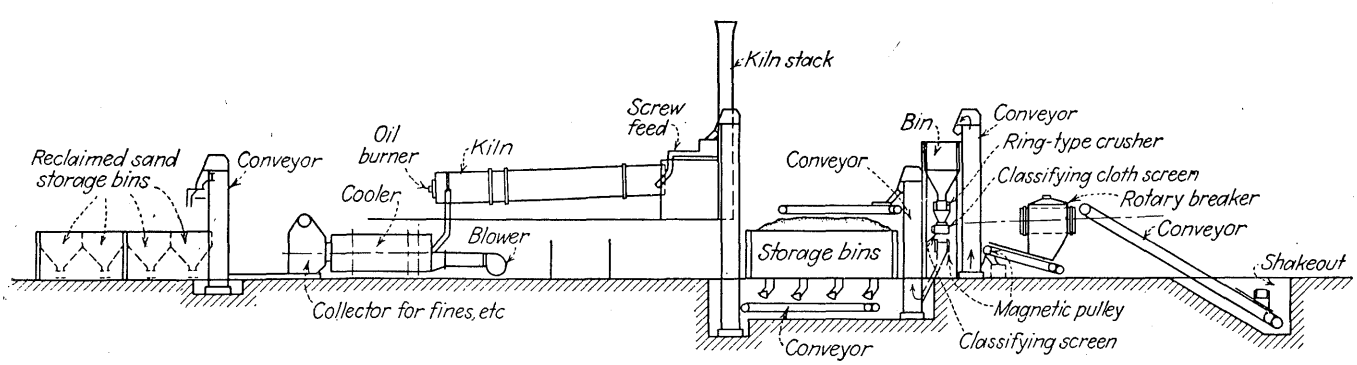


Fig. 17.1 — Thermal sand reclaiming unit.

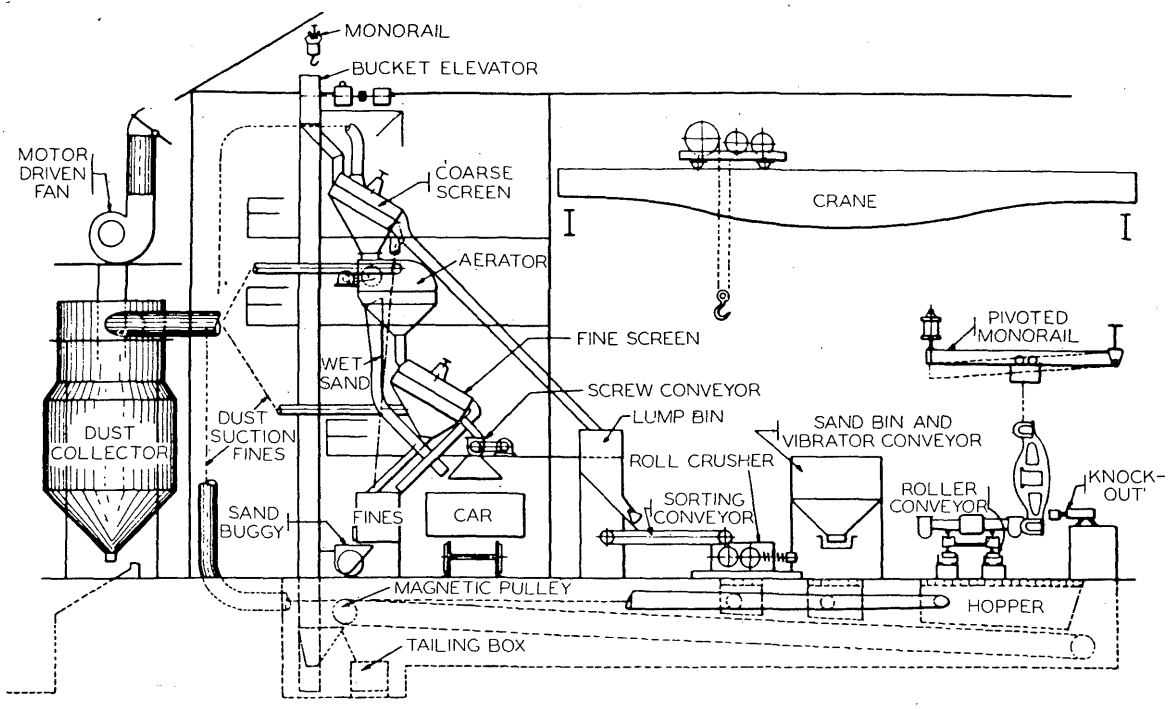


Fig. 17.2 — Casting shakeout and dry sand reclaiming system as installed in a steel foundry.

screening system with a fineness number of 37 to 40, of which 5 to 7 per cent is material which passes the 70 mesh sieve. After screening, it has a fineness number of between 32 and 35, of which one-half per cent is material which passes through the 70 mesh. This sand has a base permeability of between 450 and 500, with a clay content reduced from the original 3½ to 4 per cent to 1½ to 2½ per cent. The same principles of dry reclamation can be applied to other foundries.

Sand, from the unit discussed, is used in practically all the large cores made in this plant. The core mixture used consists of reclaimed sand, cereal binder and bentonite and gives cores that have a dry permeability of 320 to 360.

WET RECLAMATION

The wet processing of used core sand has received an impetus through various methods of wet shakeout and wet sandblasting. Sands processed by the wet system have, in turn, become acceptable to foundries because of the acceptance by many foundrymen of synthetic sand. In such wet processes, substantially all the bonding material is removed from the sand. The sand is classified by grain size to approximate the desired distribution and dewatered by leaching or by a dewatering mechanism and driers.

Certain binders are difficult to remove, and washing by means of pumping into classification systems is sometimes insufficient to obtain a sand which may be used instead of new sharp sand. In such cases, an intermediate scrubbing operation is necessary. This operation can be done wet and continuously by mechanical means.

The core sands presenting the greatest difficulties are the oil-bonded cores where plumbago or graphite is used as a wash. Such sands do not wet down easily. Another difficult sand to reclaim by the wet method is cement-bonded sand, which must not only be broken down so that there are no conglomerate grains, but the individual grains must be substantially free from dead cement. Steel core sands, using clay or bentonite with or without oil or pitch binding materials, are relatively easy to wash. In the case of sands containing a large clay content, a problem arises in conjunction with the removal of the finely divided material, because sewers must be protected.

The table shows the new core sand used by one steel foundry together with the condition of the core sand reclaimed by the wet method before and after washing and classification.

Sands recovered by the wet method may be used in core mixtures for blown oil-sand cores. They also may be used in cores and molds which are rammed by means of sand throwing devices. Naturally, all sands recovered by the wet method must be rebonded. Different mixes of such sand with appropriate binders also may be used in making facing sand. Typical facing sand mixtures which may be used are listed.

FINENESS ANALYSES OF NEW AND WET METHOD RECLAIMED CORE SAND

Screen No.	New Basic Sand Retained on, per cent	Sand Entering Washer Retained on, per cent	Washed and Classified Sand Retained on, per cent
6	0.0	0.00	0.00
12	0.0	0.20	0.00
20	0.4	1.80	2.20
30	1.4	3.00	3.40
40	3.8	6.20	7.20
50	14.4	14.00	18.80
70	35.0	25.20	30.20
100	34.0	27.20	27.00
140	9.2	10.40	6.60
200	1.0	1.80	1.40
270	0.2	0.20	0.80
Pan	0.2	2.20	0.80
	99.6	92.20	98.40
Clay, per cent	0.4	7.6	1.40

Gray Iron—18-25 gal reclaimed sand; 1 gal fire clay and small quantity pitch.

Steel—15 parts reclaimed sand; 1 part fire clay and ⅓ part bentonite.

A large proportion of sand normally wasted may be recovered by the wet process, resulting in a sharp sand having a grain distribution as determined by the classifiers. Where large amounts of sand are normally wasted, it is desirable to recover this in a continuous system which involves continuous drying from classification. As usual with any system in a foundry, the amount and design of equipment is largely determined by the amount of material to be handled.

Cleanliness of the reclaimed sand may be determined in three ways.

(1) Comparison of tensile strength, having a given permeability and grain distribution, using linseed oil as a binder. Where dirt remains on the individual sand grains, it will absorb a larger amount of oil for a given strength than when the grains are as clean as in new sand. It has proved practicable to get higher strengths with recovered sand, with the same amount of oil and by identical processes, than with new sand, usually because a small amount of silt is present in any new sand shipped into a foundry.

(2) A second method is gas evolution, particularly in oil-bonded cores where the sand grain is surrounded by partly burned oil, carbonized cereal matter (frequently used to obtain green strength), or some slight amount of bentonite or clay. In certain types of work, this sand must be cleaned before reusing because more gas may be evolved with this sand than with new sand and new oil. This may be particularly important in low density metals, such as aluminum, magnesium and their alloys. Sands may be processed by the wet method to remove this burned oil to such a degree that no increase of gas is noted upon ignition.

(3) The third method of determining cleanliness is, of course, the microscope.

Figure 17.3 shows the results obtained with two sands reclaimed by the wet method. The photomicrograph at top, left, is of sand as received for processing by the wet method. That on the top, right, is a second sand taken from a foundry heap. The two center photomicrographs show each of the sands in their reclaimed condition while those at the bottom are photomicrographs of the new sands from which the original mixtures were made. A comparison of the photomicrographs in the center and bottom rows illustrates how closely the wet method of sand reclamation comes to returning the sand grains to their original condition.

The larger, rounder grains of sand are more readily cleaned by the wet method than the smaller irregular grains. A larger proportion of the fine rather than of the larger grains is lost in classification. The process, in general, will show a loss in the finer sizes similar to that obtained by dry air flotation methods. It has been found necessary to make additions in the finer sizes rather than in the coarser material.

It is said that sand reclaimed by the wet method will show characteristics superior to new sand, in that certain of the sand grains, having weak cleavage planes, will have been broken either by mechanical action or by exposure to hot metal and will be lost as fines, the tougher grains remaining in the system.

In practice, it is found that approximately 85 per cent of the sand which goes to the dump in foundries is good sand and of this amount, between 85 and 90 per cent may be recovered. In a wet system, certain amounts of new sand, or of scrap sand obtained from other sources, or from the dump, must be added to make up for the loss inherent in classification, in sand adhering to castings through penetration, and in the natural breakdown of the sand grains through heat or mechanical action.

Separation of core sand involves also a separation from the sand of the oversize material, cinders, iron, nails, etc., as well as a separation of the fines. This generally can be accomplished by wet screening, although in certain instances magnetic separation may be required in addition.

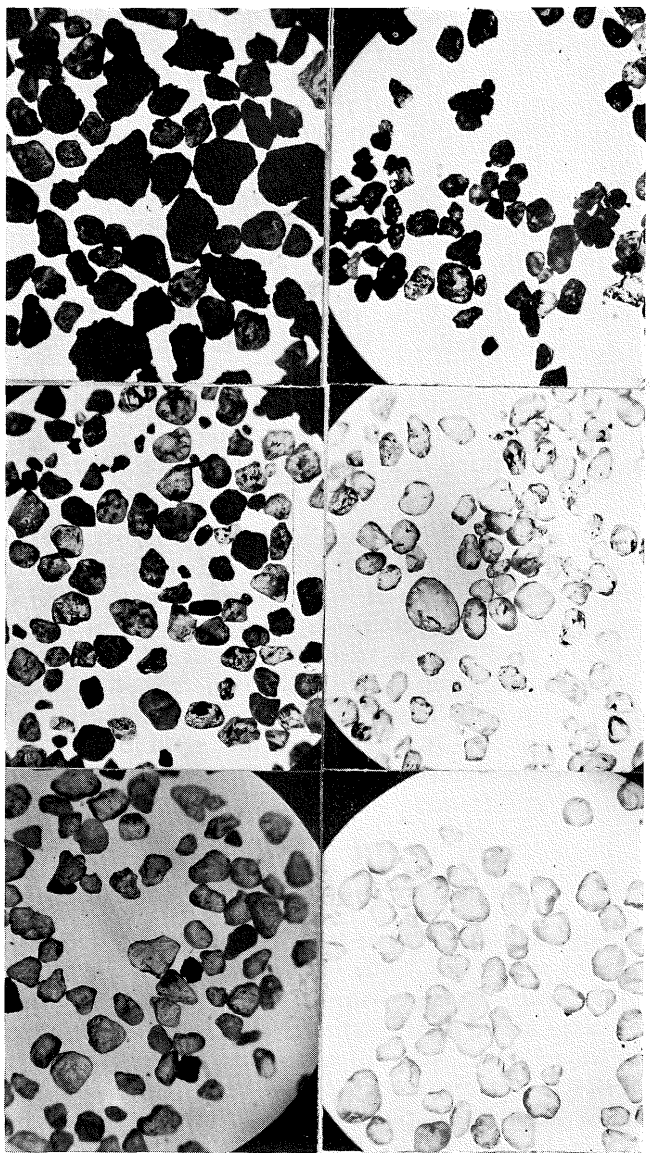


Fig. 17.3 — Photomicrographs of used, reclaimed and new sand, × 10. (Top left) Used sand. (Center left) Same sand as reclaimed by the wet method. (Bottom left) New sand from which the used sand shown at top left was made. (Top right) Heap sand. (Center right) Same sand as that at top right reclaimed by the wet method. (Bottom right) New sand from which heap sand was made.

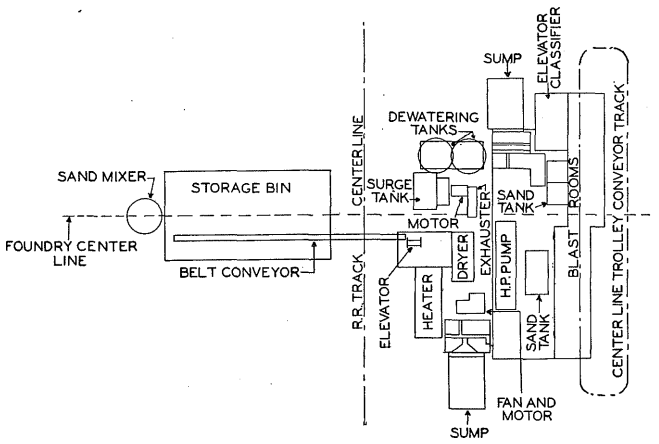


Fig. 17.4 — Layout of casting cleaning and wet sand reclamation unit in a large steel foundry.

Certain pitch bonded sands do not scrub clean and it is believed that pitch leaves a certain strength in the sand which can be retained economically. In such instances, a certain amount of adaptation of the mixes for the core or facing material must be made. A typical mix made from sand recovered from pitch bonded cores is composed of 250-300 lb reclaimed sand, 5 qt pitch and 5 qt fire clay.

Properties of the mixture are permeability, 75; green compressive strength, 3.5 psi and moisture, 5.5-6.0 per cent.

It should be borne in mind in the reuse of any water-washed sand that the product should be mixed in a manner similar to sharp sand to obtain the most satisfactory results. The wet reclamation process has been successfully applied in several steel foundries on a large scale and in a large number of gray iron foundries making heavy castings. A layout for a typical wet reclamation system is illustrated in Fig. 17.4. This installation knocks out cores from approximately 200 tons of steel castings per day, classifies and dries approximately 15 tons of sand per hour. Other installations, not so large, have been made in gray iron and nonferrous foundries. In gray iron foundries where the amount of sand is not so great, it has been found possible to deal with the wet sand in a batch manner, allowing one of two piles to dry to a usable moisture content while dumping relatively wet sand on the other pile. Where large volumes of sand are concerned, this requires too much floor space and too much handling.

It is practicable with the wet system to make grain size separations into as many as three groups — coarse, medium and fine.

It was at one time believed that one of the causes of trouble from reusing sand too frequently was accumulation of nonmagnetic iron oxide. This does not seem to occur with wet classification of sand and it is considered doubtful that the presence of relatively large amounts of this material is inherently undesirable, although it may be for certain work. This discussion, in any event, is academic because there is no accumulation of ferric oxide due to continuous use of core sand in steel and gray iron foundries.

In conjunction with the wet reclamation method, observations indicate that somewhat higher permeability appears to be obtained with washed sand than with other sands having apparently identical grain distribution.

The wet system generally is limited to the reclamation of core sand, although molding sand may be converted into core sand by this method. A certain amount of molding sand may be put through such a system for additions to the heap to keep it open.

Chapter 18

CASTING SURFACE AS AFFECTED BY CORE-SAND MIXTURES

INTRODUCTION

The condition of the surfaces of metal castings formed by cores is largely dependent on the smoothness of the cores. Smooth cores usually will produce smooth castings. However, the surface condition is influenced by the penetrating tendency of the cast metal. Liquid steel does not enter the minute cavities on the surfaces of sand cores as some other metals do, unless section size is large. Cast iron fills the voids between the sand grains when it is poured at high temperatures. A leaded bronze will penetrate an open core to considerable depth, depending on the temperature of the metal and the pressure to which it is subjected. Hence, it is necessary to adjust the core-sand mixtures according to the metal which is to be used and the surface finish required.

EFFECT OF STICKINESS OF MIXTURES

One of the factors which affects the smoothness of cores is the characteristic of some sand mixtures to stick to the surfaces of core boxes. The addition of fuel oil to the mixture reduces this and is a fairly common practice in steel foundries using sticky core binders. When any sand remains in a core box after the core has been removed, the core will not be smooth on those surfaces where the sand has separated. Some core binders coat the surfaces of core boxes with a sticky film which prevents a perfect draw from the boxes. The amount of cleaning required depends on the core-sand mixture being used. In particular, the wetness of the sand influences the property of the sand to stick to core boxes and thus produce rough cores. As a rule, the lower the moisture content, the better the separation.

EFFECT OF PRESSURE ON CORE SURFACE

The greater the pressure applied in forcing the sand mixture into the core box, the more smooth will the surfaces become. Some mixtures flow readily into a core box and other combinations of sand and binder require considerable ramming to produce smooth surfaces. Also, the smoothness of the internal surfaces of a core box will affect surfaces of cores made in this box.

EFFECT OF GRAIN DISTRIBUTION

The distribution of grains of different sizes in a sand determines to a large extent the smoothness of cores produced with this sand. Smooth surfaces can be obtained readily when sands with small grains only are used in the core-sand mixture. The openings between large grains of sand cause the surfaces of cores to be rough. When both large and small grains are present in a mixture, the small grains tend to fill spaces between the larger grains and thus produce a smoother surface than could be obtained with only the large grains. In some core-sand mixtures, a finely divided material such as silica flour, rattler dust, or molding sand is added in an attempt to improve the smoothness of the cores. As the void space in a sand of uniform size may amount to 40 per cent of the total volume, a relatively large proportion of fine powder would be necessary to produce smooth surfaces.

If smooth surfaces were the only requirement of cores, the preparation of core-sand mixtures would be a simple matter. However, this is usually not the case. Cores must have sufficient permeability to permit gases, which are generated within the cores during pouring, to escape freely when metal is poured around them. Furthermore, all cores must have sufficient strength to withstand the forces to which they are subjected until the metal has solidified.

The permeability of a core is the measure of the resistance offered to the flow of gases through the core. This property depends upon the size and continuity of the openings between the sand grains. Cores made of sand having large uniform grains will have a higher permeability than cores made of sands having small uniform grains. The permeability of cores made from mixtures of large and small grains of sand approaches the lower values. Therefore, core sands must be selected to produce the necessary permeability for any given use.

EFFECT OF CORE STRENGTH

Cores must have sufficient strength after baking to retain the exact shapes into which they were formed until the metal has solidified around them. The strength required of a specific core depends upon its application or its position in the mold. A core must be strong enough to support its own weight, as well as to resist the buoyant effect of the liquid metal in which it is submerged. The strength of a dry sand core is determined by the kind and proportion of the binders used as well as by the sands from which the mixture was prepared. The presence of a finely divided material such as clay or silica flour, which is sometimes introduced to produce smooth surfaces on cores, lowers

the resulting dry strength, and additional binder must be supplied to overcome this effect.

CORE PROPERTIES TO PRODUCE SMOOTH SURFACES

The most desirable properties for dry sand cores are obtained when the core sand contains grains of uniform size and of sufficient fineness to produce the required smoothness on the surfaces of the cores. It is necessary to select from available sources those sands from which the most satisfactory combination of properties can be obtained.

Effect of Core Sand Mixtures

Campbell investigated the effect of core sand mixtures on the surface condition of castings. He prepared special dry sand molds and inserted in them oil-sand cores made from sand whose grain size was carefully controlled. He used washed and dried silica sand. Single grain-sized sands, all of which were retained on each of the 30, 40, 50, 60, 70 and 140 mesh sieves, served as base sands for his core mixtures. Each of these single grain-sized sands was mixed with raw linseed oil in the ratio of 1:50 with 4 per cent water. Cores were made and baked for 1 hr at 425 F (218 C) and after cooling to room temperature were placed in the dry sand molds. Gray iron, electric furnace steel and red brass were poured and the castings were allowed to cool to room temperature in the molds.

After removing gates from the castings, the surfaces were sandblasted and the specimens were then compared for surface finish. Campbell found that the surfaces of castings which were formed by cores containing silica sand that had passed a 20 mesh sieve and were retained on a 30 mesh sieve were very rough, while the surfaces of the castings poured in contact with cores containing 70 to 140 mesh sands were quite smooth. Variations in smoothness of the steel specimens were not as pronounced as was found with other metals. When brass was poured under similar conditions, the surface finish of the castings produced progressed from rough to smooth as the fineness of the sand used increased.

Effect of Bank Sand

Campbell also tested the effect of adding a bank sand containing rounded silica grains, the majority of which ranged from 40 to 70 mesh. Additions of bank sand to the extent of 0, 10, 20 and 30 per cent by weight were made to a silica sand and tested in the same manner as were the plain silica sands of a single grain size. The results showed that there was practically no difference in the surface smoothness of the resulting castings.

Effect of Hot Strength (Core Collapsibility)

A core possesses a certain degree of hot compressive strength at elevated temperatures at or near the metal pouring temperature providing the atmosphere around the core consists of the gases that the core liberates when it is heated. When these gases are trapped around core specimen in a dilatometer furnace, the test is said to be made under own atmosphere.

A core with a low hot strength will generally also show a quick core collapsibility under load at elevated temperature. When a core possesses low hot strength and quick core collapsibility, then the surface of the core becomes loose sand quickly after the metal strikes it and produces rough cored surfaces and may contribute to metal penetration and fissure defects.

Effect of Silica Flour

The effect of silica flour additions to core sand mixtures on the surface conditions of castings has been investigated and the conclusion has been reached that silica flour improves casting finish by reducing metal penetration. The addition of silica flour increases both hot strength and time of core collapsibility and thus is beneficial for cores used in heavy castings.

Effect of Iron Oxide

The addition of one to two per cent iron oxide to core sand mixtures for brass, bronze or iron castings is often found to improve the surface finish particularly in corners. The iron oxide with a silica sand forms an iron silicate which is sticky at elevated temperatures forming a bond of low strength but sufficient to hold the sand grains in place.

Effect of Fly Ash

Fly ash obtained from precipitators of power plant boilers improves the flowability of core sands. It may be used to improve the finish of cored surfaces. Fly ash increases hot strength and time of core collapsibility.

Chapter 19

ECONOMICS OF CORE PRODUCTION

INTRODUCTION

Maximum possible economy in a core room depends upon many factors. Some of the important ones are: location of core room in respect to other departments, such as receiving or molding; core room layout; selection of equipment; selection of raw materials; storage of raw materials; accurate dispensing of raw materials; scheduling of work; accurate cost system; selection of personnel; and efficient operation of equipment.

FACTORS TO CONSIDER IN CORE ROOM LAYOUT

In a discussion on core room layouts, N. K. B. Patch has well stated the problems involved. His material on this subject is detailed in the following paragraphs.

In the core room which supplies the foundry with the necessary cores obviously the construction of the room and its equipment influences the efficiency with which the whole plant may be operated. If the plant is to produce large castings requiring quantities of relatively large cores, then the amount of room necessary and the type of equipment for the production of these large cores must be borne in mind in designing the plant.

Furthermore, the location of the core room with respect to the foundry floors is an important matter to consider in the plan of the entire foundry. If the cores are to be small but in large numbers, as, for example, in the production of plumbing supply equipment, or small bearings and bushings, oven and core machine equipment is quite different from that where cores are to form the major part of molds. Such cores are of massive design, requiring large ovens in which to dry them and equipment capable of moving these heavy cores in and out of the ovens.

In other words, to plan an efficient core room that will supply a given foundry, the first consideration is "What type of work is the foundry to produce?" The second is "Where in the foundry is this work to be produced, and therefore where will be the most convenient place to locate the core room?"

In planning a core room, ample light and ventilation must be provided. The fumes from drying cores and waste heat from opening and closing core oven doors both influence the comfortable working conditions for the employees in this department. To secure maximum production, employees must be comfortable and their surroundings must be healthy so that they may lose the least possible time because of illness.

Floor Types

A number of types of floors have given satisfaction in the core room. Most core rooms are so laid out that all traffic is more or less confined to certain limited parts or areas of the floor space. These aisles or traffic-ways should be provided with floors that will withstand the abrasive effect of the fine grit that accumulates thereon, in spite of the frequent sweeping that such departments should receive regularly.

Therefore, a hard finished concrete is one satisfactory type of floor. A floor made of high grade paving brick is also satisfactory. Either of these types will require a minimum amount of repair. A good, tightly-laid, hardwood floor will serve very well but it will need repairs from time to time. While the first cost of such hardwood floors may be relatively low, when the repairs are taken into account, such floors become more expensive than either of the two former types.

Ventilation

Ventilation of the core room is something that should have the consideration of those who have studied the subject of ventilation thoroughly. Often obnoxious fumes and gases are present in the core room atmosphere. They are frequently heavy enough so that they do not rise up to ventilators in the roof. The increased weight of these fumes means that, as they cool, they separate from the rest of the atmosphere and fall back to the level of the working space, in spite of the updraft of the rest of the air in the room.

Illumination

Natural illumination is the best type. In spite of the best natural illumination, artificial illumination also must be provided, since many days are so dark that artificial illumination must be used. Since coremaking is work that must be done accurately, and also since employees may be hurt if they do not have adequate light to insure safe operation of the mechanical devices in the core room, the best artificial illumination available is the cheapest in the long run.

With the increasing number of types of lamps and illuminating units available today, the designing engineer who is planning a new foundry or is modifying an old one will do well to get the help of illuminating engineers. They are versed in the proper application of modern illuminating equipment and the measurement of available light. They can aid effectively in

planning artificial illumination equipment for the foundry and core room.

Locating the Core Room

A well planned core room is one in which the supplies are brought in with a minimum expense from the storage departments to a point where they progress, as they are fabricated, to that point where they become completely finished cores. This means that the core sands, core binders and other supplies should reach the core room at that point where the sand mixers are provided and from the mixers these compounded core mixtures should be fed with a minimum of labor and expense to the coremakers and their respective core machines. These latter should be located where they can feed their output of cores to the drying ovens without undue handling and with a minimum amount of delay and labor.

Selection of Equipment

Selection of equipment, such as core machines, core ovens, core cutting-off machines, etc., should be considered most carefully for there is a large variety of equipment. Each has its particular application where it can serve best. For example, in core ovens the drawer type is excellent for small cores and cores which dry rapidly. The car type is available for cores having large volumes that require extended drying time and which may be of such mass as to be cumbersome to handle. There are many core oven designs — some are highly insulated so that a minimum amount of heat is dissipated into the room in proportion to the amount of heat in the oven, and others are designed to give maximum circulation of heated atmosphere within the furnace as compared with those in which the circulation is simply that influenced by the temperature. Each has its good points. Obviously, the first cost of one necessarily differs from that of the others.

In the planning of a core room, first consider the kind of work the ovens are going to dry, and then plan for the oven which will handle this work with a minimum amount of labor cost, coupled with a low fuel cost for maintenance of the desired temperature. Sometimes the first cost of the equipment is so vital that one must compromise with the ideal, in which case it is well to remember that these compromises are possible from many standpoints.

As to the question of core machines, here also the kind of work to be produced decides what machine will most effectively produce the required cores. The modern mass production foundry depends on some type of a machine. Development of mechanical production of cores and molds has reached such a high degree of efficiency that no foundry can afford to be without some mechanical apparatus with which to produce cores and molds at a minimum labor cost.

The type of cores to be made should be studied and then plans made for the installation of that core machine which will make those cores with a minimum cost for labor and handling. Jarram roll-over machines have regularly given a high degree of satisfaction in the production of some cores. Machines designed to blow the sand into the core box are used today in the production of small cores, particularly in the production of valves, fittings and such small work, and the size of cores being produced by such machines is growing rapidly.

A large choice is available in these different machines and the engineer who plans a foundry will do well to investigate all different types before arriving at the final choice of equipment.

Compressed air is expensive to develop and consequently to waste it increases the cost. In the consideration of machines for making cores, the question of compressed air consumption is an important item in considering efficiency. Repair cost of such machines is also an important element.

The first cost of some second hand equipment may seem to be very economical and mean material saving in the initial expense, but repairs and maintenance thereafter may be such to more than compensate for any such initial saving. Where cars are to be used for carrying the cores in and out of the ovens, frequently the temperature is high enough to preclude any proper lubrication of the axles and the engineer will do well to choose that car that will give a minimum amount of trouble due to resistance of the movement of the car. This resistance is set up by poor lubrication, or poor design of the journals.

In some instances, it may be due to the fact that the car is working under conditions for which it was not designed. It frequently happens that the car type oven is used when in reality it is not best for the purpose. A unit which could be moved in and out of the oven on a jack truck or carried on an overhead trolley system would have given far more satisfaction, both as to economical operation and ease of movement.

It should be emphasized here that ease of movement is not only a saving in labor but frequently results in a material saving in cores, since it is not an uncommon experience to have cores broken or distorted in shape, thereby making them useless, because of the trouble in moving the core carrying equipment. A batch of cores destroyed in this way, because the core carrying equipment started suddenly or stopped suddenly, is a serious waste of labor and an expense that should be anticipated in planning the core carrying equipment.

Core Distribution

In planning the core room, it is also important to provide some method of economical distribution of the cores from the core room to the molders' floors. Core trays that are capable of being handled in multiples without danger or harm to the cores have proved to be an excellent step in the right direction. The transfer of cores to the molders on overhead trolleys also is proving satisfactory in some foundries where relatively heavy cores must be distributed.

If cores are to be delivered to the molders in the form of a complete assembly, it is particularly desirable that these assemblies arrive in units on trays that are designed to accommodate them without any danger or harm to the assembly. Where cores are to be assembled in the core room, the necessary department must be provided where such assemblies may be made and properly set in jigs that will insure the accuracy of assembly.

Core Treating Facilities

Many cores are treated with a wash of some sort, for

example, graphite or silica or some of the clay washes. In small foundries, washes are applied with brushes or the cores are dipped into a small bath of the desired wash. However, where cores are being made on a mass production basis, it is not an economical process to paint on the wash by hand. Furthermore, such washes, standing around in small containers, settle out of the water in which they are suspended and consequently the wash varies in the amount of dilution.

A good practice is to maintain the core wash in constant agitation after it has once been compounded in conformity with the desired formula by passing a jet of compressed air through pipes to the bottom of a tank in which the wash is contained. Such tanks should be located where dipping or washing of the cores may be made under the most economical conditions. For example, if the cores should be washed while hot, such a tank should be located where the cores may be dipped shortly after they have been removed from the oven.

Most foundrymen prefer to have the fins removed from the cores before they are dipped and, therefore, the planning of the core room should provide for a movement of the cores from the oven to the group who remove the fins and from them they should progress to the dipping tanks and then to the drying ovens for drying the wash after its application. From there, the cores should move to the assembly benches where they are assembled into the units for transmission to the molding floors.

A well planned core room needs the best kind of study and understanding of the product to be produced before any construction of the unit should be attempted. After such study, each piece of equipment should be carefully considered from all angles. The location of each piece of equipment should be planned to give maximum value from its service and use a minimum amount of labor in its operation.

SELECTION OF RAW MATERIALS

Raw materials selected for producing cores in a foundry are usually the key to success or failure. They should be selected, first, on the basis of suitability to perform the task at hand and, secondly, on the basis of cost. Thus, in selecting raw materials, one should first find the raw materials, such as the sands and binders, that will make satisfactory cores at the lowest cost per casting with maximum casting quality and then select the lowest cost combination.

Selection of Binder

The cost of core binders may equal the cost of sand in certain sections of the country where good sand can be obtained at a low delivered price per ton. In many sections, the cost of the core binder is substantially one-half the cost of the sand. Thus, it is apparent that the cost of the core binder is an important item. The cost of a core binder involves not only its initial price per gallon or per pound, but also the amount necessary to produce good cores with ease and its effect on the quality of the casting surface produced.

Selection of Core Sand

Sand is one of the most important items purchased by a foundry. It is important because of what it does, and not what it costs per ton of castings produced in a foundry. The cost of the sand in the bin at one foundry may be $3.00 per ton. This same foundry obtains 10 tons of castings per ton of core sand. In other words, such a foundry might produce $900 worth of castings with $3.00 worth of core sand.

This example is given to impress foundrymen with the importance of selecting core sand on an overall cost basis and not alone on cost per ton of core sand delivered in the bin. The core sand will affect the amount of binder required, green strength of a core mix, baking rate, amount of venting, core collapsibility rate, ease of core knockout, and casting surface.

To Save Oil Binder

Much thought is given in the foundry to saving oil binder in the core room. As a rule, great care is exercised to obtain the oil which will produce the best cores with the core room practice and equipment available. The producers of core oils frequently are accused of shipping an inferior grade of oil when the real cause may be a change in the core sand. For example, the fineness or the amount of clay substance may vary, causing a marked change in the strength of a core.

It is good practice to take great care in the selection of a core oil and to decide on one which will produce good cores at the lowest cost. However, foundrymen should not stop their efforts at this point. It is also good practice to place emphasis on the proper selection of a core sand that will give the strongest core. Thus, by combining the best core oil with a core sand that gives the strongest core, one is able to reduce the quantity of core oil required to produce the desired strength.

As an illustration, refer to the data tabulated in Table 19.1. The sand *A* has 0.2 per cent clay substance while sand *B* has no clay substance. The sand *A* has a 60 AFS fineness number as compared to 39 for sand *B*. Thus, sand *A* possesses a slight amount of clay and is finer than sand *B*.

TABLE 19.1 — ILLUSTRATING THE IMPORTANCE OF SELECTING SAND FOR A PARTICULAR CORE OIL

Fineness Data Sieve No.	Sand A Percentage Retained	Sand B Percentage Retained
6	0.0	0.0
12	0.0	0.0
20	0.2	0.0
30	0.4	2.0
40	1.8	52.4
50	8.6	25.4
70	37.2	12.0
100	46.8	5.6
140	4.8	2.2
200	0.2	0.2
270	0.0	0.2
Pan	0.0	0.0
AFS Fineness No.	60.4	39.0
Clay content (per cent)	0.2	0.0

Baking Time (hr)	Tensile Strength, psi (Baked at 400 F [204 C])	
1	133	170
1½	153	236.5
2	155	230
2½	150	225

Cores made from these sands *A* and *B* showed a large difference in tensile strength. Ratio of oil to sand was 1 to 100. Sand *A* required a 2 hr baking time to secure its maximum tensile strength of 155 psi, as compared to a 1½-hr baking time to produce a maximum tensile strength of 236.5 psi for sand *B*.

Considerable oil may be saved by using sand *B*, providing the casting surface is not of prime importance. Another factor to be considered is that sand *B* has less green bond than sand *A*, since it contains less clay substance and it also is coarser, which will reduce the green bond of the core sand mixture.

Green Strength

Green strength of a core mixture, sometimes referred to as the green bond, is greatly affected by the clay content, grain size and distribution of the core sand; the finer the sand, the greater the green strength. As the distribution of the sand grains spreads over more sieves, the green strength becomes greater. Thus, when a coarse-grained sand is selected or one with narrow distribution, consideration must be given as to whether the cost of adding green strength producing materials, such as cereal binders, is justified by benefits gained.

Baking Rate

The finer the core sand, the slower a core will bake. Thus, cost of fuel used to bake cores and cost of labor should be considered in selection of a sand.

Venting

The permeability of a core may be controlled by the fineness of the core sand. Since much of the venting of a core is accomplished by the permeability of the sand, the fineness of the sand selected should be considered in connection with the amount of mechanical venting that will be required with each grade of sand. Mechanical venting is a labor-consuming item. Therefore, sand requiring the minimum amount of mechanical venting should be selected.

Collapsibility — Knockout — Casting Surface

A core collapses in the mold because the heat from the metal travels through the pores of the sand in form of hot gases. Therefore, a core made with a high permeability sand will collapse and knockout easier than one made with a low permeability sand. A core made with a sand that contains a certain amount of clay substance will collapse more slowly and knockout with more difficulty than a core made with a sand containing less clay substance. Thus, the labor cost of knockout is affected by the core sand selected.

A core that collapses too slowly may cause hot cracks, tears or strains in a casting. A core that collapses too rapidly may cause rough surfaces, penetration or fissures. All these flaws increase cost and indicate why the selection of core sand is so important in the economical operation of a foundry.

STORAGE OF RAW MATERIALS

The loss of raw materials in a core room, due to inadequate storage facilities, amounts to an item that is worth considering. Dry core binders stored in wet or damp rooms deteriorate rapidly. Poor floors in storage rooms make it next to impossible to salvage binders spilled from broken containers. Core sand stored in the open is lost by being blown away and by being contaminated with other materials. Good housekeeping is necessary to avoid loss of raw materials.

DISPENSING OF RAW MATERIALS

Practically all the raw materials used in a core room may be purchased by the pound and they are most efficiently dispensed by the pound.

The practice of using dented volume measures for core binders at least encourages laxness in the workers. The amount of dry material that a volume measuring device contains varies considerably. The material may be packed or be loose. Weighing is the correct method for all dry binders and for the core sand.

Liquid binders may be dispensed accurately by clean volume measuring devices. Measuring sand by volume is very poor practice. The actual quantity of core sand contained in a volume measure may vary according to the manner of filling the container as well as because of a variance in moisture. For accurate dispensing of sand, it should be dry and weighed.

SCHEDULING OF WORK

The cost of producing cores depends on innumerable items. However, the costs may be controlled to a large extent by efficient scheduling of work in a core room. By careful study, one is able to group men and certain core sizes into efficient combinations. Fast workers are given light or semi-mass production work. The worker who lends himself to more muscular effort is given the heavier cores. Efficient distribution of helpers does much to reduce cost.

Where core binders are selected to produce cores that lend themselves to storage, it is a good plan to group several days' or a week's requirement of cores and make them at one time. Continual changing of core boxes is very inefficient. A little paper work in grouping core requirements together to give a semi-production volume run is one way to cost reduction in a core room. Making cores in small numbers, in many varieties each day, is easy on the planning effort, but costly.

CORE COSTS

Measurement for Costing

To know coremaking costs, some method must be used to provide accurate data on each operation. Time study is one such method.*

Many foundries think only in terms of pounds. In their thinking, they manufacture and sell by the pound. Generally speaking, this is decidedly incorrect. We all recognize the difference between the job with no cores and one that contains many. It is easy to see the difference between 100 lb poured into a casting that is solid and another 100 lb poured into a casting which is hollow. The cost to make one pound of hollow casting is more, for several reasons. In the first

*Much of the information on the application and value of time study in the core room is taken from a paper by Phil Carroll, Jr., *"Practical Time Study Measurements for Foundry Operations,"* AFS Transactions, vol. 49, pp. 519-523 (1941).

place, all of the cores must be made and set. Then, the mold itself will be substantially larger. That means more work and more space. The larger casting will be more difficult to shakeout. Certainly, the removal of the cores and rods will be more difficult and the chipping and grinding will probably cost several times as much as for the solid casting.

Time study is a practical method of determining actual manufacturing costs. It also provides the basis for incentive systems. Even if time study were never used for incentive purposes, in many foundries it would pay for itself if it served for nothing more than the development of the cost of the different types of castings. It would have economic value because it would help to produce the proper price structure to supplant the average per pound price used by so many foundries.

When the foundry wants to get a casting machined, it is quoted a price based on the amount of work done. Most machine shops obtain their basis for pricing from operation times, determined from time study. They follow this procedure whether the product is made from sheet, bar stock, or casting. Why should the foundry determine the price of the same casting on the basis of weight instead of work?

The labor involved in making the casting is oftentimes overlooked again in considering the probable scrap involved in producing a job. Experience would seem to indicate that this condition is further exaggerated by the greater tendency of the complicated castings with the high work content to become spoiled in pouring or cleaning. Foundries seem to have more failures in the complicated castings than with the simple ones. All of these points are raised to indicate, if possible, why the measurement of work done, regardless of the type of operation, is essential to proper pricing, particularly in the foundries where the pound instead of the piece has been the measure.

Productive operations should not be placed in the overhead simply because they cannot be measured. It should be apparent that operations performed directly upon the product should be classed as productive and measured by time study. With a measured labor denominator, secured by time studies, it is entirely possible to apply overhead directly to the product. The machine-hour rate method might be used to illustrate. In simple terms, we might say that a machine-hour rate is the cost to rent the machine for one productive hour.

When someone buys a casting, he should pay rent for the foundry facilities that were used to make the casting. The rent to be paid should be related to the time standards allowed to make the casting.

For simplicity, let us forget that the rent should be higher on the floor than on the bench. It ought to be higher on a big coremaking machine than on the floor. The point is that the rent should be applied in some proportion to the time required to process the casting or core and not on its weight. Here is where time study measurements might prove to be more valuable than as a basis for wage incentive. It is obvious, however, that incentive will provide the means for increasing earning capacity and thereby assure that anticipated cost determined from standards will have a greater probability of realization.

Other Controls

Time study measurement can be extended into other types of managerial control. Budgets can be established to measure the relation between the several elements of expense and the productive results in the foundry proper or in the core room. Just as there are classes of castings and cores, so there will be classes of expense that apply to them. These separations are refinements that are necessary when there is any substantial difference between the types of products turned out. Budgets can be made to assist in the control of costs, the proper allocation of expenses by lines of products, and also to serve as the basis for incentive rewards to those who show results in the control of costs.

Time study measurement of all types of work is exceedingly important if any attempt is made to plan production. Planning is vital. The scheduling of production without reliable time standards and incentives to insure their attainment is an impractical undertaking.

Planning is not very reliable if only a portion of the production is measured. It is essential that all jobs be measured, for otherwise there would be too many unknowns in the total plan. It is here that the predetermination of standards for the small lots and one piece orders is so important. Measurement of this type of work is practical to do by the standard data method. Time standards and incentives seem very essential to the greater utilization of skilled manpower and plant facilities. Both of these are extremely important.

In foundries, the practical application of time study measurement and incentive seems to have an additional element of importance. Foundries can further profit by the use of these in helping to correct certain misconceptions of costing. From the standpoint of the overall results, the use of labor measurement may prove to be more valuable from this standpoint of profit determination than from the considerations usually attributed to time study and incentive. There is no question that both can be applied to foundry work and meet all of the definitions of practical.

Because many foundries have a fairly high percentage of jobbing work, it is recommended that the measurement of labor be approached from the standpoint of the standard data method. This technique is not new. It is common sense applied according to the principles devised some 60 years ago by Frederick W. Taylor. But it is peculiarly adaptable to the measurement of nonrepetitive operations and for that reason will meet the foundrymen's specifications of practical.

Meagre tests show that incentive standards can be set from data for approximately one-seventh the cost to obtain standards by the direct time study process. Standards determined from the same basic data are sure to be very much more consistent over the entire range. Consistency makes for greatly improved industrial relations, and the improvement is extended because data standards can be explained to supervisors and workers alike.

By means of standard data, time study efforts are effectively applied again and again to measure small lots and miscellaneous work. This can be done practically because every job is a combination of element time standards which have been determined. Standards

TABLE 19.2 — CORE COST

Gray Iron	Malleable	Steel	Nonferrous
Direct Labor	**Direct Labor**	**Direct Labor**	**Direct Labor**
Coremakers	Coremakers	Coremakers	Coremakers
Core pasters	Core pasters and painters	Core pasters	Core pasters
Core assemblers	Core assemblers	Core assemblers	Core assemblers
Core gagers		Apprentices	
Indirect Labor	**Indirect Labor**	**Indirect Labor**	**Indirect Labor**
Sand handling and preparation	Sand handling and preparation	Sand handling and preparation	Sand handling and preparation
Core carriers	Core carriers	Core carriers	Core carriers
Core inspectors	Core inspectors	Core inspectors	Core inspectors
Core oven tenders	Core oven tenders	Core oven tenders	Core oven tenders
Core box tenders		Core box tenders	Core box tenders
Cranemen		Cranemen	Cranemen
Plate handlers		Core gagers	Core gagers
Cleaning cores	Cleaning cores	Plate handlers	Plate handlers
Wire cutters and straighteners	Wire cutters and straighteners	Cleaning cores	Cleaning cores
	Sweepers	Wire cutters and straighteners	Wire cutters and straighteners
	Clean up and disposal labor	Chainmen	
General Labor		**General Labor**	**General Labor**
Other labor not charged to direct labor		Other labor not charged to direct labor	Other labor not charged to direct labor
Core Sand	**Core Sand**	**Core Sand**	**Core Sand**
Cost of core sand, including freight, cartage, and unloading	Cost of core sand, including freight, cartage, and unloading	Cost of core sand, including freight, cartage, and unloading	Cost of core sand, including freight, cartage, and unloading
Core Fuel	**Core Fuel**	**Core Fuel**	**Core Fuel**
Cost of fuel for core ovens including freight, cartage and unloading	Cost of fuel for core ovens, including freight, cartage and unloading	Cost of fuel for core ovens, including freight, cartage and unloading	Cost of fuel for core ovens, including freight, cartage and unloading
Tools and Misc. Supplies	**Tools and Misc. Supplies**	**Tools and Misc. Supplies**	**Tools and Misc. Supplies**
Core oil and compounds	Core oil and compounds	Core oil and compounds	Core oil and compounds
Shovels, riddles and brushes	Shovels, riddles and brushes	Shovels, riddles and brushes	Shovels, riddles and brushes
Core wire and rods	Core wire and rods	Core wire and rods	Core wire and rods
Core plates and nails	Core plates and nails	Core plates and nails	Core plates and nails
Glutrin and molasses	Rosin and pitch	Molasses	Molasses
Rammers and rammer butts		Rammers and rammer butts	Rammers and rammer butts
		Air hose and fittings	
		Bar iron and steel	
		Chains and bolts	
		Silica flour, flour	
		Chills — Fireclay	
		Incandescent lamps	
	Bonding material	Lubricants — Lumber	
Tools, etc.	Tools, etc.	Tools, etc.	Tools, etc.
Patterns and Pattern Dept.	**Patterns and Pattern Dept.**	**Patterns and Pattern Dept.**	**Patterns and Pattern Dept.**
All core box making labor and materials for making, altering or repairing boxes, which are not chargeable to a customer. Core department charged on basis of pattern hours applied against coremaking, overhead included, to cover cost of patterns made or repaired for core dept.	Making, altering, or repairing core boxes when not chargeable to a customer.	Making, altering, or repairing core boxes when not chargeable to a customer.	Making, altering, or repairing core boxes when not chargeable to a customer.

Accounts Common to Costs in Core Department

The following accounts are common to all departments.

Gray Iron	Malleable	Steel	Nonferrous
Supervision	Supervision	Supervision	Supervision
Clerks	Clerks	Clerks	Clerks
Repairs to Buildings	Repairs to Buildings	Repairs to Buildings	Repairs to Buildings
Repairs to Equipment and Machinery	Repairs to Equipment and Machinery	Repairs to Equipment and Machinery	Repairs to Equipment and Machinery
Compensation Insurance	Compensation Insurance	Compensation Insurance	Compensation Insurance
Payroll Taxes	Payroll Taxes	Payroll Taxes	Payroll Taxes
Vacation Expense	Vacation Expense	Vacation Expense	Vacation Expense
Power — Heat — Light	Power — Heat — Light	Power — Heat — Light	Power — Heat — Light
Plant General	Plant General	Works Burden (Plant General)	Plant General
Maintenance	Maintenance	Maintenance	Maintenance
Total Fixed Charges	Total Fixed Charges	Total Fixed Charges	Total Fixed Charges
Administrative and Selling	Administrative and Selling	Administrative and Selling	Administrative and Selling

TABLE 19.2 — CORE COST (Continued)

Distribution of Indirect Costs to All Departments			
The core department overhead rate is established as a percentage of the core direct labor cost. Cost of producing core material should be omitted from overhead and computed on a weight basis and charged directly to each job on this basis.	Those items which generally follow core direct labor (such as pasting and painting, inspection and counting, wire cutters and straighteners) are distributed on that basis, and those items which generally follow weight of cores used (such as core sand, core fuel, sand handling and preparation, oven tenders) are distributed on that basis.	The core department overhead rate is established as a percentage of the core direct labor cost.	The core department overhead rate is established as a percentage of the core direct labor cost.

for new work can be predetermined and this process is improved when skilled mechanics assist in applying the data.

However, standard data is not a cure-all. It is only a tool — a means to an end. Its effectiveness results from its almost universal application toward the complete measurement of all work. When this is done, management can take advantage of the possible extensions of labor standards into other controls and thereby make the effects of good measurement more intensive and cumulative.

Distribution of Indirect Costs in the Core Room

Those items which generally follow core direct labor, such as inspection and counting, wire cutters and straighteners, are distributed on a basis of direct labor.

The total cost of baked sand, including the cost of sand, core oil and compounds, core oven fuel, sand handling and preparation labor, oven tending, etc., should be omitted from general overhead, computed on a weight basis, and charged directly to each job on this basis.

As far as applying total burden to the direct labor in the core room is concerned, it should in no case be a percentage of direct labor. It is highly important that only a small portion of indirect expense be distributed on the direct labor. The remainder of the core room expense should be charged in proportion to the weight of the core. By following such a procedure, a large core, with a small amount of direct labor, is charged as it should be. On the other hand, a small core, with a very large amount of direct labor, is not charged for material that is not used in making it.

The following is an example of what may happen in a foundry which does not properly distribute its core room cost. In one foundry a mold cost $3.00 to make. The foundry superintendent decided to revise the method of molding and use a cover core. In this manner, the cost of the mold could be reduced to $2.00. The core was made for about 20 cents and the superintendent figured that he had saved 80 cents on the molding cost. However, he forgot to figure how much the core weighed and when the final cost was ascertained, the job cost more to make with the cover core than it did without it.

Another illustration is of a foundry which was making a casting weighing 600 lb. The casting required a core weighing 4200 lb. In quoting on the casting, core weight was not considered. There was over $30.00 worth of material in the core alone. Naturally, the job was not a profitable one on the basis on which the cost had been estimated.

Core Room Cost Factors

The number of items involved in determining the cost of operating a core room, and hence of various core jobs made, are more numerous, in many instances, than some foundrymen realize. Some years ago, the Foundry Cost Committee of the American Foundrymen's Society began a study of the various cost factors involved in the production of castings and presented a report entitled "Classification of Foundry Cost Factors." Several pages of the report were devoted to a classification of factors which must be taken into consideration in establishing the cost of cores. Table 19.2 is taken from the report.

SELECTION OF PERSONNEL

The cost obtained in a core room depends to a large extent upon the personnel. All the supervision, from the person in charge of the core room to section supervisors or inspectors, should not be employed as such until each has definitely shown that he is capable and willing to be governed by team work. Any supervisor, be he ever so intelligent, who is not ready at all times to display teamwork by co-operating with those above and below him, is a liability and not an asset to the firm and his fellow workers. This same qualification applies also to every worker in the core room.

This emphasis on teamwork was not made to minimize such requirements as health, loyalty, ability and aptitude. Teamwork is emphasized for the personnel of the coreroom because the workers are continually asked to handle special requirements of the foundry.

Chapter 20

DEFECTS CAUSED BY FAULTY CORES

INTRODUCTION

The core department of a foundry should have a diligent core inspection division to avoid imperfect cores being delivered to the molding department. The inspection division also should report quickly any trend or appearance of faults so that proper corrective practices may be immediately instituted to reduce the number of defective cores made. A discussion of core flaws, with emphasis on their elimination, may encourage foundrymen to strive for better core practice in these plants. Some of the more common defects found in cores are described.

CORE FAULTS

Cores Off Gage

Cores are measured for size, particularly for height, in both the green and baked condition. Simple straddle gages generally are used with the ends of the gage resting on the core box or core drier. A core under gage in the green condition is easily corrected by increasing ramming, or by throwing sand on parting of the core at the section where core is under gage. This also can be remedied by increasing the green strength of a core mixture through the use of a cereal binder, small addition of clay substance, bentonite, molding sand, or the addition of a bank sand. Tempering the sand correctly also will prove advantageous. Turning the core over too hard will cause a core to sag. A sand of fine grain will increase the green strength, which tends to prevent sagging.

A core overgage in the green condition may be brought to gage by lowering the core strike-off bar or by reducing the amount of sand thrown on the parting of the core. A core undergage in the baked condition, when cores gage correctly in the green state, indicates that the core has sagged either during transportation in the green state or during the baking period. A tall core that sags during transportation generally possesses insufficient green strength. When only a few of these cores sag, it is generally found that some of the core sand mixture is tempered with insufficient water. A mixture on the dry side will sag during transportation. A core mixture that causes the core to sag or become undergage during baking generally is caused by using an excess amount of water. The core will sag substantially one hour after it enters the oven.

Sticking to the Box

Trouble is experienced frequently with core sand adhering to the core box, causing a rough pitted core surface. Certain core binders are tacky or sticky, and, in such cases, the addition of an oil, such as fuel oil, will cause the sand to free from the box. Adding the correct amount of water to a core mixture will enable coremakers to obtain cleaner lifts. A core mixture with excess moisture will stick to the box.

Spraying the core boxes with kerosene and lard oil, and then wiping excess oil from the box, proves very helpful. This operation may be performed at frequent intervals, for example, every twelfth core. The addition of kerosene to the core mixture is often beneficial.

Dusting the surface of the core box with parting improves the lift. The core box surface also may be painted with a lacquer containing a fine emery dust which causes the core box surface to become rough. A highly polished surface will cause more sand to stick than a moderately pitted surface. For this reason, cast iron core boxes sometimes are allowed to rust slightly before use. Heating the core box to a temperature in the neighborhood of 100 F (38 C) improves the lift from a core box.

Soft Rammed

A core may be rammed too soft to gage properly, or it may contain a porous section into which molten metal will penetrate. Soft ramming also produces cores with low core hardness and low hot strength. Increased strength also increases firmness of a core in the green state.

Rough Surface

Core sand will stick to core boxes due to excess moisture, cold core boxes, dirty core boxes, the use of a sticky core binder, or failure of the coremaker to clean the core equipment. The core equipment should be sprayed or wiped with a mineral oil after completing the day's production to prevent the core box from being coated with an air dried core sand layer.

Shifted Cores

The core inspection department should be on guard for cores that are shifted. Shifted or out of shape cores are due to careless baking of cores, rough handling in turning over operation, improper stripping of a core, inaccurately located guide pins, or incorrect equipment. Rough handling of the green core also may cause shifted or out of shape cores. Shifted cores also may be due to inaccurate pasting.

Loose Sand

Areas of loose sand on the surface of a core may be ascribed to using core sand containing frozen lumps or to the use of poor mixing equipment, with the resultant failure to thoroughly mix binder and sand. Another reason may be due to insufficient mixing time or failure to keep mixing and storage equipment clean.

Loose Surface

A core whose surface is coated with a layer of loose sand is a good source for dirt inclusions in metal castings. The surface of the core may become low in core hardness due to the use of insufficient moisture, overbaking or fast baking. The surface may be hardened by slowing baking and placing cores in an oven with reduced temperatures for the first hour. Rough core surfaces also decrease core hardness. Certain binders also may be added to the mix to improve core hardness, for example, resin.

Weak Cores

When one secures cores of variable baked strength, one should check into the method used to measure the sand and binders and into the equipment used in mixing. Exact routine procedures should be instituted and put into daily practice in measuring, mixing, ramming and baking.

The storage of the core sand also should receive consideration, for the amount of water contained in the core sand will affect the quantity of core sand supposedly measured, thus causing a variation in the amount of sand used per batch which affects the ultimate strength of the core.

Core sand that is mixed with an oil binder should be used as soon as possible. Storing mixed sand causes the water to evaporate and to migrate to the bottom of the pile. One should remember that the moisture content greatly affects the green strength, baking rate, core hardness, warm deflection, baked strength, and the amount of core sand per unit volume of a core or density.

Core Surface Peeling

Where the core wash peels off or cracks on a baked core surface, the core wash dries to a higher hardness than the core surface. The remedy is to either reduce the hardening of the wash or to increase the core hardness. The safest practice is to have the wash of a slightly lower hardness than the core.

Flexible Cores

A core that is too flexible or raggy indicates that the core binder contained in the core is underbaked, due to insufficient air in the oven, or insufficient temperature in the oven, insufficient time of baking, or using a binder that bakes too slowly.

Green Centers

The centers of large cores are frequently found underbaked, or green. In such cases the core binder, baking practice and equipment may be greatly aided by employing moisture control of the core mix. The use of any excess moisture will slow up the baking. The moisture must first be evaporated from the center of the core before the center will start to bake. In cases of cores having green centers, it often is advisable to reduce the moisture content of the mixture so that it is necessary to evaporate less moisture.

Perforated core plates will greatly aid in improving the baking of the core center. A further improvement may be secured by using a more open sand to increase the permeability of the core, which improves the air circulation within the core. Increasing the air circulation within the oven will improve the baking of large cores.

Where core oil is used as the binder, the core oil may be caused to bake faster by adding a polymerizable oil, a binder that hardens on cooling and does not require air to bake such as resin, or by adding an oxidizer which acts as a catalyst.

Cracked Cores

Cores baked in driers which hold the core quite firmly may show cracks in one or more sections of the core. It is now the opinion of some foundrymen that a core binder that has a low warm deflection (0.005 in.) will crack more easily than a core with a high warm deflection of, for example, 0.012 in. The warm deflection of a core will be low where a short chain of saturated hydrocarbons is formed. Cracks in cores seem to increase as the baking temperature increases where vegetable oil binders are used. A fast bake, due to either a fast baking oil or baking temperature, increases cracking.

CASTING DEFECTS DUE TO CORES

Casting defects due to the use of improper cores are varied and form a large portion of the flaws in castings. Where cores are used to form a portion or all of a casting, a profitable field lies in the general improvement of the core room practice to improve the quality of the casting. The profits secured by producing better castings with better controlled cores is aside from the profits secured by increasing the number of good cores

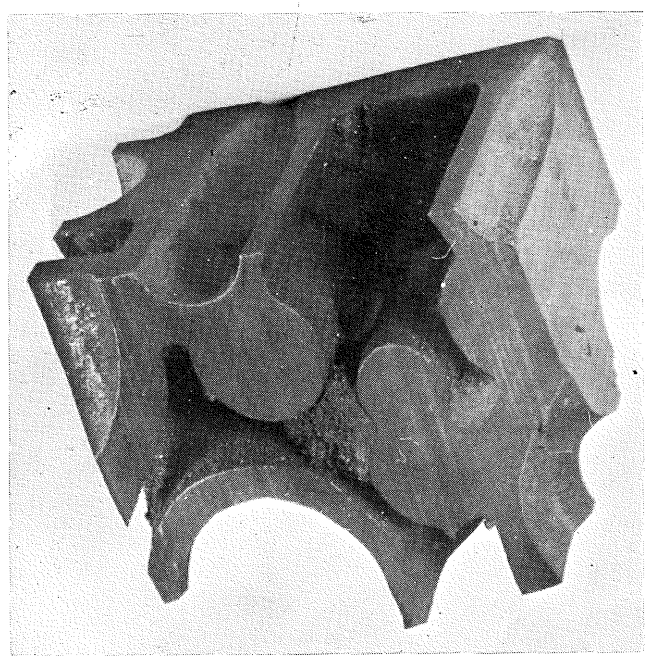


Fig. 20.1 — Casting showing metal penetration.

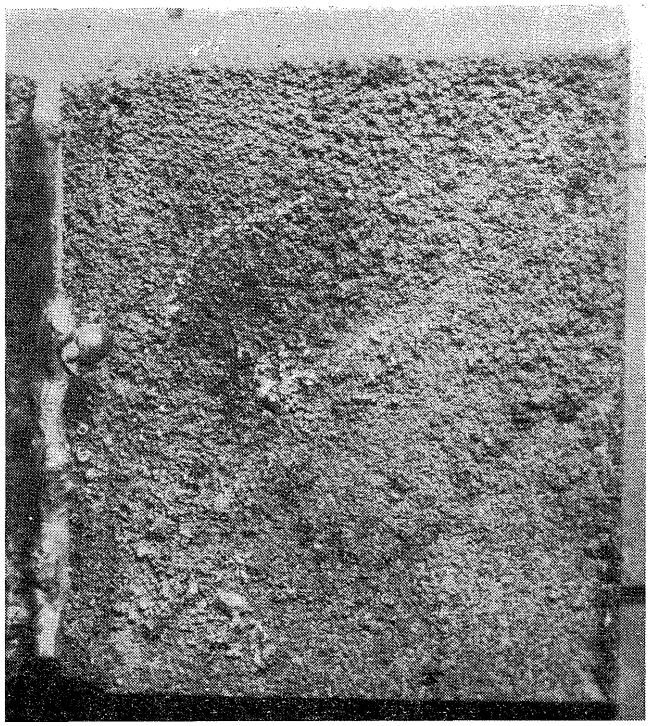


Fig. 20.2 — Penetration of metal due to porous surface of core.

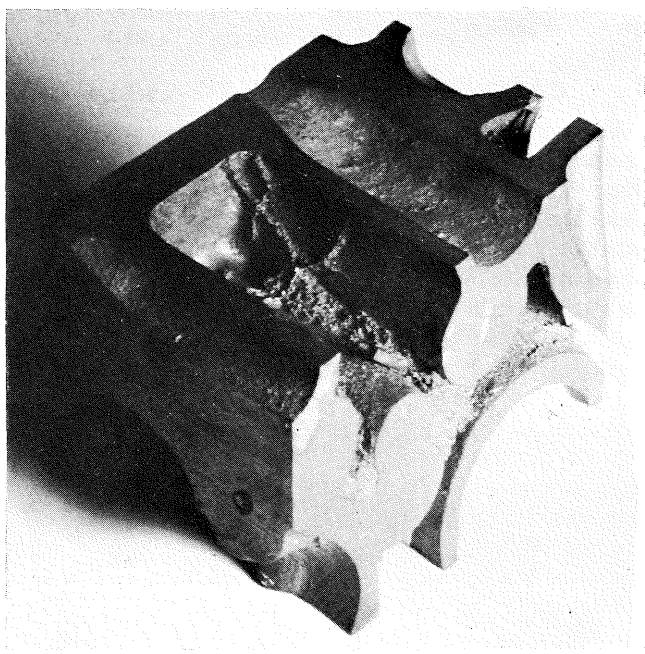


Fig. 20.3 — Fin on cored surface of casting.

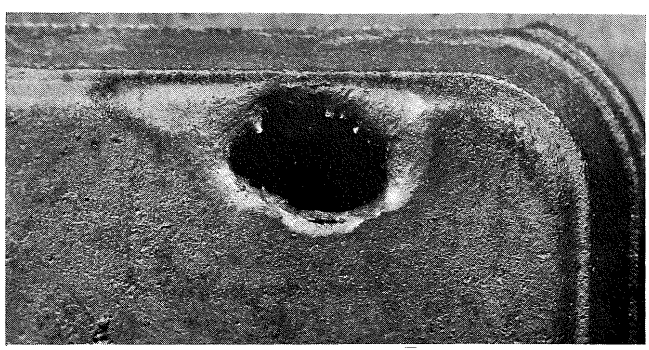


Fig. 20.4 — Core blow in casting.

produced per man as the result of improving conditions in the core room.

Metal Penetration

Molten metal will penetrate a core with a porous section such as that caused by poor ramming. Metal penetration caused by poor ramming is illustrated in Fig. 20.1. Metal penetration also may be caused by using a core sand of excessive coarseness or by a low sintering point sand. In the latter case, the remedy is obviously the use of a higher sintering point sand; in the former, the use of a proper wash to close up the openings between grains generally will overcome that difficulty.

In heavy sections of a casting, where the mass of molten metal is large in comparison with the volume of a core, one frequently experiences metal penetration throughout the core. In such cases, the core possesses insufficient hot strength which causes the core to collapse before the metal has solidified. The core becomes heated above the freezing temperature of the metal which allows the molten metal to penetrate into the small pore space of the core (see Fig. 20.2). Wrapping the core in asbestos paper is one method of overcoming this difficulty.

The hot strength of a core may be increased by the addition of iron oxide, molding sand, clay, bentonite, fines, silica flour and by using a fine core sand.

Fissures

A casting flaw found on cored surfaces, which proves very vexing to foundrymen, is the fault known as fissure, fin or nigger wool. This defect is shown in Fig. 20.3. It usually occurs in sections where the core is subjected to a considerable amount of heat, perhaps near corners. Some feel that the defect is caused by high expansion of the core. It is true that cores expand a varying amount, depending on many factors, such as the hardness, fineness, etc. The expansion may be as low as 0.001 in. per in., or as high as 0.030 in. per in. of the core. The atmosphere in which the core is immersed will influence the rate that the core binder burns, thus influencing the rate of expansion. From comparison between expansion test and core mixture producing fissure defects, one is not always able to find a definite relation.

A correlation of core collapsibility of mixtures producing, and those not producing, fissure flaws indicates that the rate of core collapsibility is the best explanation. A core that collapses in 3 min under test will produce fissures in engine block castings while a core that collapses in 7 min will be free from fissure defects.

Core Blow

A core blow, Fig. 20.4, is formed before the molten metal solidifies due to a greater gas pressure within the core section than exists on the outside of the core. The outside pressure is equal to the ferrostatic pressure of the layer of molten metal lying on the core at any particular section of the core and the gas pressure at the mold surface. The majority of core blows are caused by insufficient venting of a core within the core itself or vents through the mold to the atmosphere. Excess core gas may be formed by underbaked cores or

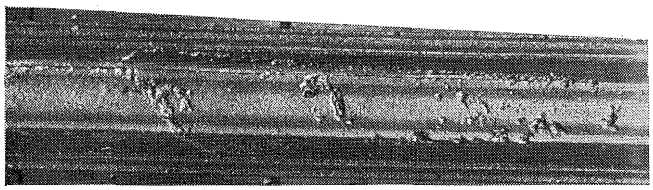


Fig. 20.5 — Core sand inclusion on surface of casting.

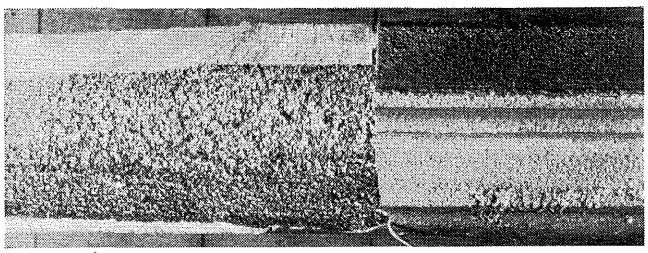


Fig. 20.6 — Core raise on casting.

by the use of an excess amount of binder. A sagged core vent may obstruct the passage of gas and cause a blow.

Green core paste at the parting of the core, or actually in the vent of the core, has caused many scrapped castings due to a core blow.

Core Sand

A casting disfigurement may be caused by loose core sand on the surface of a core, or fins at parting of the core, or loose core sand in restricted parts of the core which has not been removed by the core finishing department. A core sand inclusion is illustrated in Fig. 20.5. The casting has a scattered indentation.

Core Raise

A section of a core or the entire core may raise for a number of reasons. A core raise is illustrated in Fig. 20.6. Note that the upper section of the tube section of the casting has been virtually cut off due to the core raising. A core which is held in place by chaplets may raise where the chaplet stems are of insufficient size; where chaplet height, chaplet supporting post, or flash are incorrect; or where the chaplet is set into the pattern and the molder may not have inserted the chaplet the complete distance.

Pouring the casting with hotter iron than normally used will cause chaplets to burn up too fast and allow the core to raise. Improperly adjusted chaplet lifting mechanism may also cause the core to be held too high in the mold and cause a core raise.

Soft cores that bend upward between chaplet supports or allow chaplet to penetrate into the core surface may cause a core raise. An under gage core will allow the core to raise where it is held down with core prints.

Core Down

A core which is pushed too low into the drag portion of a mold will cause a core down deformity. A common reason for this fault is pinching the core too much between the cope and drag chaplets. When the drag chaplet is subjected to excessive pressure due to using an oversized core, oversized chaplets, poor chaplet gages, or long flash chaplet posts, the core is pushed down. The drag chaplet will soften first from immersion in the molten metal and become shorter, allowing the core to settle down.

Core Shift

A core may shift in a mold if it is not securely held in place by proper core prints and properly loaded chaplets. Another reason for shifted cores is poor core setting where the cores were never correctly centered in the mold.

Agitation or Scars

A scar on a thin walled casting may be formed by core gas agitating or warping the molten metal as is shown in Fig. 20.7. Odd as it may seem, a core of high permeability in a shallow mold may actually cause this defect. The high permeability of the core causes it to burn fast, and forming much gas quickly which cannot be all taken off by the vents at low pressure. The result is that metal is disturbed by gas pressure. A lower permeability core will burn at a slower rate and form less gas during the pouring operation.

Core Buckle

A core may buckle similar to a buckle in molding sand. A section of the outer surface of the core around $\frac{1}{10}$-in. in thickness expands and peels off in a V-shape, forming a cavity behind which molten metal will flow. When outer surface of the shell of a core is greatly different in hardness, a buckle may form.

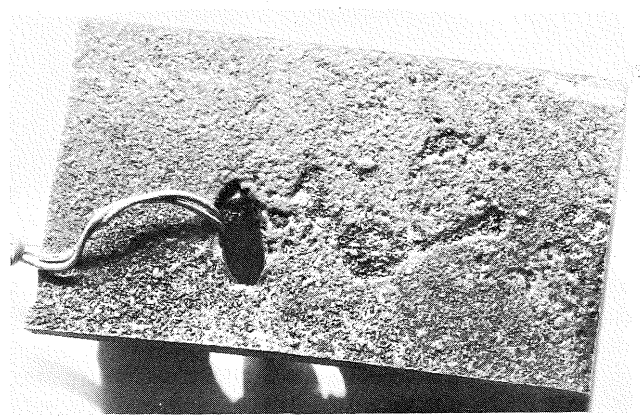


Fig. 20.7 — Casting defect caused by metal agitation.



Fig. 20.8 — Core buckle on casting.

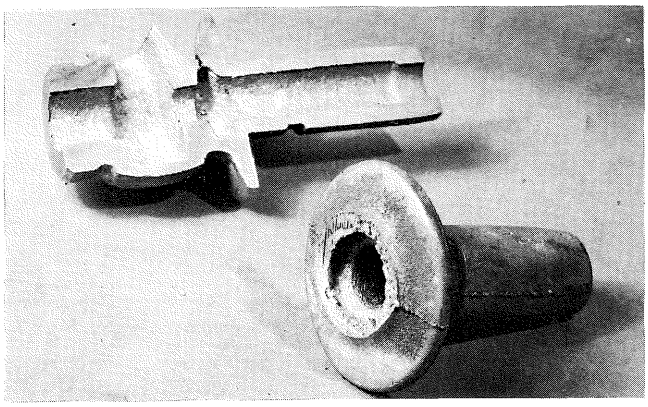


Fig. 20.9 — Hot tear in a brass casting.

Core Scab

A cored surface may also show a scab deformity. This seems to form in cornered sections of a core and on cores that have an exceedingly hard surface, like those produced with a strong, oil-bonded sand with a high moisture content.

Core Peeling

A blemish which appears at times on cored surfaces of castings is a rough and raised section of metal. It is generally raised only $\frac{1}{10}$-in. A defect of this kind is shown in the right hand section of Fig. 20.8. The core may peel or flake off due to the core surface softening by moisture absorption or by applying a very hard core wash on a softer core.

Hot Tears

Hot tears, due to failure of core to collapse in time to accommodate shrinkage of metal, may be found in all types of metals, whether ferrous or nonferrous. For light-sectioned castings, core collapsibility may be too slow, due to the use of a sand with an excessive amount of binder. This is the cause of the hot tear of the brass faucet casting shown in Fig. 20.9.

The core collapsibility is generally used as an index for nonferrous, malleable and gray iron cores. For steel cores, the cores collapse more slowly as a rule and will support a hot strength load so that the hot strength test is used as an index. As an example, a core with hot strength of 68 lb at 2500 F (1371 C) caused hot tears on steel valve castings. When the hot strength of the core was reduced to 17 lb for heavy valve castings and to 5 lb for light and medium valve castings, the hot tears disappeared.

Core Wash

A core will wash when the core surface collapses too fast, or in the case of heavy metal sections, when the hot core strength is low. The application of a good core wash on the core surface at the gate area is frequently practiced.

Chapter 21

SHELL CORES

INTRODUCTION

The application of shell molding technique in the core room offers a good way to improve core production. Dollar savings can be secured in most cases. A typical shell core with casting produced is shown in Fig. 21.1.

The quantity of core sand used for a given casting is reduced from 25 to 50 per cent when shell cores are employed. The floor space required is also reduced. Cores may be made close to the molding area, reducing losses and transportation cost.

Since the cores are hollow, no core vents are required. Cores are formed and hardened in the core box. This allows for core contours that reproduce the accuracy of the core box. Pasting of core halves and fins are minimized since most of the cores are made in one piece.

The advantages offered by shell cores can be summarized as follows.

(1) Adequate venting with finer sands.
(2) Better casting finish.
(3) Faster production.
(4) Less weight, easier handling.
(5) Lower cost.
(6) Made as required, no storage.
(7) Excellent storage stability if required.

THE SHELL PROCESS

The shell process was developed by Dr. Johannes Croning of Hamburg, Germany, in 1943. It was buried in the archives of the German Patent Office and kept secret by Dr. Croning and his associates until 1947 when it was uncovered by U.S. Government Office of Technical Services investigators and revealed to the U.S. public in a PB Report No. 1168.

In its infancy, the shell process or Croning process as it was then known, was limited to shell mold production. The mixture made was a simple mechanical mixture of sand and powdered resin suitable for dump box operations, but unsuitable for blowing purposes due to the resin segregation that took place in a core blower.

The shell process aroused considerable interest based on the fact that the process presented tremendous possibilities towards complete automation of foundry operations.

The shell process was not a foundry cure-all. It was soon discovered that shell molds had some undesirable characteristics very difficult to overcome and that the production of good castings could not be predetermined by the excellent appearance of the shell mold. The major difficulty was in the dimensional instability of the mold in the presence of molten metal. Fortunately, it was also found that with proper pattern design, appropriate gating and risering, specific sand particle size, and various additives, the undesirable characteristics could be overcome and excellent castings produced.

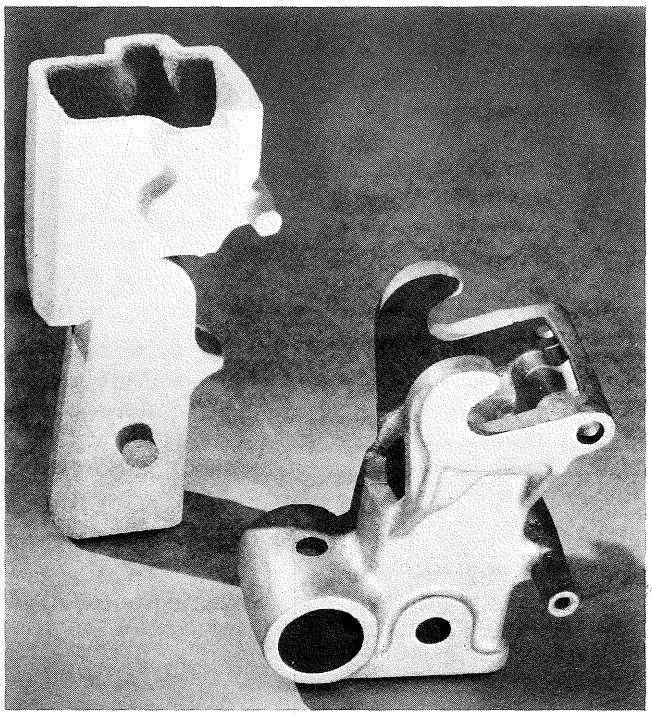


Fig. 21.1 — Typical shell core and casting.

In order to overcome the segregation difficulties in blowing operations, sands were coated with resin solutions and considerable progress was made in adopting resin coated sands to shell core production. A major breakthrough came about as a result of Fitco's development of a coating process which incorporated metallic soaps as lubricants. U.S. Patent No. 2,706,163 was issued to Chester W. Fitco and assigned to the Arthur J. Schmit Foundation.

The incorporated lubricants permit high flowability of the resin coated sand producing denser dumped or

blown cores or molds which result in increased strength properties. The higher strength obtained permitted a reduction in the amount of binder used and its corresponding cost.

The advantages offered by resin coated sand over dry mixes other than blowability are listed.

(1) **Shell Molds**

(a) No dust.
(b) No segregation.
(c) More uniform structure.
(d) Lower material cost.
(e) Minimum lubrication of pattern.

(2) **Shell Cores**

(a) Better venting.
(b) Better casting finish.
(c) Faster production.
(d) Less weight – hollow cores.
(e) Minimum lubrication.
(f) No dust.
(g) No segregation.
(h) Lower cost.
(i) Less handling.

With the development of a more suitable coated sand and lower material costs, a new and aroused interest resulted in a further development of more suitable equipment for large scale production of these sands. These improvements came about in the following order.

(1) Addition of lubricants resulting in free-flowing properties and higher densities.

(2) New and improved sand coating production equipment.

(3) Powdered resins and resin solutions developed to satisfy the industry's requirements.

(4) A solvent-free, hot coating process developed.

(5) Various methods of sand preparation were further improved.

The various types of equipment as used in the industry made some forms of phenolic resin preferable. Basically, most all resins are similar. They differ in that one is a flake and another may be a resin solution, a powdered resin, or a resin solution commonly referred to as water-borne and especially made for the hot coating process.

The base resin, as a flake, in the form of a resin solution or a powder may be, in some cases, exactly the same. The difference that exists in various resins of the same type, for example a flake, are in the phenol-formaldehyde ratio, the type of catalyst used, its melting point and its viscosity at 257 F (125 C) usually referred to as IPF or Inclined Plate Flow. Solutions will vary accordingly and, in addition, they may vary in resin content and the type of solvents used. Powdered resins will vary in the same manner as the flake type and, in addition, they may vary in the amount of hexamethylenetetramine in order to obtain the most desirable degree of cure.

The various types of phenolic resinous materials produced for foundry use can be classified as follows.

(1) **Powdered Resins**—Used in dry mix operations. The phenolic resin used is a two-step type with hexamethylenetetramine accelerator added mechanically. The hexa content will vary from approximately 10 to 20 per cent depending upon degree of cure desired.

Powdered resins used in dry mixes do not contain any added wax or lubricants. These additives interfere with proper bonding of sand particles and result in considerably lower tensile strength.

(2) **Powdered Resin**—Used in sand coating operations. Resin used is a two step type with hexamethylenetetramine and lubricant added mechanically.

(3) **Resin Solutions**—Used in cold coating operations and in most cases, in conjunction with hot air systems to speed up the drying cycles.

Resin solutions are composed of two step novolak type resins in solvents such as alcohols or ketones, or a mixture of solvents and water.

(4) **Flake Resin**—(formerly crushed). Flake resins are of the two step type and commonly referred to as novolaks. Flake resins are used in hot sand coating operations and require the addition of hexamethylenetetramine. Flake resins generally contain the necessary wax or lubricant to produce maximum properties in the coated sand.

(5) **Water-Borne Resins**—Liquid. Resin containing a minimum amount of volatile solvent and specifically designed for hot coating operations.

Water-borne resins are usually combinations of two step and one step resins and possess slow thermosetting properties which are insufficient for good shell mold operations. Additions of hexamethylenetetramine are necessary to produce desired speed of cure.

RESINS

The term resin covers a very broad variety of natural and synthetic materials, many of which are used in or as binders in the foundry industry.

For example, shellac has been used as a coating on patterns and rosin, casein, pitch, gilsonite and various petroleum polymers are used as fortifying agents in core oils and facings.

The second class, or synthetic resins, covers a large group of materials which are also divided into two classes: thermosetting and thermoplastic. The thermoplastic resins are, by themselves, unsatisfactory for foundry applications.

The use of thermosetting resins and, principally, the phenol-formaldehyde and urea-formaldehyde types have made great strides in the foundry industry primarily as core binders. Other synthetic resin binders such as polyester resins are used to produce core driers for dielectric machines, epoxy resins as a pattern material, and furfuryl alcohol resins as cold set binders. The phenol-formaldehyde resin, the workhorse of the plastic industry, is used exclusively in making shell cores by the shell or Croning process.

Thermosetting resin binders were first introduced to the foundry industry in 1930 by Harry M. Dent and Frank W. Less of what now is the Durez Division of Hooker Chemical Corporation.

U.S. Patent No. 1,777,998 was issued in 1930 covering thermosetting resins as core binders. This introduction covered phenol-formaldehyde resins and it

was followed by an introduction of urea-formaldehyde thermosetting resins in 1942.

Phenolic resins used were of the water soluble or emulsified type and in combination with cereal flour, replacing almost completely the oil binders. Phenolic resins substituting for oil required the same operating procedures. The major advantage over oil was in their speed of cure which shortened the baking cycle by 75 per cent.

The urea-formaldehyde resins requiring an acid accelerator were also used in combination with cereal flour and cured in continuous dielectric ovens.

The major desirable features of these two systems were as follows.

Phenolic	Urea
(1) Fast cure speed.	(1) Fast cure speed.
(2) Nitrogen-free.	(2) Dielectric curing.
(3) Good moisture resistance.	(3) Low cost.
(4) Better heat resistance, more suitable for iron and steel.	(4) Poor heat resistance, more suitable for aluminum and bronze.
	(5) Good storage stability.

The disadvantages are listed below.

Phenolic	Urea
(1) Limited storage stability.	(1) High nitrogen content — unsuitable for low carbon steel.
(2) High heat resistance — makes shakeout in aluminum and bronze difficult.	(2) Low heat resistance — unsuitable for iron and steel general use.
	(3) Low moisture resistance.

Addition of powdered phenolic resins to sand core oil mixtures tends to speed up the oven curing cycle of oil-bonded cores.

SIMPLE CHEMISTRY OF PHENOLIC RESINS

Resinous products obtainable from phenol and formaldehyde reactions, range from water soluble liquids through solvent solutions to brittle solids and powders. They can be converted from the fusible state in which they are sold to an insoluble and infusible state by use of heat, or heat and an accelerator.

Accelerator

Although it is generally known that hexa produces thermosetting characteristics, the effect of various amounts on the physical characteristics of molds and cores is sometimes either misunderstood or ignored. Errors can be made which will cause considerable difficulty.

The phenolic resins used in shell molds and cores are called two step resins. The two steps are comprised of the following.

(1) The production of the base resin, which is generally referred to as a novolak. This resin does not have thermosetting properties. In many ways, it resembles resin in that it may be melted and solidified repeatedly. It is supplied as a solid or a solution.

(2) Addition of hexa, which is a mechanical dispersion. Hexa is a reaction product of ammonia and formaldehyde. When it is added to a phenolic resin and heated, a reaction takes place between the resin and the formaldehyde in the hexa. The ammonia acts as a catalyst for this reaction and is gradually liberated as free ammonia.

The following is a brief review of phenolic resin chemistry.

Raw Materials and Structural Components

The raw materials are phenol and formaldehyde. In addition, an acid or a base is necessary as a catalyst. Ammonia and primary or secondary amines, in addition to serving as basic catalysts, can form intermediate reaction products with formaldehyde or with formaldehyde and phenol. The chemical groupings or building blocks important to the chemistry of phenolic resins can be accounted for in the following manner.



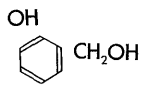
phenol

HCHO

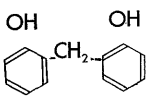
formaldehyde

NH_3

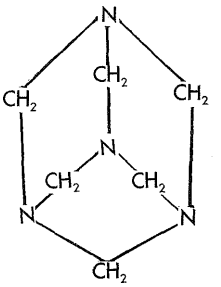
ammonia



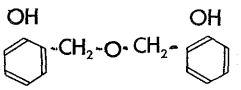
methylol group or phenol alcohol



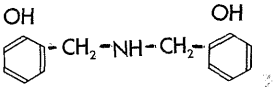
methylene link



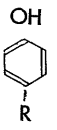
hexamethylenetetramine (hexa)



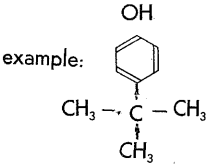
dibenzyl ether group



dibenzyl amine group

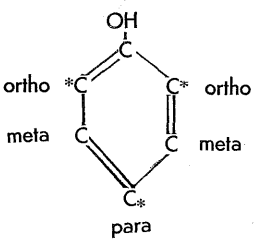


R is symbolic of the many substitution groups that may be attached to phenol

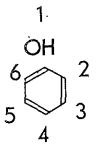


para tertiary butyl phenol from phenol and isobutylene

Structurally, resin consists of a benzene ring with one hydrogen atom replaced by a hydroxyl group. The presence of the hydroxyl group enhances the reactivity of the two ortho positions and the para position.

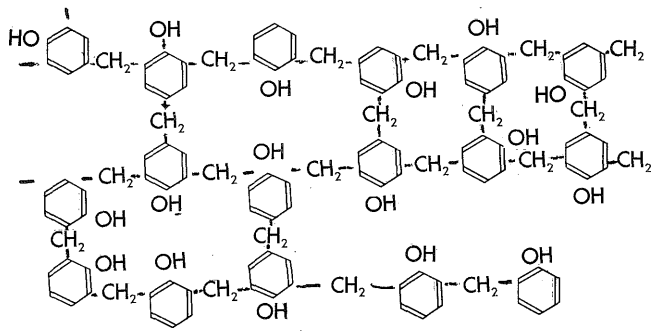


or



Having three reactive positions, phenol can be crosslinked with methylene groups, derived from formaldehyde, to form a three dimensional network. In

this form, the polymer is infusible and insoluble and may be referred to as the set resin.



Note that the structure of the cured resin is well crosslinked but is not necessarily uniform in arrangement.

The ratio of methylene to phenol groups determines the degree of crosslinking or the cure. Ideally, 1.5 methylenes per phenol would provide maximum set while 1.0 methylenes per phenol would result in a soft cure. While other factors may influence the cure, the above provides a fair estimate of what may be expected of a given resin formula.

Types of Phenolic Resins

In polymer chemistry, phenolics are referred to as condensation polymers. This means that an increase in molecular weight of the resin is accompanied by the elimination of some low molecular weight byproduct such as water. It also means that the increase in molecular weight is a step reaction.

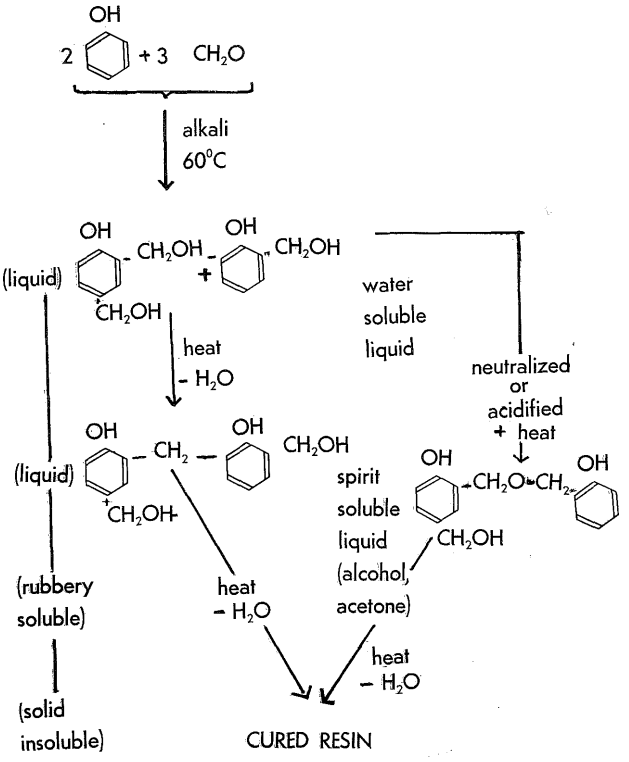
Phenolic resins can be divided into two groups: one step and two step types. The term one step means that the resin formula contains all of the formaldehyde necessary for conversion to an infusible state and that a basic catalyst has been employed. The term two step indicates that a novolak resin has been prepared by an acid catalyzed reaction of phenol and that the addition of a curing agent, such as hexa, is necessary at a later stage to produce thermosetting properties.

Water soluble resins are essentially one steps in which little or no advancement has taken place after the initial reaction between the phenol and formaldehyde to form phenol alcohols.

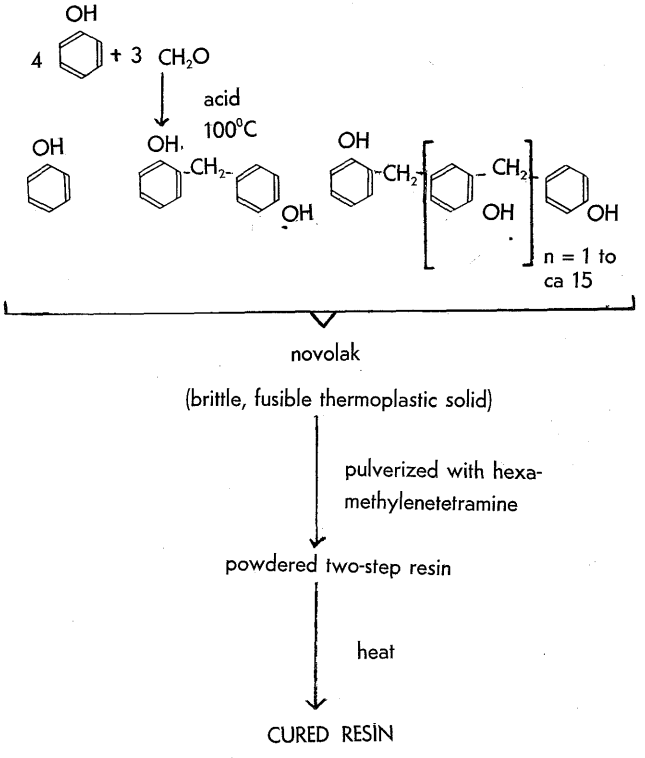
Water soluble resins — the term water soluble is a misnomer. Phenolic resins are not water soluble. They are in reality initial reaction products between phenol and formaldehyde producing phenol alcohols which are water soluble. Phenol alcohols resinify rapidly and the resinification is accelerated with temperature. As resinification takes place, the free phenol alcohol acts as a mutual solvent between the formed resin and water present. When resinification increases, the water tolerance decreases and gradually a point is reached where the amount of phenol alcohol present is insufficient to promote solubility between the resin and water, and as a result the water tolerance is reduced to a point where a separation of resin and water takes place.

REACTIONS THAT FORM TYPICAL PHENOLIC RESINS

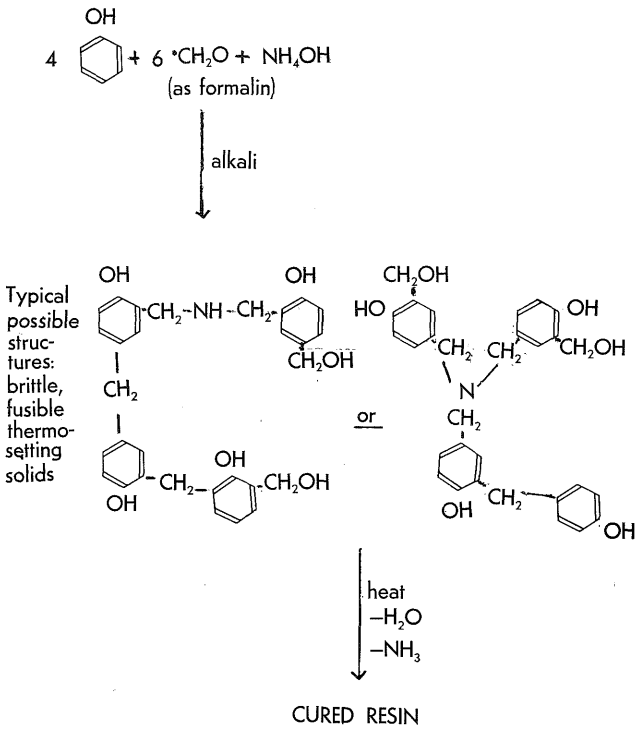
Water Soluble and Spirit Soluble Liquid Resins



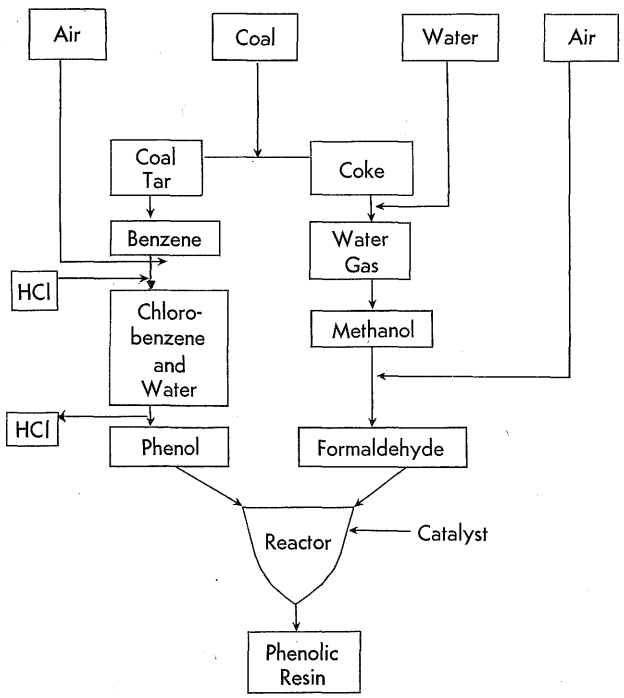
Novolak and Two Step Resins



Brittle One Step Resins



FLOW DIAGRAM FOR PHENOLIC RESINS



SANDS FOR SHELL CORES

The range of sands being used in this process is so wide that one could not set up any limiting boundaries. Table 21.1 sets forth the several sands commonly used.

Highest tensile strengths are obtained from a round, clay-free, grain having a microetched surface and a normal 3 or 4 screen distribution. Best blowability and flowability are also present, as is maximum density. With this comes high expansion of quartz and subsequent thermal instability. Intricate, hard to blow cores, those of essentially round cross-section and completely enclosed cores are usually made of such sands. Grains can be too smooth, as witnessed by the inability to keep a coating on glass beads.

A sand coated with 3 per cent resin showed the following resin distribution. The coarsest 64 per cent of the sand carried 2.01 per cent resin, the intermediate 28.4 per cent carried 3.9 per cent and the finest (−270) 7.4 per cent carried 8 per cent. Thus, bank sands can be used at much lower resin contents by blowing out most of the very fine silt and clay which might only amount to 2–5 per cent of the total sand.

Sands having 85 per cent on one screen are being successfully used, as are 6 more screen sands, for specific uses.

Very angular sand is used to obtain minimum density and expansion. If they are clean, 4 per cent resin is adequate. If they are dusty, as in the case of olivine, more resin is required to be able to handle the cores. Angular sands have higher permeability than round grains, due to the lower density which also causes lower strength.

Sands may have objectionable films on them as in the case of some flotation-separated zircons. Certain coastal areas yield zircon with a natural coating of organic, marine animal grease called chitin. These, and probably some silica sands, will improve by thermal reclamation. It is impossible for a 3 per cent zircon sand to increase in cold tensile strength from 300 to 900 psi by having been burned off. Some suppliers have offered a calcined zircon sand.

The best way to reduce core gas from a shell core is to use a sand that has a low resin content and/or is very coarse. In one case, a 26 AFS St. Peters sand blast sand was required to make a difficult water jacket core in aluminum. It carried only 2½ per cent of resin for 400 psi core tensile and 450 shell permeability. The core produced a textured, pebbly surface, but no penetration. Other cores, such as radar wave guides may require 180 AFS fineness sand with hand-rubbed coatings as well.

While the accent is on finer sands for shell molding, more attention must be paid to permeability on shell cores, which require in many cases, coarser sands. Casting finish depends a great deal on gating, pouring, venting, reasonable compaction, etc., so that fineness as such, is not the only important contributor to finish.

Obviously, one will try to use the nearest, cheapest sand. If a reasonable resin content and coating procedure can be worked out to give acceptable castings, no further search is needed. Sometimes, a blend of the cheaper sand, with 20 per cent or more of a more suitable sand will represent the best compromise.

Shell molds and large, flat cores tend to require angular and/or low density mixes, while internal cores tend to require the lower gas pressures and better blowability obtained with low resin, round-grained sands.

Any excess moisture in the sand over the usual 0.2 per cent residual will interfere with the coating. A

TABLE 21.1 — SOME SANDS USED FOR SHELL CORES

Source	AFS No.	Shape	Color	%, Quartz	%, Retained On 50	70	100	140	200	270	Pan	Clay
Wedron, Illinois	108	Rounded	White	99.9+		0.4	28.4	44.8	18.8	5.0	2.6	0- .2%
Millville, New Jersey	124	Sub-angular	White	99.9+		0.3	15.3	41.6	31.6	7.8	3.4	0- .2%
Mill Creek, Oklahoma	87	Rounded	White	99.9+	0.4	7.4	45.0	36.3	10.4	0.1	0.4	0- .2%
Overton, Nevada	124	Rounded	White	99.0+			0.2	8.4	50.7	28.2	6.7	0- .2%
Vassar, Michigan	83	Sub-angular	Tan	93	0.7	13.9	50.8	23.8	9.5	1.9	0.5	1-3 %
Oceanside, California	70	Angular	White	87	7.4	31.5	33.7	15.1	5.5	0.7	0.1	0- .2%
Providence, R.I.	141	Sub-angular	Buff	97		3.0	15.4	26.8	29.6	13.4	11.2	1-1.5%
Australia, Zircon	118	Rounded	Gray	99.5 $ZrSiO_4$		0.2	3.2	51.9	43.2	1.5		None

reddish cast to the sand sometimes results, indicating inferior strengths. Sand must be below 100 F (38 C) consistently, for cold or warm coating.

Shell Sand Preparation

Dry Mix

Dry mixes are prepared by mechanically mixing dry sand and powdered resin. The mixing is usually done in a slow speed sand mixer, cement mixer, cone blender or "Y" blender.

An average clean silica sand requires 5 to 7 per cent resin for a dry mix dump core or mold. Not more than 0.2 per cent kerosene is added first and mixed until dispersed, which is 30 to 60 secs, depending on the mixer. The resin is added and mixed 15–20 min in a blender or tumbler mixer. Vertical wheel mullers take around 7–9 min. If a high speed muller is used, 5 min or less should be adequate. Occasionally, as much as 10 per cent resin is used for special jobs. The resin powder usually has the hexa and wax in it, as purchased. Bank sands will require 2 per cent more resin for equal strengths unless specially prepared. Overloaded mixers take disproportionately longer times.

The dry mix can be overmixed or overmulled, resulting in lower strength characteristics. Overmixing develops heat in the mass, which, in turn, causes the powdered resin particles to soften and agglomerate. The agglomeration results in a reduction of resin distribution and lower strength.

Resin Coated Sand

There are what may appear like several different methods that can be used to resin coat sand. Basically, however, there are only two: cold coating and hot coating. The methods and procedures used in each will vary somewhat, depending upon the type of mixer used and the auxiliary equipment available.

Cold and Warm Coating

The cold coating process is entirely dependent upon rapid evaporation of solvent. The operating cycles will, therefore, vary depending upon the size of batch used; the volume, velocity and temperature of the input air; the speed with which the sand is turned over; the surface area exposed to the air blast; the amount and type of solvent used; and the melting point of the resin, either as a powder or in solvent solution.

Some types of mixers are more suitable. For example, a mixer with a large surface area exposed to the air is preferred over a sigma blade type, unless heated air can be introduced into the batch when needed.

The original cold coating method was to add a resin

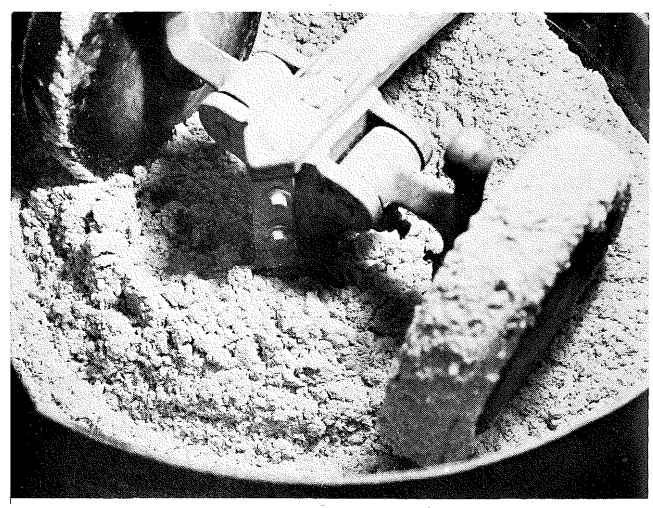


Fig. 21.2 — Initial dispersion of cold coating resin.

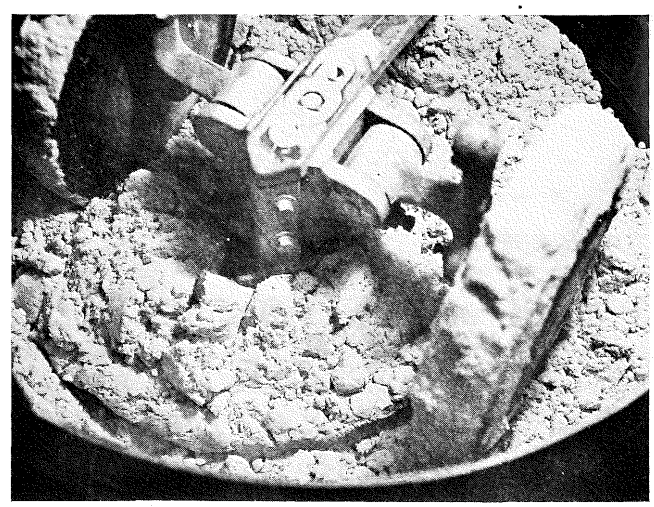


Fig. 21.3 — Maximum toughness stage.

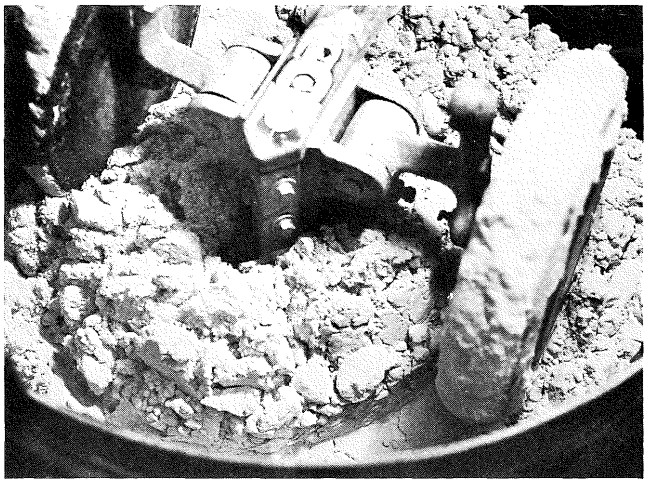


Fig. 21.4 — Beginning of breakdown.

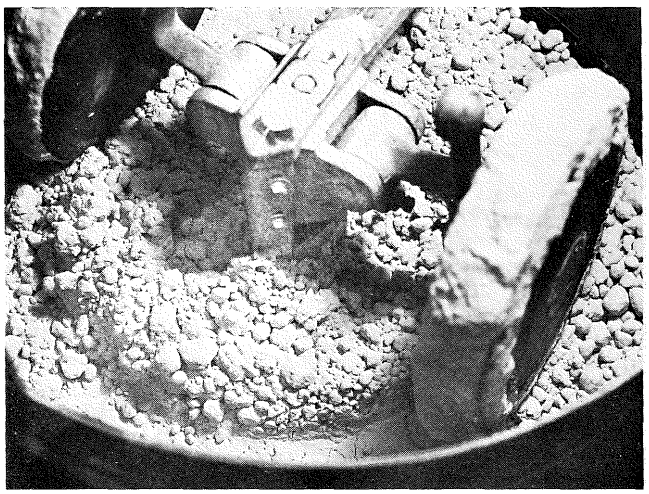


Fig. 21.5 — Intermediate breakdown stage.

plus hexa plus wax powder to cold dry sand, followed by a mixture of 75 per cent alcohol and 25 per cent water. The resin dissolved, coated the sand and evaporated to comparative dryness in the muller. Figure 21.2 shows the stage where solution and coating are complete, giving a wet sand mass much like an oil sand.

Continued evaporation (possibly 5 min) creates a tough, doughy mass that wants to hang together like a batch of bread dough. Figure 21.3 shows this condition. At this point, the entire batch can be carried around and around by a plow without any particular progress. This can be remedied by the installation of a punched wear plate to create a drag on the batch. The offending plow can be replaced with Swedish clock spring steel that flexes and lets the mass be crushed under the wheels.

A point often missed is that even after the resin is evenly dispersed, there must be continual crushing and shearing of the mass so that each grain has a smooth, dry coat of resin and is not stuck to several other grains. Figures 21.4 and 21.5 show further steps in the drying and breakdown process. If the batch is to be dumped by eye, Fig. 21.6 illustrates a popular point of discharge.

The sand is dumped and spread out (1 in. or so deep) to dry a few hours or overnight before screening. The reason is that the resin has a habit of forming an impervious skin, locking in some solvent. The water in the solvent greatly improves the situation, but heat and/or time is also necessary. Finally, the sand is screened (mesh only slightly larger than the maximum size of grain used) and sacked or stored. Figure 21.7 shows the nature of the sand at this point.

The fact that the grains are now very smooth makes the sand more flowable than the original sand. Thus, a wattmeter on the muller can be used to indicate correct discharge time when the power falls below that required to move bare, dry sand. Should mulling be continued beyond optimum, the watts will rise as the resin is scuffed off the grain.

The higher density obtained with coated sand is primarily due to the fact that the resin is on the surface of a sand grain as a smooth film. As long as the

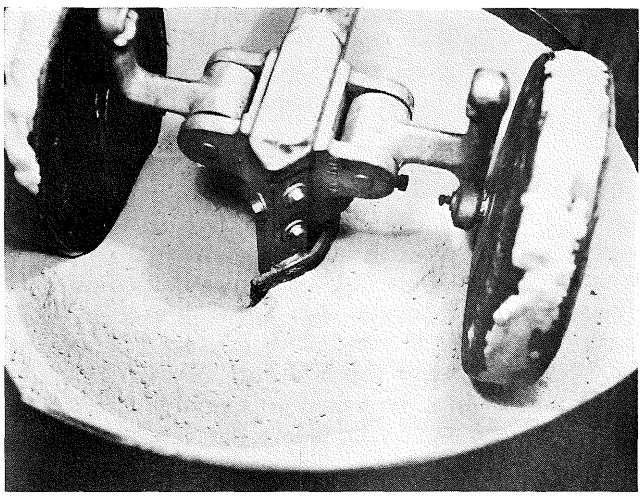


Fig. 21.6 — Batch ready for discharge.

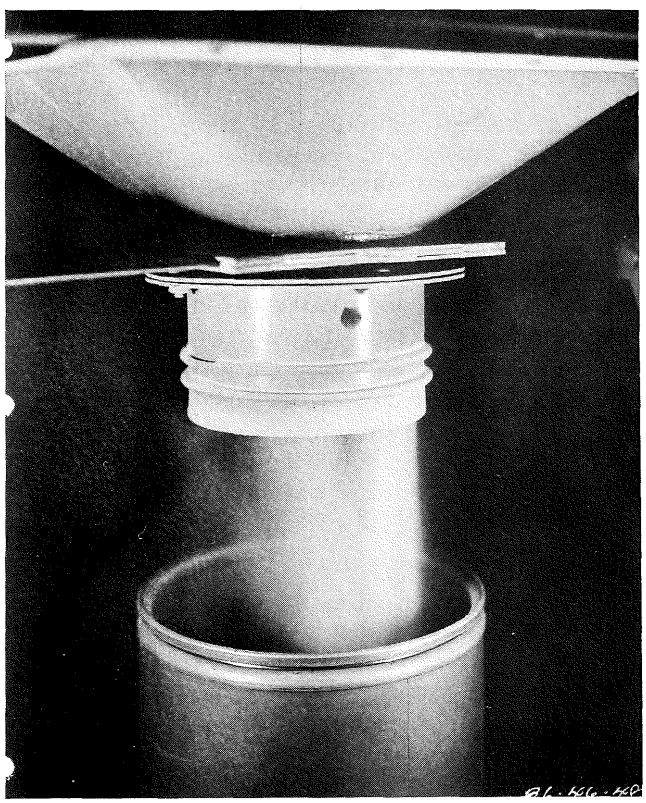


Fig. 21.7 — Finished sand being screened.

coating remains smooth, the coated sand grains will pack closer together. When the coating is abraded or roughened, the sand grains will no longer pack together as closely. The density, as a result, will decrease.

The difference in density between a dry mix and a coated sand product is approximately 20 per cent. As the density decreases (as a result of overmulling or excessive screening) the tensile strength drops accordingly. It is therefore, very important that whenever a strength comparison is made, the densities must also be compared. The tensile specimens should be weighed and the weights recorded with the tensile strength obtained.

It is not to be inferred that maximum density and flowability must always be sought. Cores or molds that might crack from thermal shock are at their worst at maximum flowability. Cold coated sand will not stand shipment or storage in high piles as well as warm or hot coated sand and therefore, is limited to installations where use is small and investment is limited.

An improvement on the above process is to hood the muller and introduce hot air right after good dispersion has occurred. A hood temperature of 250–300 F (121–149 C) is normal to produce sand at 115–125 F (46–52 C). This sand can be screened out of the muller and if carried in an air stream until cool, can be sacked immediately. This may mean elevation into a cyclone over a bagger with an air travel of 50 ft or more. Batches of 500–700 lb can use as much as 3,000,000 BTU/hour input during drying.

Great care must be taken to exhaust all alcohol fumes from the flame area before lighting. Bag houses should always be used to control whatever dust is produced. The muller should be preheated to operating temperature before coating the first batch.

A sand coated for maximum flowability will not leave any whitish resin mark on the fingers and will give maximum strength for the sand and resin used. A typical batch of cool or warm coated sand might be as listed.

500 lb dry clean silica sand
15 lb resin + hexa + wax powder
Mull dry 10 seconds
70½ oz denatured alcohol
23½ oz water
Mull until flowable (similar to Fig. 21.6).

The cold process might take 15 to 20 min, whereas the warm process could be 8 to 12 min.

Either the cold or warm process may be carried out with purchased resin solutions in alcohol–water at 60 per cent or 70 per cent solids level. Although the hexa and wax must be added separately, the resin dust loss is greatly reduced.

A liquid resin batch might be as follows.

500 lb dry clean silica sand
40 oz hexa + wax powder, 3 : 1 by weight
14 lb, 6 oz resin solution (70 per cent solids)
Mix dry ingredients 1 min, add resin.
Mix to even dispersion (maximum wet point).
Turn on air only 15 sec.
Turn on heat and mull to free flowing.

A high speed mixer might complete the cycle in 5 min, whereas the moderate speed machines would take 8 to 12 min. Figure 21.8 shows a high speed muller for either cold or hot coating.

Even the best of hot coated sands will cake if shipped 2000 miles or more, while the warm coated sands, properly dried, can stand up to 1000 miles. Continued pressure and frettage does the damage. However, seemingly badly caked sands go through a screen with little or no effort. If coated sands are stored in a damp place, they will cake. Continued heating in the 140 F (60 C), or over range will also cause lumping.

A record of coating conditions is easy to keep on prepared forms. Date, type, and batch stamping on the bags allow intelligent investigation of any difficulties that may arise months later. Using hot and cold tensile strength, stick point, hot distortion, and density tests to evaluate coated sands, many variations and special additives can be used to cope with each shell job. Quality of the final sand is in direct ratio to the amount of control exercised. The parameters of successful sands are discussed further under *Quality Control.*

The Hot Coating Process

Coating sand by the hot process may be accomplished by one of two different methods. In one, a solid resin in lump or flake form, plus accelerator is used. This method calls for adding the resin to preheated sand, allowing the resin to melt and disperse, adding a lubricant if the solid resin does not include a lubricant, and finally, a water solution of accelerator (hexamethylenetetramine — referred to as hexa) for partial cooling. The still warm sand is discharged onto a screen and generally picked up in an air stream for final cooling and delivery to the sacker.

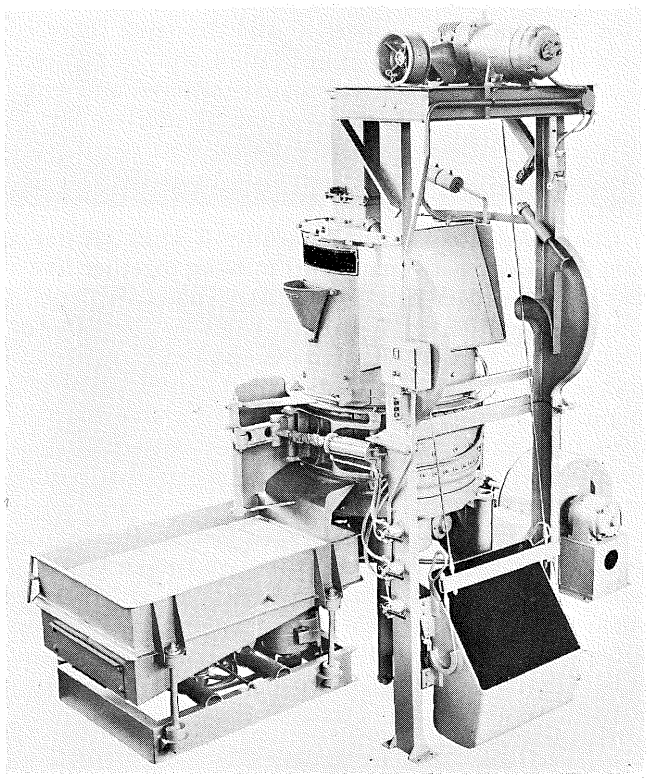


Fig. 21.8 — High speed muller for cold or hot coating.

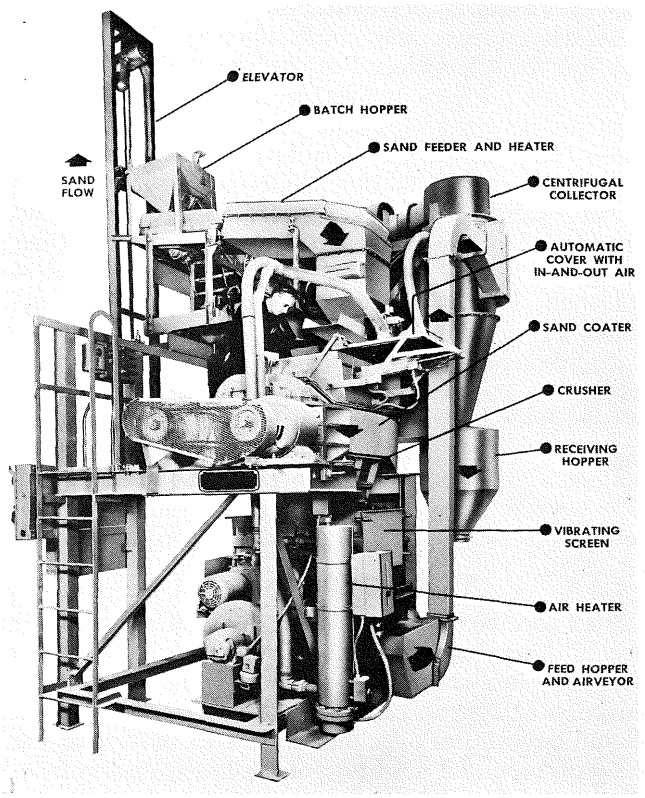


Fig. 21.9 — Complete hot coating unit.

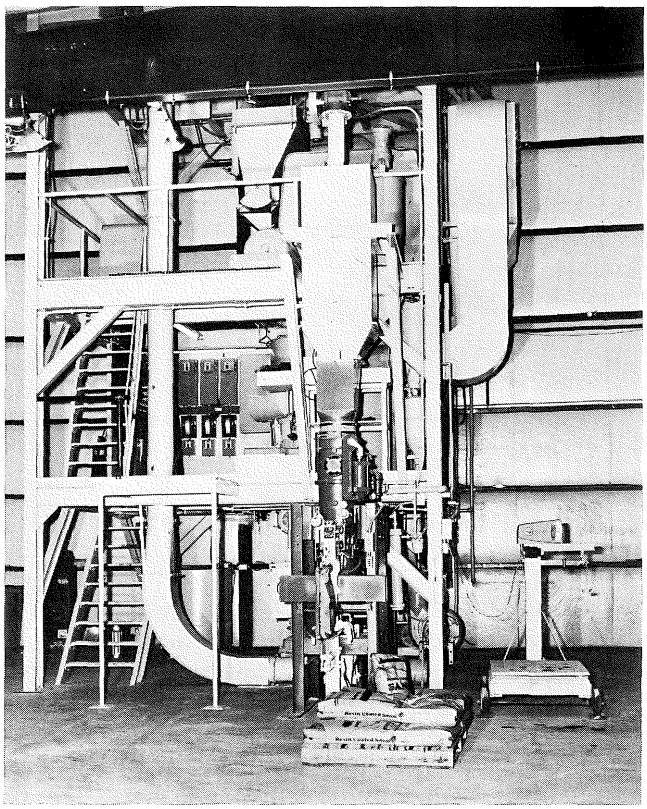


Fig. 21.10 — Automatic hot coating installation.

The second method utilizes a so-called, water-borne resin. This is predominantly a water solution of a resin which is added to preheated sand, the volatile constituents are driven off, the lubricant and hexa solutions are added, then the mixture is cooled and screened.

The addition of a water solution of hexa serves a dual purpose. First, it is an excellent way of distributing the necessary accelerator throughout the sand mass. Second, the water used is an excellent quenching agent and provides for very rapid cooling and fast breakdown of the sand to its original fineness.

Many innovations have been made to both of these hot coating methods in the manner of addition of the resins, accelerators, and lubricants. The finished products, however, are relatively the same. Figure 21.9 shows a complete hot coating unit.

Most all mulling or pugging mixers are adaptable to the hot coating process. Typical hot coating procedures are as follows.

Flake or crushed resin (containing wax)
100 lb sand
2 lb, 2 oz to 3 lb, 6 oz flake or crushed resin
6 oz to 10 oz hexa dissolved in 1 qt water.

Approximately 2½ to 4 per cent resin content.

Heat sand to a predetermined temperature and dump into muller (sand temperature range is a low of 260 F [127 C] to a high of 325 F [163 C], depending upon the type of equipment and resin used). Add resin and mull approximately 45 to 90 sec, add water solution of hexa and turn on cold air blower. Continue mulling or pugging until approximately 75 per cent breakdown to individual particles takes place, and dump.

Water-borne resins (liquid hot coating)
100 lbs, sand
2 lb, 2 oz or 3 lb, 6 oz water-borne resin, 70 per cent solids
6 oz or 10 oz hexa dissolved in 1 qt water
2 oz or 3½ oz wax (calcium stearate or equivalent)

Heat sand to a predetermined temperature, dump into muller (generally 280–325 F [138–163 C]) and add resin. Mull 1 to 2 min. Add wax and hexa. Proper mulling cycles must be established to conform with the type of equipment used and coated sand stick point desired. A completely automated hot coating installation with sacker is shown in Fig. 21.10.

In the hot coating process, the mix can be easily overmulled by extending the period during which the resin is fluxed onto the sand. The high temperatures involved can cause excessive losses of resinous constituents, resulting in high stick points and low strength properties. Hot-coated mixes can also be easily overmulled during the cooling and breakdown period. The resin coating is roughened or removed by abrasion resulting in lower strength characteristics. Overmulling tendencies increase as the equipment and batch size are increased.

The ability to alter the stick point in the hot process is at once an advantage and a necessity for added control measures. Automated cycling and close supervision is the key to reproducibility.

Effect of lubricant. As mentioned previously, the difference in density between a dry mix and a resin-coated sand is approximately 20 per cent, and it is this higher density that provides higher strength properties. The use of lubricants in the coating formula re-

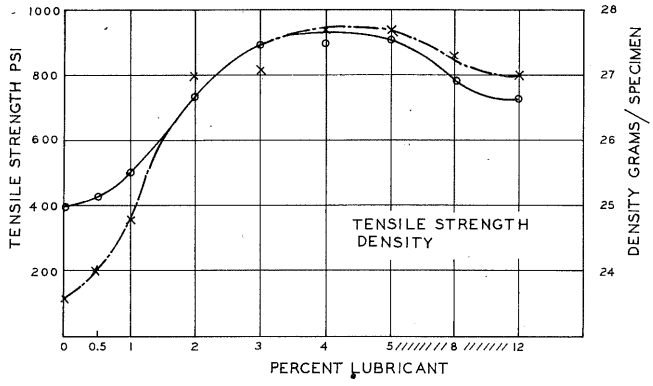


Fig. 21.11 — Wax content affects cold tensile strength.

sults in higher densities. The mechanism involved is, simply, that the coated sand grains are lubricated. This reduces the coefficient of friction between them, and enables them to pack closer and produce a higher density.

The type and amount of lubricant added are very important because not all lubricants will produce the desired result. As the amount of lubricant is increased, the tensile strength properties will increase to a maximum and then fall off. The per cent lubricant that will produce maximum strengths will vary slightly with the type used. Calcium stearate, a metallic soap, is a popular shell lubricant.

The time of lubricant addition during the mulling cycle has very little effect on the characteristics of the final product. It seems that it is preferable in most instances to add the lubricant while the resin is still in a tacky condition in order to keep the air from blowing it out of the muller. Figure 21.11 illustrates the effect of a lubricant on strength properties and density.

Maximum strengths and densities are obtained with approximately 4 per cent lubricant, based on the weight of the resin used, with very little loss up to 5 per cent. By coincidence, the maximum lubricating effect on a pattern or core box is also obtained with approximately 5 per cent.

SPECIAL ADDITIVES

Shell cores for magnesium must contain some inhibitor such as sulfur and potassium fluoborate. One-half per cent of each is adequate. Molds are flushed out with sulfur dioxide just before pouring as an added precaution.

One or two per cent iron oxide is used as a hot strength addition with good reason. The iron oxide is also used with 4 per cent fine, granular calcium carbonate as a chiller to help prevent stucco surface on carbon steel castings. It is a poor substitute for zircon sand. Another method is the double investment. The first $\frac{1}{16}$-in. thick coat is fine sand with iron or manganese oxide. The next $\frac{3}{16}$-in. is made of sand with 30 per cent calcium carbonate.

Another method is to put a thin coat of furan resin on the grain and then char it with sulfuric acid. The precoated grain is then coated with resin. This reduces the expansion of the sand, but is expensive and a little complicated. Much of the benefit can be obtained by using a very angular grain with the 4 per cent carbonate, 2 per cent iron oxide, single coat.

Besides causing early cracks upon pouring, expansion causes enlargement of molds during solidification. If a rigid but permeable skin is formed on the metal immediately, the still molten portion can seep through the dendrites to contact the new, expanded position of the shell. If the fill-out is complete, no defect is caused. If the skin was also impermeable, no defect is caused. Stucco results from only partial filling of the space between the original and final position of the shell. Naturally, additional feeding is also required in these cases.

Thermoplastic resins such as the alcohol soluble pine resins are used to give some elasticity to the shell or core. This must be done with caution since dimensional tolerance is in the balance. Some resins carry an acid such as oxalic acid to increase the effectiveness. This process is patented. A check on the relation of hot-to-cold tensile will give control of thermoplastics.

SHELL COREMAKING

Shell core boxes are generally made of gray iron or steel, although some nonferrous boxes are being used. The core box should be contoured and uniform in thickness. Its heat capacity is very important and should be uniform over the entire area. Wherever the design is such that a portion of the box is distant from the source of heat, projecting lugs should be incorporated as an integral part of the box. Inserts mechanically incorporated for this purpose are unsatisfactory.

For easy removal of the core, it is very important that the core box surface be smooth, free from pinholes, screw holes and under cuts. Materials such as patternmaker's putty, wax and solder cannot be used as the operating temperatures are considerably above their melting points.

Standard venting techniques can be used, although in many cases sufficient venting will take place at the parting line so that vents are not needed. Standard shrink rules are applicable although in some cases shrinkage is slightly less than anticipated.

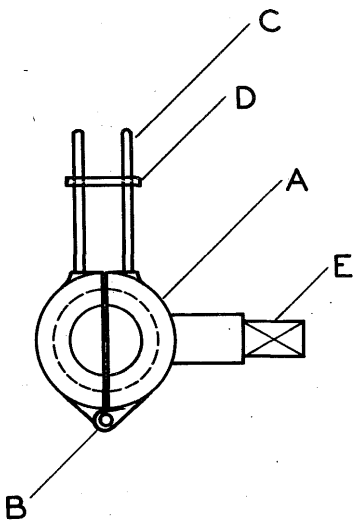
It is not necessary to allow for the expansion of the core box at operating temperatures as the shrinkage of the core on cooling is about equivalent to the expansion of the core box. A draft allowance of approximately one-half degree is sufficient to facilitate easy removal of the core.

New core boxes are rubbed lightly with silicone grease and heated to 450 F (232 C) once or twice to avoid sticking. A dilute water emulsion of silicone is used as often as needed to prevent sticking.

Shell cores are almost always blown at modest pressures of 20 psi or so. The entire range might be 5 to 40 psi air pressure. Special care must be taken to dry the air used for blowing. All sand should be screened as it enters the sand magazine to avoid chance lumps, bits of paper, etc.

The core box should be properly mounted on the heated platens of a shell core blower or if small in size, it can be part of a small hand operation. Putting oversize boxes on small machines can result in fallback because of cool parts of the box being too far from the heated platens on which they are mounted.

The speed of cure is a function of time and temperature. For maximum operating cycles, the box tem-



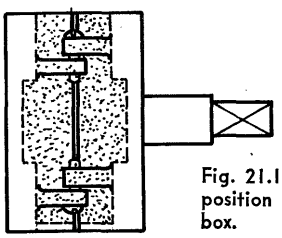


Fig. 21.12 — Fill position of core box.

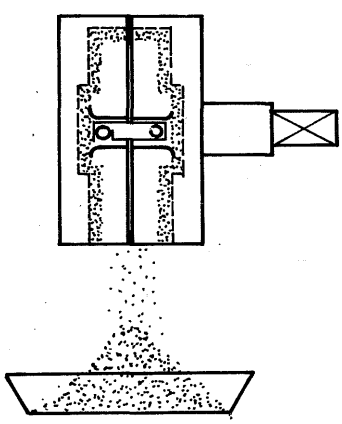


Fig. 21.13 — Dumping out the loose sand.

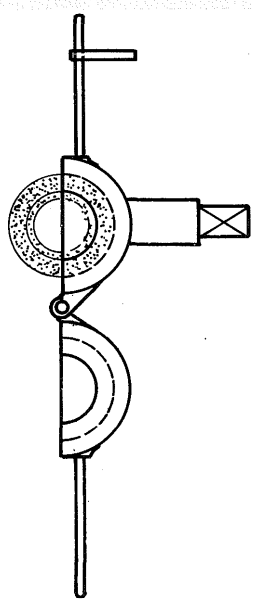


Fig. 21.14 — Cured core removal position.

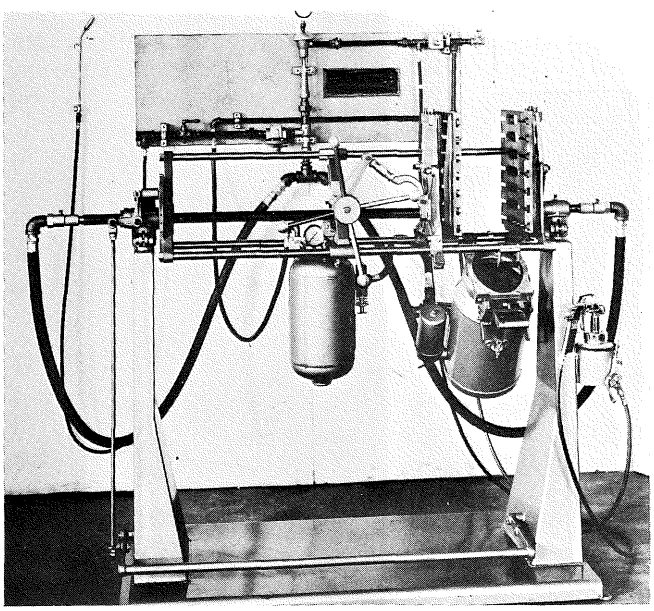


Fig. 21.15 — Light rollover shell blower.

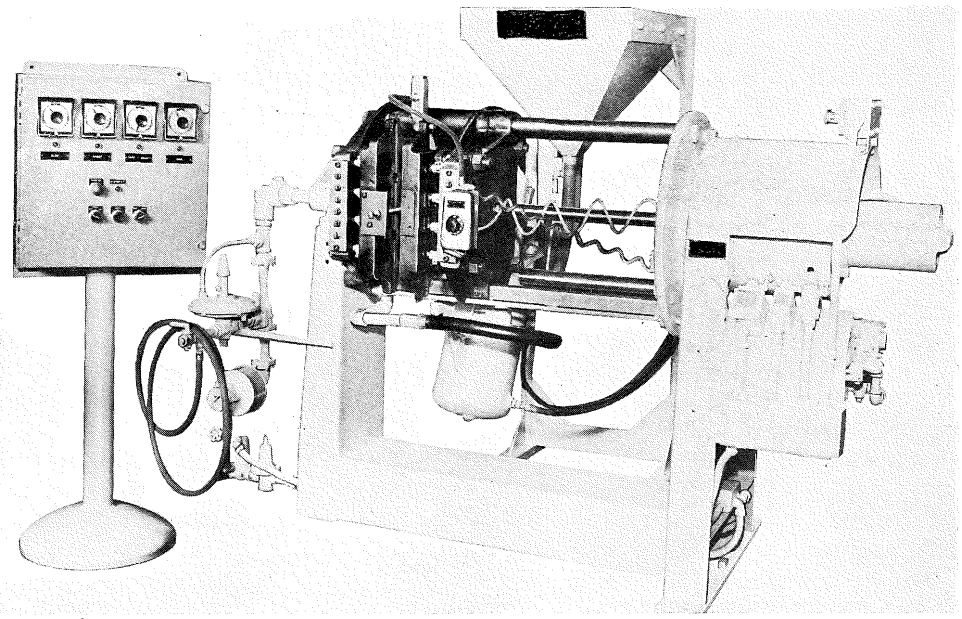


Fig. 21.16 — Automated rollover machine.

perature should not be less than 350 F (177 C) and not more than 550 F (288 C). Temperatures in excess of 550 F (288 C) may burn the cores and produce a soft surface.

The core box heating system should be designed to provide rapid temperature recovery between cycles. Both gas and electric heat are used, but gas seems faster and more flexible for high production.

One of the first types of core machines carried the hinged core box on a trunnion which allowed the core to be swung under a blower and then into an oven for curing. The box is inverted to drain and opened to remove the core by hand. Figure 21.12 shows the top and elevated view of such a box blown full of sand. The core box *A*, hinged at *B* and supported by trunnion *E*, is held closed by lock *D*, snapped over handles *E*.

Figure 21.13 shows the box inverted, dumped and ready to go into the curing oven. Figure 21.14 shows the box swung open for removal of the cured core.

A popular machine has the box halves mounted on heated platens, one fixed and one sliding. The sand hopper is below the core box and clamps up to it using silicone rubber as a gasket. The assembly is rolled over and air pressure applied into the sand magazine. After the desired buildup, the assembly is returned to its original position for drainage. If the air pressure is released too soon, delamination and fallback can occur. On large or thick cores, this can be especially bad.

After curing, the box opens usually by an air cylinder. The boxes should be made so that the core releases from the sliding half box easily, leaving it to be picked out of the stationary half. On large cores, a torch is sometimes inserted into the hollow core to hasten the cure.

Figures 21.15 and 21.16 show the rollover type blowers. Best operation and production result from matching the box and machine size. A screen at the mouth of the magazine can be used to eliminate semi-cured lumps during draining.

High production machines have pushout pins and

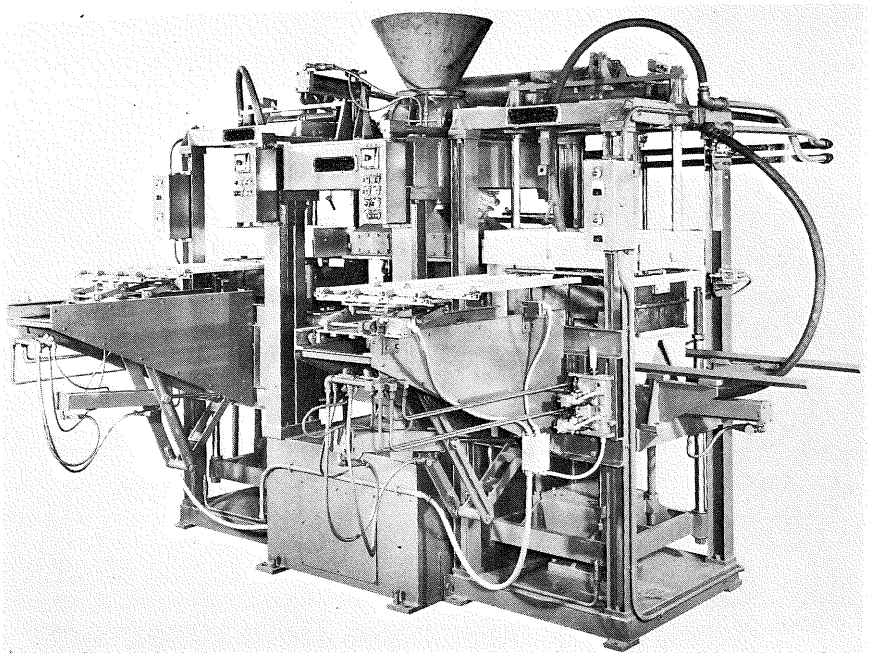


Fig. 21.17 — Two station shell or hot box blower.

automatic core removal built in. One such machine is shown in Figure 21.17.

Some machines, such as that shown in Figure 21.18 have the blow magazine above the box and use angle of repose blow slots or holes to hold the sand. The core box is still rolled over to dump. Thus, the dump sand which can contain lumps is kept separate to be screened and reused. Schemes to return this sand to the magazine by an air stream can result in excessive resin scuffing.

Some cores are blown over a hot mandrel which may also support collapsible sideways drawbacks. One machine blows from a fixed magazine below the box which swings on and off the angled blow plate.

QUALITY CONTROL

Quality control in the production of good quality castings should begin with the basic raw materials. In addition, each operation should be controlled to produce maximum quality segments which are finally assembled to produce good metal castings.

There are a number of problem areas easily controllable, but troublesome, if ignored. They can be listed as follows.

Core Boxes

The best metal for the box is cast iron, when both heat capacity and heat conductivity are considered. It also is stable in shape and dimension at 500 F (260 C) and is easily cast and finished. We must regard a shell core box as a heat source in addition to its other requirements. The back of the box must make reasonable contact with the heated platen, if so mounted. Manipulation of the thickness of iron at corners can help build up thin corners on the shell, which cause the entire shell to be made much thicker than desired. Draft, and/or pushout pins must provide easy release. The fit at the parting line, correct alignment and adequate closing pressure reduce costly fin removal. Peel back results from parts of the box, usually the joint, being too far from the heat source and not able to keep up the temperature.

Boxes can be made so as to form internal sand struts and braces in hollow cores to avoid packing the core with sand to prevent core collapse from pressure.

If the policy is to use solid blow plates, vents are needed to insure good packing. The back-vented blow plates replace most of the vents in the box proper.

Mixing

Resin segregation, hard and soft spots, result from damp and overmulled batches or poor initial resin dispersion. Compound grains result from poor breakdown while the resin is still soft enough to withstand

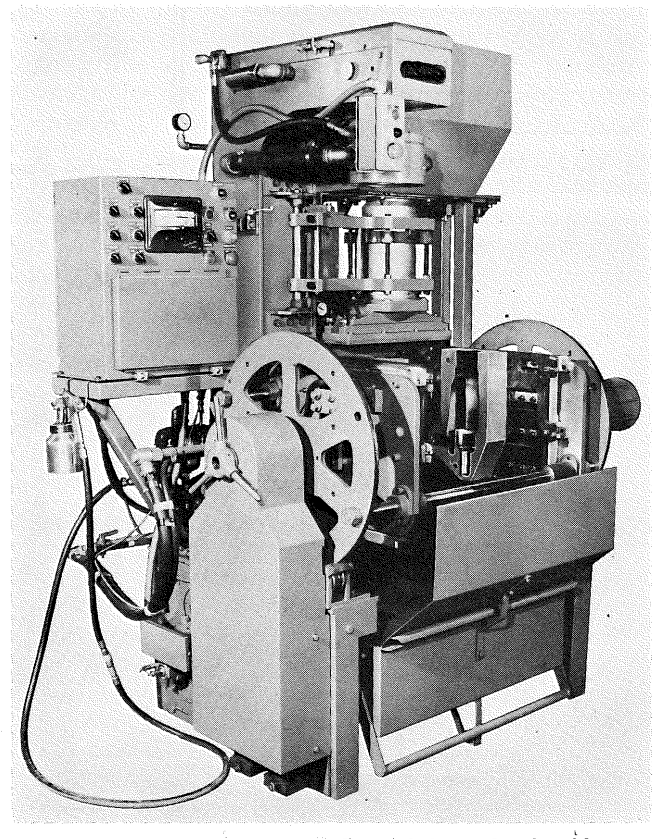


Fig. 21.18 — Swinging magazine rollover shell and hot box blower.

the abrasion. Lumpy sand results from incomplete drying of the solvent. A low hot strength with adequate cold strength results from excess thermoplastics or insufficient hexa. Type and amount of wax governs parting and strength to a great extent.

Curing Temperature and Time

While temperature controllers may be set at fantastic temperatures of 600 to 800 F (316 to 427 C), the temperature of the metal box face must not be much over 450 F (232 C) for best results. If it is necessary to cure a thick shell, lower temperatures allow thorough baking without surface scorching. On the other hand, few people appreciate the amount of heat phenol-formaldehyde can stand.

Certain cores, needing the very minimum in gas, have been post heated for several hours in a 425 F (218 C) oven. The gas is less than half its original value. Although some cold strength is lost, the bond is cokey in nature and holds the metal. Casting long, thin members in shell sand can be done with less misruns in this way.

The same result is not obtained by short curing a lower resin sand. A short-cured core or shell is least liable to crack out on contact with the metal. It has higher hot sag and lower cold strength. While many cores are baked one or two minutes, laboratory tests show many sands do not reach their peak cold tensile short of 10 or 15 minutes at 425 F (218 C). The successful temperature range is small, no more than 420–470 F (216–243 C).

Sand

The density of shell core sand is of the utmost importance. Round grains, smooth resin coats, adequate wax content, efficient blowing — all point toward high cold tensile, low permeability, high density and therefore, high expansion. High blowability and best finish also are obtained. Angular grains, rough resin coats or dry mixes, and inadequate wax content give opposite results. Many have been misinformed as to the effect of angular grain shape on permeability and strength. Actual tests show that angular grains do not nest together very well, thus allowing relatively few and small points of contact for strength, while leaving open large pores for venting and accommodation of any expansion movement.

The smoothness of the surface of the grain is very important to strength and resin consumption. Resin will not stay on a glass bead because it is too smooth, but a jagged grain needs excess resin to cover its large surface area. Optimum tensiles result from a round grain with a lightly etched surface.

It is possible for an unwashed sand to have an unfavorable organic coating. It is usually oily or like a vegetable slime and can be removed by burning at a lowered heat. Impurities like feldspar and lime are not necessarily bad. Feldspar reduces the effect of thermal shock and lime tends to chill steel to prevent stucco surfaces. Too low a resin content can cause breakthrough simply by burning up, regardless of original strength. Sands needing more resin to give a reasonable cold strength will also hold metal longer for this reason.

Cold tensile strength then, relates chiefly to the handling problem, while hot tensile relates to metal containment in conjunction with resin content as a time factor. Stick point relates to speed of cure (hexa content) and, in some cases, presence of solvent. Thicker coats of resin lower the stick point.

Hot expansion (hot distortion test) relates to resistance to thermal shock and early cracking. Hot sag (hot distortion test) and the hot tensile test relate to dimensional accuracy and shape reproduction. Both hot expansion and sag are related to mold cavity growth and stucco surfaces on steel.

Shell core hardness is a more direct measure of the tendency of the core to shed or rub off than the tensile strength.

Gas volume measures the tendency toward misruns and flows. Resin content, cure time, temperature and permeability are the parameters.

For fast quality control at the coating muller, the hot tensile test and stickpoint are recommended. They can be performed by the muller operator readily.

The most revealing and important test to be used in fitting a sand and resin to a job is the hot distortion test, which measures expansion and sag or thermoplasticity.

Cold tensile, hardness, permeability and gas volume find frequent use in controlling and evaluating shell cores.

Some of the everyday problems encountered and their suggested remedies are as follows.

SAND INCLUSION (DIRT)

Cause	Remedy
Metal washing sand loose, unbonded sand in mixture. Squirting gate.	Increase resin, reduce severity of gate, check temperature and time settings, keep coated sand covered, discard sweepings.

POOR CASTING FINISH

Coarse or compounded sand grains. Low blowability. Improper use of angular sands, excessive metal pressure and/or temperature, low core density.	Exclude coarse and angular sand. Increase wax content. Rework gates and risers, check metal temperature and fluidity, check pouring rate and decrease, if possible, consider extra core box vents.

CORE CRACKS DURING POURING OR SOON AFTER

High density of core; excessive hardness and strength. Inability to sustain thermal shock.	Use thermoplastic resins, if feasible. Use angular, low density sand, short cure the core to reduce expansion, add 2 per cent iron oxide.

PEEL BACK AND LAMINATION

Separation between form-cured shell surface and plastic semi-cured layer. Loss of support from sub-sand and air pressure before desired thickness can harden. Residual solvent.	Increase heat capacity and/or temperature of core box at trouble point. Be sure solvent is evaporated completely, increase stick point, increase hexa and/or speed of cure, increase hot strength (especially at short cure times). Hold air pressure on longer.

STICKING

Poor mixture of sand and resin, permitting resin segregation. Wax too low, not enough silicone on box, misdirected blow hole.	Use coated sand, free of loose resin. Increase calcium stearate wax, use silicon spray oftener, relocate blow hole.

SEIZING

Cause	Remedy
Identified by difficult removal from pattern or core box, but no apparent sticking to the surface. Slow cure, low temperature, insufficient hexa, low hot strength.	Increase cure speed, higher temperature, extend cure time, increase hexa content, increase hot strength.

MISRUNS — BLOWS

Excessive gas pressure.	Decrease resin or, if impossible, post heat core at 425 F (218 C) to reduce gas. Vent the mold heavily at open core print if explosion occurs in hollow core.

BURNTHROUGH OR BREAKTHROUGH BEFORE SOLIDIFICATION

Resin burned out too soon, thin corners, excessive thermoplasticity, too thin a core.	Reshape core box to gather more sand behind reentrant angles. Use higher resin content, make shell thicker, arrange for internal struts to bear metal load. Pack with sand as a last resort.

LABORATORY TESTS FOR RESINS

(Nonvolatile Matter by Weight 275 F [135 C] Solids)

Scope

This method is intended to measure the 275 F (135 C) nonvolatile matter in resin solutions. Nonvolatile matter expressed as percentage indicates amount of film-forming material available in the resin.

Principle

Upon heating specimens in a controlled temperature oven, volatile portions are allowed to escape and the residue weighed.

Apparatus and Materials

Chemical balance—accurate to 0.0001 g.

Oven—a constant temperature oven arranged so that the shelf on which sample dishes will rest is flat and level. In a gravity type of oven which depends upon the natural circulation of air for uniformity of temperature, only one shelf must be used for supporting the specimens, and the bulb of the thermometer for indicating the oven temperature shall be in close proximity to the specimens. The glass thermometer for use with the oven should have a range of 32 to 302 or 392 F (0 to 150 or 200 C) and should be accurate within 1.8 F (1 C).

Drying dishes—these should be made of metal, flat bottom. The drying dishes should have an inside diameter approximately 2¾-in. and a depth of approximately 5/16-in. The standard single friction tin can cover having a diameter of $2\frac{13}{16}$-in., or, the bottom of a 2 oz Philadelphia style seamless metal ointment tin having a diameter of $2\frac{13}{32}$-in. is suitable for use.

Desiccator tongs.

Desiccators.

Sample bottle—a small bottle, 30 ml capacity fitted with a ground glass eye dropper as stopper. Fisher catalog No. 2-990 or equivalent is suitable.

Method

Heat 3 marked drying dishes in the 275 F (135 C) oven for ½-hr; cool in a desiccator and accurately weigh each.

Fill the clean dry weighing bottle with a representative portion of the resin and accurately weigh (including the eye dropper and rubber bulb). Transfer a sample to a weighing dish and reweigh the bottle. A specimen corresponding to a residue weight of about 0.5 g should be used (see sample size table below). If necessary, run a rough preliminary estimation of nonvolatile content in order to establish the approximate amount of final sample to be weighed. A total of three specimens should be weighed.

Tilt the dish so that the bottom is completely covered by the sample but avoid excessive wetting of the sides. Place the dish in the constant temperature oven within 30 min after preparation and heat for a period of 3 hr. At the end of the 3 hr heating period the tins are removed to a desiccator, cooled to room temperature and weighed immediately upon removal from the desiccator.

For those resins which are very viscous, generally over 90 per cent solids, it is permissible to weigh the sample on the drying dish after transferring it by a glass rod or spatula.

Calculation

$$\text{Per cent solids} = \frac{\text{weight of residue} \times 100}{\text{sample weight}}$$

Sample size to be used:

For 30% solids, use 1.7 to 2.3 g sample
40% solids, use 1.25 to 1.75 g sample
50% solids, use 1.00 to 1.40 g sample
60% solids, use 0.8 to 1.15 g sample
70% solids, use 0.7 to 1.0 g sample
80% solids, use 0.6 to 0.9 g sample
90% solids, use 0.55 to 0.8 g sample

Reference

ASTM D-115-55.

MELTING POINT DETERMINATION

(Capillary Tube Method)

Scope

This method is used to determine the melting point of various materials which are ordinarily solids at room temperature.

The method requires the observation of shrink and clear points. Pure organic compounds show no temperature difference between shrink and clear points, but, resins, waxes, etc., are generally not single compounds and, therefore, display a spread between these two points. The sharpness of the melting point is an indication of the purity of the material under examination.

Apparatus and Materials

Capillary tubes; glass, sealed at one end, approximately 40 mm long and 1 mm inside diameter.

Special apparatus. This assembly is housed in a wooden cabinet 10" x 20" x 12", closed on all sides and equipped with a clear glass door on the front to

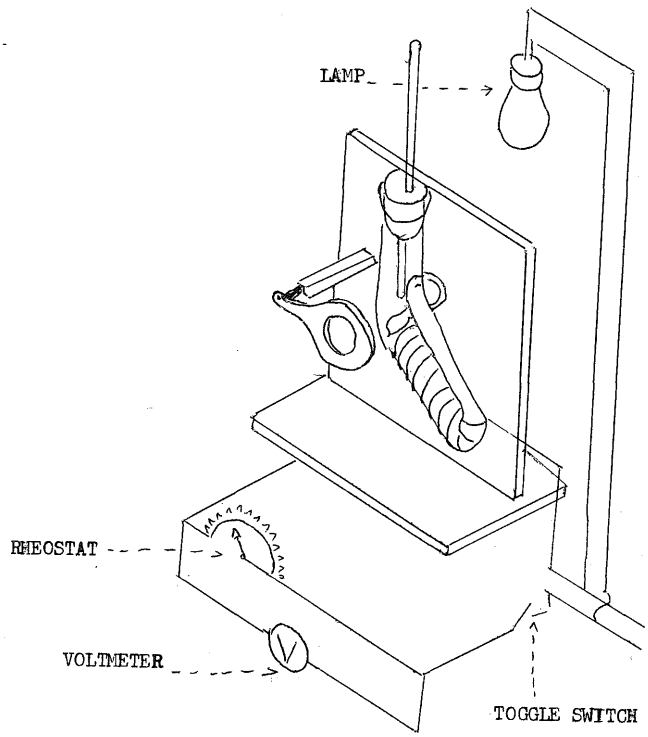


Fig. 21.19 — Melting point apparatus.

permit observation of the capillary and thermometer. A slot in the roof of the cabinet allows the thermometer to protrude. The rheostat, voltmeter and switch are mounted on the cabinet side. The lamp is inside the cabinet to provide lighting. Figure 21.19 is a diagram of the apparatus.

Mortar and pestle.

Screens, 100 mesh, 10 mesh.

Method

If the sample to be tested is not pulverized, a representative portion of it must be ground in a mortar until all of it passes through a 10 mesh screen. The sample should then be screened through a 100 mesh screen. Using the screen fines, fill a melting point tube by dipping the open end of the tube into a small mound of the powder and then tap the sealed end of the tube on a hard surface, or, holding the open end of the tube (after dipping into a mound of the powder), draw a file across the lower end of the tube to promote settling of the powder. Repeat the process until the tube holds about 3/8-in. of the settled powder. Attach the filled tube to the melting point equipment thermometer with a rubber band or a small section of rubber tubing, positioning the capillary in such a manner that the sample is on a level with the thermometer bulb. Place the melting point thermometer with attached capillary in the heating bath.

Turn the heating unit on, setting the rheostat at a voltage which will produce a temperature rise of 1.25 to 1.75 C/minute at the melting point.

When taking the melting point of resin mixtures of compounds, observe the temperature at which the powder begins to shrink away from the tube walls and the mass seems to shrivel and sinter together. Report this as the shrink point. Observe the temperature at which opaqueness disappears and transmitted light indicates clarity of the melt. Report this as the clear point.

When taking the melting point of individual compounds which fuse to a mobile liquid, observe the thermometer at the moment when the first clear drop of sufficient size to detach itself from the solid mass and roll down the tube makes its appearance. Report this as the melting point, and record also any irregularities such as failure to clear, etc.

A calibration chart should be set up for determining proper voltage for different melting points and rates of heating. This must be established by observation and practice.

The bath temperature at the start of a determination should be at least 30 degrees below the expected melting point.

Apply any necessary calibration corrections to the thermometer.

ASH DETERMINATION

Scope

This method is intended to give the per cent of noncombustible material in a given sample.

Principle

Organic material is burned off at high temperatures. It should be noted that water of hydration and easily volatile salts will also be driven off and will appear as combustible matter; therefore, ash should be determined on the virgin sand and the result used in the subsequent calculations on the coated sand.

Method

Ignite a pair of clean crucibles to dull red heat either over a flame or in a muffle furnace for about 5 min. Remove from heat and allow to cool in a desiccator.

Accurately weigh the empty crucibles. Then add about 10 grams of sample to each and reweigh.

Ignite at dull red heat 1472 F (800 C) until free from carbonaceous matter, usually about 4 hr. Cool in a desiccator and weigh.

Ignition should not exceed dull red heat because higher temperatures will enhance volatility of some inorganic compounds, particularly chlorides.

Calculation

$$\text{Per cent ash} = \frac{\text{weight of residue} \times 100}{\text{sample weight}}$$

VISCOSITY IN CENTIPOISES

Scope

This method is used for viscosities of liquids ranging from 1 to 32,000,000 centipoises.

Principle

The method is based on the use of the Brookfield instruments for direct measurement of viscosity. These machines operate on the principle of measuring the torque imparted to a freely rotating cylinder by a liquid surrounding the cylinder. The torque is directly proportioned to the viscosity of the liquid and the instrument is calibrated to read centipoise directly.

Apparatus

Brookfield Syncro-lectric viscosimeters, Models HVB and LV.
Constant temperature bath—77 F (25 C).
Viscosimeter stands.
Beakers — various sizes.

Method

Caution: Be certain of the temperature adjustment of the sample; a difference of less than one-half degree will introduce serious errors.

Hi-Visc. Viscosimeter—8,000—32,000,000 c.p. (Model HVB)

Operating Instructions

(1) Exercise care in attaching spindle to machine. Grasp upper coupling and hold firmly while attaching left hand thread spindle. The spindle is also held by coupling. Avoid undue side pressure which will affect alignment. Turn the spindle to attach, never the upper coupling.

(2) Place the machine on the special support stand and lower the guard and spindle into material to be tested to a depth indicated by the groove cut in the shaft. Level the instrument by adjusting the leveling screws in the base of the support stand.

(3) Start motor. Take reading when pointer has reached a position where it is stationary in relation to the rotating dial. Several revolutions may be necessary to establish this. Take several check readings. A knob on the side may be turned to regulate operating speed. Have motor running while changing speed indicator to desired speed. After completing tests, set the speed indicator at 2 rpm.

When testing material of unknown viscosity, make a trial test using spindle of highest capacity, i.e., smallest diameter. The reading obtained multiplied by factor for that spindle will indicate proper spindle to use. Care should be exercised not to use a spindle of large size in a high viscosity material, as too high a pressure would force the stop provided to prevent the pointer from making more than one revolution of the dial.

A 600 cc Griffin low form pyrex beaker should always be used for No. 1 and No. 2 spindles. Nos. 3-7 are accurate in any container over 2¾-in. in diameter.

The spindles are numbered 1-7 and the ranges of each at the different speeds are shown in Table 21.2. The multiplying factor may be determined by dividing the range by the dial scale. For instance, the range of No. 4 spindle at 2 RPM is 800,000 c.p. Dividing by the 500 scale gives a factor of 1600. If the 100 scale is used, a factor of 8000 is obtained.

Care of Viscosimeter

(1) Motor requires no oiling.

(2) Always remove spindle from instrument to clean. Hold upper coupling firmly while unscrewing spindle.

(3) Be sure contact surfaces of coupling and spindle are clean. This will aid for perfect alignment.

Caution: (1) Protect spindles from strain or violent contact when attaching to machine.

(2) Always turn speed indicator to 2 rpm after completing test. *This is important.*

Low Range Viscosimeter—1 to 9,200 c.p. (Model LV)

Operating Instructions

(1) Attach guard to machine.

(2) Attach spindle to machine as follows: grasp upper shaft coupling with thumb and forefinger. Hold firmly and screw left-hand thread spindle coupling securely to it. Avoid undue side pressure which will affect alignment. Turn the spindle to attach, never the upper coupling.

3) Place the machine on the special support stand and lower the guard and spindle into material to be tested to a depth indicated by the groove cut in the shaft. Level the instrument by adjusting the leveling screws in the base of the support stand.

(4) Press down clutch lever and start motor by snapping the toggle switch. Release lever and allow rotation to continue until spindle has made 8–10 revolutions (8–10 sec). Press down clutch lever with thumb and snap off switch with the other hand. If pointer is not in view when dial has come to rest, throw switch on and off rapidly until pointer reaches vision plate. Be sure to keep clutch lever depressed while doing this so that reading may be held.

(5) Take reading indicated by pointer. To check readings, start motor before releasing clutch to reduce oscillation and permit quicker reading. If variations in readings persist, insufficient rotation period may be indicated.

Always release the clutch while spindle is immersed so that the pointer will float back to zero rather than snap back.

If pointer makes a complete circuit of the dial, thus indicating a viscosity beyond the capacity of spindle used, it will be necessary to replace latter with one of greater capacity. Using the wrong spindle will not cause injury as there is a stop which prevents the pointer making more than one circuit of the dial.

For accuracy, the container used should not be less than 2¾-in. in diameter when using the No. 1 and No. 2 spindles. The effect on the No. 3 and No. 4 spindles is negligible within the limits set by the guard.

Full scale cannot be used on this model. Automatic stop is located at approximately 92 on the 100 scale or

TABLE 21.2

RPM	#1	#2	#3	#4	#5	#6	#7
10	8 M	32 M	80 M	160 M	320 M	800 M	3.2 MM
5	16 M	64 M	160 M	320 M	640 M	1.6 MM	6.4 MM
2	40 M	160 M	400 M	800 M	1.6 MM	4 MM	16 MM
1	80 M	320 M	800 M	1.6 MM	3.2 MM	8 MM	32 MM

M = 1 thousand MM = 1 million

460 on the 500 scale. When readings reach this point, use spindle of higher capacity.

List of spindle capacities with the dial scale on which it is most easily computed and the multiplication factors for conversion to centipoises.

Spindle	100	500	2,000	10,000
Read on scale	100	500	100	100
Factor	1	1	20	100

CARE OF VISCOSIMETER

(1) Motor requires no oiling.

(2) Always remove spindle from instrument to clean.

(3) Be sure contact parts of coupling are clean.

INCLINED GLASS PLATE FLOW TEST

Scope

This test is a measurement of the relative fluidity of heat reactive resins under specified conditions of temperature, time and gravitational pull.

Principle

The test involves measurement of extent of flow down an inclined glass plane of a preheated tablet of resin of specified size and weight at a specified temperature in a specified time.

Apparatus

A constant temperature oven; preferably of the Trent type with forced air circulation. The oven shall be equipped with thermostat controls to maintain a temperature of 125 C ± 1 C.

The oven should be modified by permanent installation within the chamber of an externally operated plate support rack to permit tilting of the test plates thereon from a strictly horizontal position to a dip of 65 degrees from the horizontal without opening the oven door. The oven shall be equipped with a 0 to 200 C thermometer graduated in 1 C divisions approximately 24 inches long. The thermometer is positioned so that the bulb is about ½-in. from the glass plate when in tilted position.

Smooth glass plates 12 in. x 12 in. x $\frac{3}{32}$-in. should be used. It is essential that the glass plates be free of oil and resin particles when being used. Plates with scratches or chipouts should not be used.

Carver hydraulic press, equipped with a mold to make tablets ½-in. in diameter.

Analytical balance accurate to within .001 gram.

Procedure

Adjust oven temperature to 125 ± 1 C.

Weigh out 0.500 grams of resin and transfer to the tablet mold. Insert steel plug and press resin at 200 psi for exactly 30 seconds. Release pressure and remove tablet.

Place tablet on the glass plate at a point about one in. from one edge. Several tablets may be run on the same plate, spaced about one in. apart.

Place the glass plate with tablets on the panel rack in horizontal position. Position the plate so that the resin will flow the long way of the glass plate when tilted.

Immediately close oven door and heat the plate and tablets in the horizontal position for exactly 3 min.

At the expiration of 3 min prewarming, tilt the rack to a position 65 degrees from horizontal by means of the external mechanism for so doing and continue the heating for exactly 20 min. (Additional to the 3 min prewarm.)

At the expiration of the 20 min immediately remove the plate and allow to cool in a horizontal position.

When glass plate has cooled to room temperature measure the total length of the flow (including the tablet original diameter) to the nearest millimeter by means of a rule or millimeter graph paper applied to the underside of the glass plate.

The above procedure specifies the use of 0.500 grams of sample for tablet preparation. For some resins, this amount of material will run off the plate; in some instances, report the flow as "over 250 mm" and then repeat the test using a smaller amount of sample (0.2, 0.3, 0.4 g).

The plastics plant will request flows for specific sized samples, as required, according to the following numbers:

For a 0.200 g sample — DCT No. 351-A
For a 0.300 g sample — DCT No. 351-B
For a 0.400 g sample — DCT No. 351-C

Report

The total length of flow in millimeters for any tablets run and the sample weight used.

The material number and batch or blend.

SHELL SAND AND CORE TESTS

Hot Tensile Strength Test

The hot tensile strength of a resin-sand mixture and the speed at which the hot strength is developed at a given temperature is of considerable value in the production of resin-bonded products. To a very large extent, hot strength and the speed with which it is developed will determine the operating time cycles.

The hot strength developed will usually vary between 50 to 100 per cent of its cold strength. Some sands have equal hot and cold tensile strength, i.e., have little or no thermoplasticity. Hot strength of a resin is a function of the type of resin and the amount of hexa added. With most resins, maximum hot strength is developed with approximately 18 per cent hexa, based on the weight of the resin.

Good hot strength allows for high production and low breakage at the shell mold machine or core blower, but may be conducive to thermal shock and breakage when in contact with molten metal.

Figure 21.20 illustrates the hot tensile testing unit.

The following is a standard procedure for determining hot tensile strength of sand-resin mixtures.

(1) Adjust the electrically heated sample mold to a predetermined temperature (currently standardized at 425 F [218 C]).

(2) Open the sample mold and fill the mold with the resin-sand mixture by using a combined hopper strike-off tool. Try to pick the instant when the thermostat lights go out to insure better uniformity.

(3) Strike off surplus.

(4) Close the mold for a predetermined curing time. Set the automatic loading timer, if available.

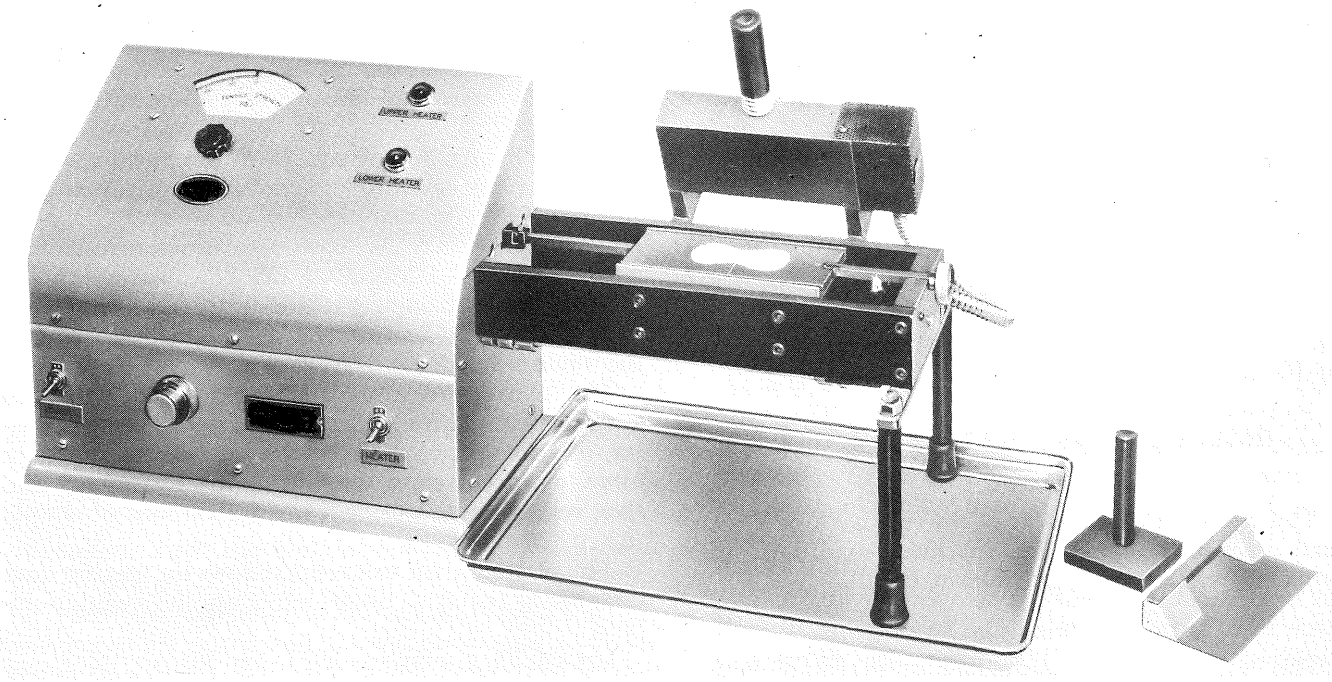


Fig. 21.20 — Hot shell tensile test.

(5) Apply tensile pull to hot tensile specimen while still in the mold by starting motor, if the tester is not equipped with an automatic timer.

(6) Read tensile strength as recorded at break. Maximum strength may not be obtained at less than 15–20 min for some resins.

Speed of Cure — Rate at which hot strength develops.

(1) The sample mold is charged as described above and four samples are made and broken.

(2) First sample is cured 30 sec and broken.

(3) Second sample is cured 1 min and broken.

(4) Third sample is cured 2 min and broken.

(5) Fourth sample is cured 3 min and broken.

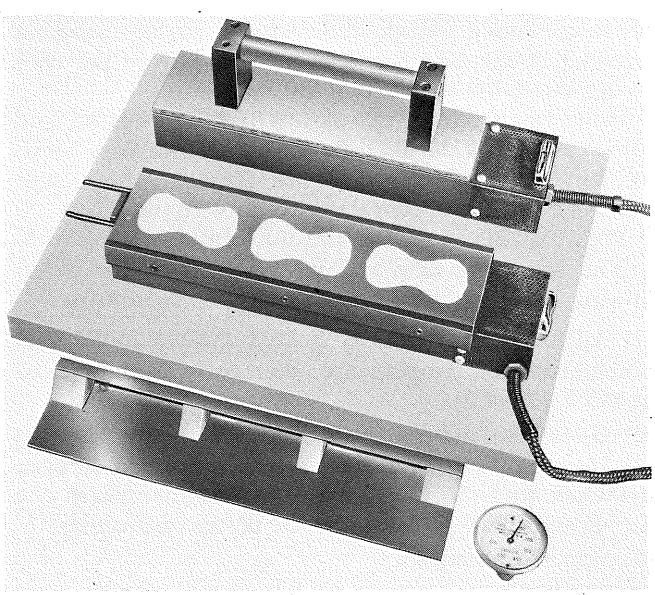


Fig. 21.21 — Heated shell tensile curing accessory.

Table 21.3 is an illustration of the results on two different sands.

TABLE 21.3

Cure Time	A	B
½-min	50 psi	30 psi
1 min	200 psi	90 psi
2 min	280 psi	130 psi
3 min	320 psi	320 psi

Both *A* and *B* may, eventually, have approximately the same hot strength but sample *A*, due to its higher hot strength after one and 2 min, will produce faster production operating cycles.

Cold Tensile Strength Test

The cold tensile test specimen is made in a heated shell curing accessory and three cavity pattern. Thermostats control the heat in the upper and lower plates to 425 F (218 C), or any temperature up to 600 F (316 C). Sand is dumped into the cavities and struck off with one motion using the hopper shown in Fig. 21.21 with the heated curing accessory. A small contact thermometer furnished may be used to check the temperature; or a larger, more accurate instrument can be used for exact and research work.

Cure time may be from 2 to 15 min. Although 2 min may duplicate shop cures, it is not necessarily a good evaluation of a mix since peak tensiles seldom develop short of 10 min. Also, being on a steep part of the time-strength curve makes reproducibility difficult. At the end of the cure time, the two split patterns are lifted out and the specimens released. Neon bulbs show when the top and bottom heaters are on and off. For best uniformity, it is good to always invest at the time the lights go off, indicating the set point of the thermostat. This helps eliminate the unavoidable thermostat operating range.

The specimens are placed in a desiccator, if they are

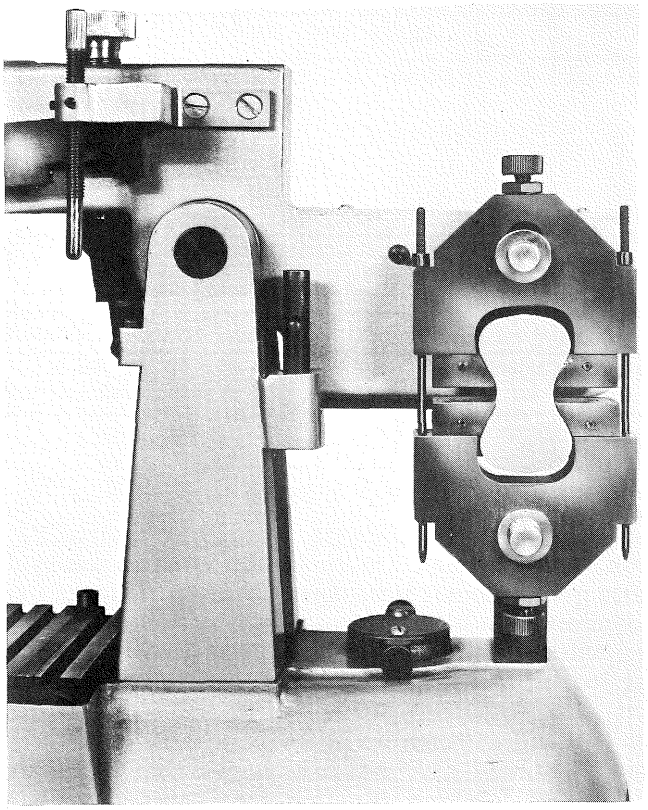


Fig. 21.22 — Breaking cold tensiles on the universal sand strength machine.

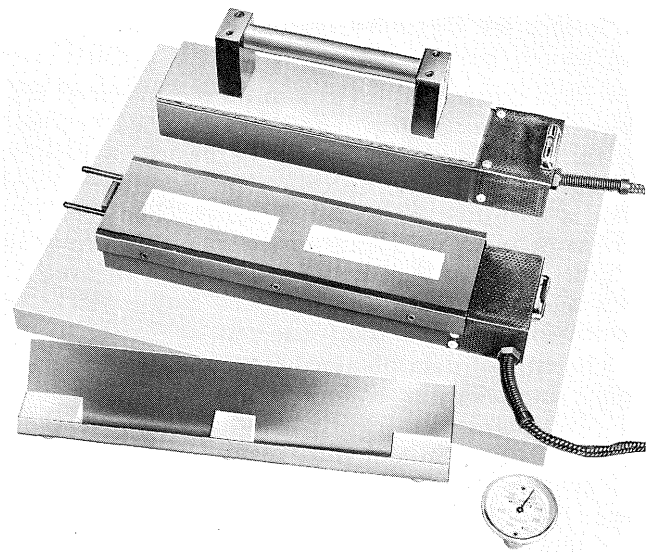


Fig. 21.23 — Heated shell transverse curing accessory.

not to be broken, as soon as they are cool to the touch. They are broken in regular core tensile grips positioned on the strength machine, except that ⅜-in. blocks are previously inserted in the grips to center the ¼-in. specimen. The average of the three breaks is recorded unless one is obviously damaged and therefore, breaks unreasonably low. The rule of discarding any result more than 10 per cent away from the average is often used. The older type tensile jaws may cut into the shoulder of the specimen and should be replaced with modern long contact jaws.

The cold or hot tensiles can be arranged to be blown with any standard bench blower instead of dumping. Special asbestos-faced magazines with leak proof blow holes are available. Shell cores are sometimes used with as low as 100 psi cold tensile strength if small or blocky, and as much as 300–500 psi for rangy delicate cores. Special purpose sands may run as high as 1000 psi cold tensile strength. The machine shown in Fig. 21.22 has a capacity of 2500 psi tensile strength on the ¼-in. specimen.

Shell Transverse Strength Test

The shell transverse test is made by loading the middle of a ¼-in. x 1 in. x 4 in. specimen supported on either 2 in. or 3 in. centers. It is a cold strength test which may be used in place of the cold tensile test. Transverse tests seem to be more reproducible than the tensile test, giving a much narrower spread of results.

The specimen is made in the manner depicted in Fig. 21.23. The procedure is the same as for cold tensiles except for the two cavity transverse pattern and dump hopper. Breaking fixtures with provision for 2 in. and 3 in. spans are available for the usual types of strength machines in use.

Figure 21.24 shows the arrangement for breaking a transverse specimen in a modern sand strength machine. The dial shown is registering deflection during the loading. Thus, flexibility in terms of cold deflection is an added bit of information necessary to a study of dimensional stability of the core wall, as well as its strength.

Hot Shell Distortion Test

Movement of the surface of a shell core when heated by molten metal is a cause of thermal cracking and dimensional inaccuracy of cored surfaces. The core surface may move due to hot shell distortion caused by either sand grain expansion on the hot side

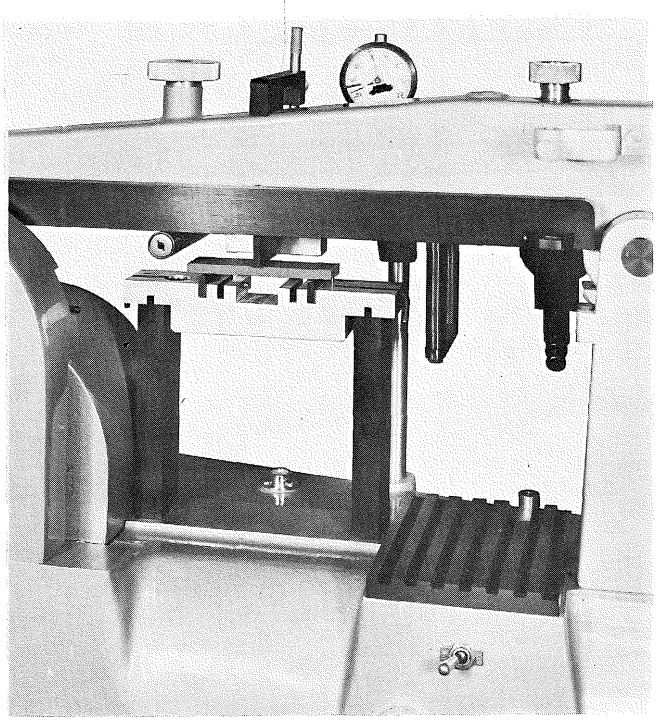


Fig. 21.24 — Breaking shell transverse specimen on 3 in. centers.

of the core or softening of the resin. This is the most valuable shell test to be used in fitting a resin and sand to the job.

In the laboratory, the hot shell distortion is the measured movement of a transverse shell specimen under load when subjected to unidirectional heating. The distortion, initially, is in opposition to the load due to the expansion of the sand on the heated surface and later, in the direction of the load application due to softening of the resin under load. Figure 21.25 shows a sketch of the arrangement of the test. A load of 1½-lb at 1500 F (816 C) is a good set of conditions. Other loads and temperatures up to 2000 F (1093 C) have been used, but do not seem to present any special advantage.

The hot shell distortion test apparatus, as illustrated in Fig. 21.26, is a static loading instrument equipped to apply heat to the underside of the test specimen and a load up to 4 lb on the specimen supported on 3 in. centers. The heat is applied by a one sq in. metal block which may be heated as high as 2000 F (1093 C). The distortion in inches and direction is measured by a dial indicator. The specimen (the same as for shell transverse strength) is formed in a split pattern which may be heated in an oven or between thermostatically controlled curing blocks, as shown for the shell transverse test.

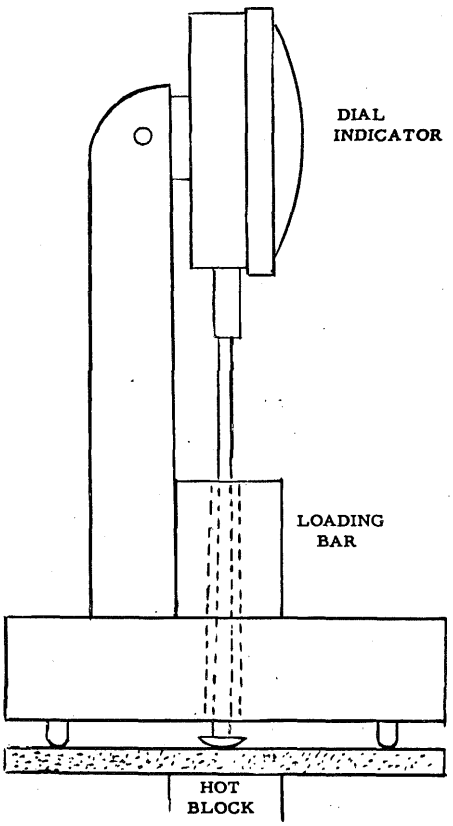


Fig. 21.25—Schematic drawing of the hot distortion test.

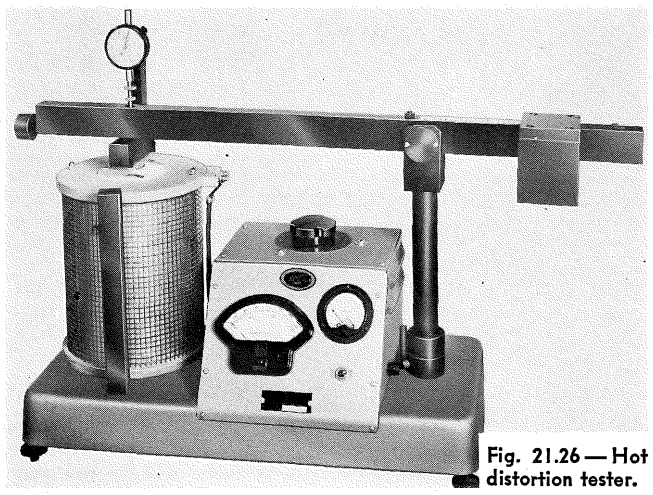


Fig. 21.26—Hot distortion tester.

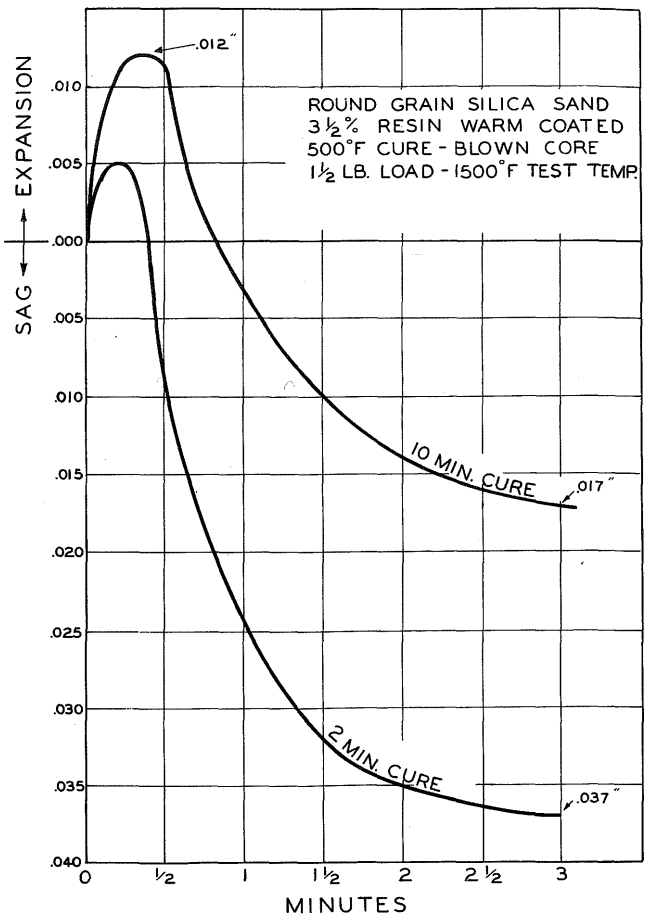


Fig. 21.27 — Hot distortion data plotted.

The type of data obtained from the hot distortion test is shown in plotted form in Fig. 21.27. The effect of cure time is also clearly shown. Long cure times embrittle the resin and allow maximum expansion of the grain to occur. Short cure times produce a great deal of sag which occurs soon enough to cancel out part of the expansion. The effect of various grains such as zircon, olivine, chamotte, chromite, fused quartz, etc., are readily studied and related to shell thermal stability. Variations in density, grain shape, binder, etc., are also important factors. While cores are less subject to thermal cracking than molds, flat areas and sharp corners will often cause trouble.

Relative maximum expansions of several sands are listed in Table 21.4. Common cure times and 1500 F (816 C) at 1½-lb load was used throughout. Final sag is dependent on the amount of thermoplastics present and the degree of cure.

The zero expansion of fused quartz, and the relationship of the other grains by composition and shape attests to the validity of hot distortion as a true indication of sand expansion.

TABLE 21.4 — EXPANSION OF VARIOUS SANDS BY HOT DISTORTION

Maximum expansion data from the hot distortion tester using fixed cure time, temperature, and resin content. Test temperature — 1500 F (816 C). Load — 1½-lb. Time for maximum expansion — 10 to 30 sec.

	Inches
Fused quartz sand	.000
Zircon sand	.0015
Olivine sand	.0045
Fine subangular silica sand	.006
Coarse angular silica sand	.006
Rounded W & D silica sand	.0075
Perfectly round silica sand	.010

Sag in order of .015 in. to 0.50 in. at 3 min, depending on resin type and cure time.

Density Test

The three cold tensile specimens are weighed before breaking for a record of density. If the specimens are not blown, it is well to weigh some standard shop core section that is either solid or filed to a definite thickness for a record of blown density as well. The density of uncured shell sand may prove to be a good tool. It can be measured in a 250 ml volumetric flask by weighing after tapping to maximum consolidation, as explained for silica sand in the AFS FOUNDRY SAND HANDBOOK (7th Ed.), p. 16-7.

Stick Point Test

The test commonly referred to as the stick point or melt point test is one which is used for the control of sand coating, usually by the hot coating process for core or shell molding. The test is run to determine the degree of advancement of the resin in the coating operation. In some shell operations, a minimum stick point must be maintained to insure good operation of the sand on the core and shell mold machines. If the stick point is too low, the coated sand will not adhere to the core box or shell pattern, but will fall off or peel back. The minimum stick point usually observed is approximately 200 F (93 C) and the maximum approximately 240 F (116 C), although lower stick points may occur on zircon or high resin sands.

PROCEDURE

(1) Apply a small, uniform trail, 4 to 7 mm wide, of coated sand along the center of the heated bar in the temperature range expected. A simple piece of sheet steel bent over slightly on one edge serves nicely, and is furnished as standard equipment with the complete test apparatus. A short funnel with a notched stem and a wooden stopper pin is also convenient.

(2) Allow coated sand to remain for 1 min.

(3) With a very light and consistent stroke, brush the sand off the bar starting at the cold end of the bar. (Use a soft camel hair brush.) When it is obvious that unfused sand has escaped the first stroke, additional strokes are used.

(4) At the point where the coated sand resists this brushing action, the temperature is taken by lowering the contact thermocouple onto the bar. This is the stick point.

There are, of course, variations of this procedure. For example, some use a 30 sec time interval instead of one min for the sand dwell time. For the removal of the loose sand from the bar after the dwell time, some use an air jet with a controlled air pressure. This is attached to the side of the apparatus on a slide so that it can be moved along the bar holding a fixed height over the sand trail. About 4 in. clearance and an air pressure of 1½-in. mercury should be about right with a 5/16-in. copper tube as the orifice.

In cold coating operations the stick point will be, with a given resin, fairly constant if the solvent has been removed completely. Residual solvent will lower the stick point.

In hot coating operations, the stick point can be changed easily by extending the hot mulling time before the hexa is added. As the stick point is increased due to extended hot mulling, the strength characteristics will also decrease and as the stick point is increased, the tendency to peel is decreased. Figure 21.28 illustrates a suitable stick point apparatus.

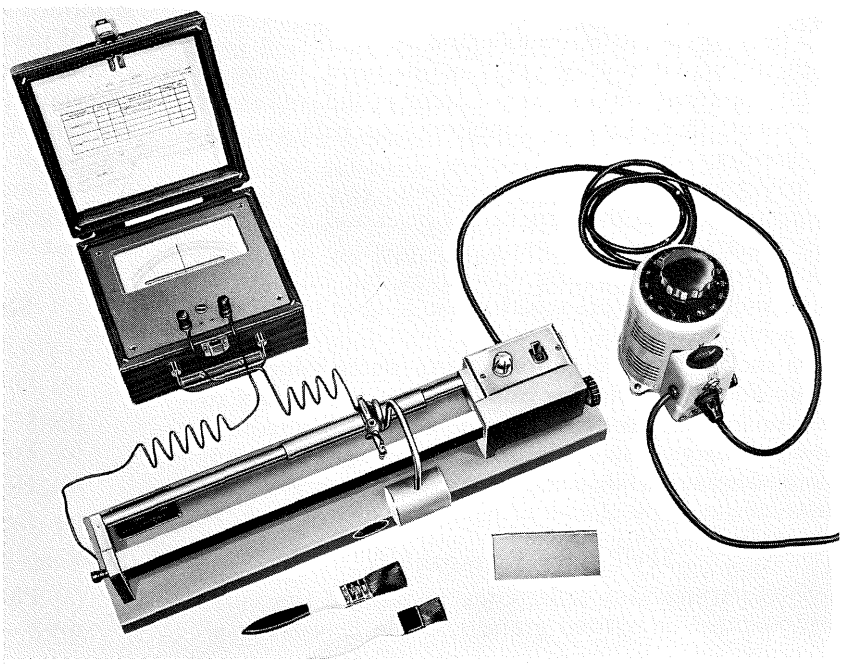


Fig. 21.28 — Stick point apparatus.

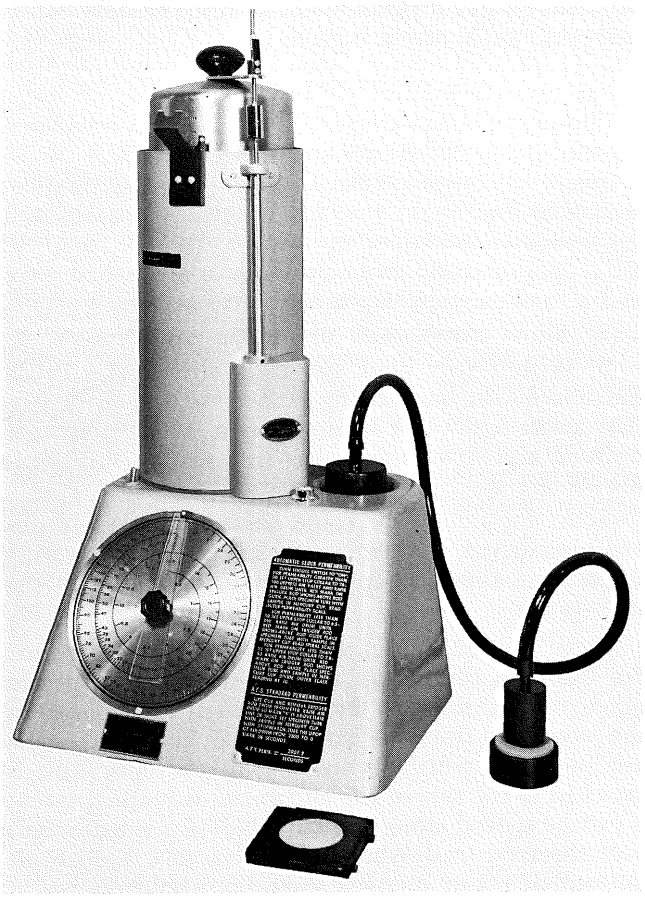


Fig. 21.29 — Shell permeability test.

Higher resin contents mean thicker coatings and this will lower the stick point toward the true melt point of the solid resin. Zircon at 3 per cent resin has a coat as thick as 6 per cent on silica sand and so, will have a lower stick point than silica sand.

The stick point test is a good test to determine factors such as:

(1) Uniformity of production batches.
(2) Control for a predetermined specification.

The stick point of coated sand is usually in line with the actual melting point of the resin. Advancement of polymerization cannot occur in the cold state. Therefore, it cannot be considered in cold coating operations.

Advancement or polymerization can only be brought about in the presence of hexa and at an elevated temperature. Therefore, it is possible to have it take place in hot coating operations, but only if the hexa and the resin are together too long at too high a temperature.

In the normal procedure, a hexa water solution is used. The water quench cools the batch instantly so that only a mechanical dispersion of hexa is obtained. A hexa reaction is easily recognizable. It has taken place to a degree when the sand begins to turn yellow in color.

Shell Core Permeability

Shell permeability reflects the fineness of the sand, compounded or natural grain, and the flowability of the sand. White shell cores have less permeability problems than solid cores, this basic property cannot be disregarded. An attachment for any regular permeability meter allows the determination of accurate shell permeability on the ¼-in. thick specimens. Figure 21.29 shows such an accessory in use.

The butts of the broken tensile specimens can be used or special round specimens may be prepared. The standard AFS permeability formula is the basis of the test.

Casting Finish

The finish on shell cored surfaces can be measured with a casting finish tester attached to a permeability meter and used the same as the shell permeability accessory. The pressure readings can be calibrated against a standard finished specimen such as the N.A.S. 823 made by the Aluminum Co. of America, to a range of five roughness height ratings, as mentioned in military specifications.

The following shell tests are AFS Tentative Standards and are described in the FOUNDRY SAND HANDBOOK (7th Ed.). Detailed instructions as to operation and maintenance of each test apparatus is also supplied by the manufacturer.

(1) Hot Shell Tensile Strength, Page 15-1.
(2) Hot Shell Deflection, Page 15-2.
(3) Shell Transverse Strength, Page 15-7.
(4) Shell Permeability, Page 15-9.

HAZARDS FROM USE OF RESINOUS BINDERS

Introduction

The various resinous binders used in foundry processes can be used with complete safety if the necessary precautions are followed. Therefore it is well to consider here the nature and characteristics of these materials, if a regimen of good safety and hygiene practices is to be adopted.

Shell process resins are two stage, whereas baked resin core binders are single stage. The two stage resin is formed by reaction with formaldehyde and an excess of phenol in the presence of an acid catalyst. The product, novolak, is thermoplastic and needs an added catalyst, usually hexamethylenetetramine, to make it thermoset.

A single stage resin is formed by reaction with phenol and an excess of formaldehyde in the presence of an alkaline catalyst. The product is thermosetting without the need for an additional catalyst.

Shell Process Hot Coating Resins

(1) Lump novolak consisting of
  (a) Phenol-formaldehyde polymer
  (b) Free phenol
  (c) Formaldehyde (trace)
  (d) Hexamethylenetetramine[1]
  (e) Release agents[1,2]
(2) Water-borne resins consisting of
  (a) Phenol-formaldehyde polymer
  (b) Free phenol

(c) Formaldehyde (trace)
(d) Ethyl alcohol (4 to 9 per cent)
(e) Water (5 to 25 per cent)
(f) Hexamethylenetetramine[1]
(g) Release agents[1,2]

Shell Process Cold Coating Resins

(1) Dry powder containing
(a) Ground lump novolak
(b) Hexamethylenetetramine
(c) Metallic stearates[1]
(d) Denatured alcohol
(e) Water[1]
(2) Varnish (alcoholic solution) containing
(a) Dissolved lump novolak
(b) Denatured alcohol (25-35 per cent)
(c) Hexamethylenetetramine[1]
(d) Release agents[1,2]

Dry Blend Shell Process

The dry blend process consists of mixing the sand grains with the dry powder previously described under cold coating resins.

Baked Resin Core Binders

(1) Liquid phenolics (single stage)
(a) Low mol. wt. phenol-formaldehyde polymer
(b) Free formaldehyde (3-5 per cent)
(c) Phenol (trace)
(d) Water
(e) Alkaline catalyst residue
(2) Powdered phenolics (single stage)
(a) Higher molecular weight phenol-formaldehyde polymer
(b) Free formaldehyde
(c) Phenol
(d) Alkaline catalyst residue
(3) Liquid urea
(a) Free formaldehyde
(b) Urea (trace)
(c) Water
(d) Catalyst residue (inert)
(4) Powdered urea
(a) Higher mol. wt. urea-formaldehyde polymer
(b) Free formaldehyde
(c) Free urea
(5) Furfurylated urea-formaldehyde resins
(a) Furfurylated urea-formaldehyde polymers
(b) Free furfuryl alcohol
(c) Free formaldehyde
(d) Urea (trace)
(e) Water
(f) Catalyst residue

1. Materials added during coating process.
2. Release agents include metallic stearates, high melting point waxes, or silicone polymers.

Hot Box Resins (Wet Resin Sand)

(1) Urea-formaldehyde resins containing
(a) Furfurylated urea-formaldehyde polymers
(b) Catalysts
Salts (range: neutral to very acid)
Inorganic acids
Organic acids
(2) Modified phenol-formaldehyde resins
(a) Phenol-formaldehyde polymer
(b) Urea-formaldehyde polymer
(c) Free phenol
(d) Free formaldehyde
(e) Free urea
(f) Catalyst (salts)

Self Curing Resin Binder Systems

(1) Furan binder containing
(a) Furfuryl alcohol formaldehyde polymer
(b) Free furfuryl alcohol
(c) Free formaldehyde
(d) Catalysts residues (inert)
(e) Strong acid catalysts
(2) Modified furan binder containing
(a) Same as furan binder
(b) Urea-formaldehyde furfuryl alcohol polymers

Toxicity

Almost all of the materials and their decomposition products used in the shell process are toxic, but organic impairment of the body is not likely to occur in the normal operation. The principal effect on man is dermatitis; and even dermatitis does not occur from completely polymerized resins but rather from the excess of free phenol, free formaldehyde, hexamethylenetetramine or alcohol.

Formaldehyde

Formaldehyde has an irritating effect on the eyes, mucous membrane and skin. It has a pungent and suffocating odor so that a toxic atmosphere is intolerable to man. However, numerous cases of dermatitis have been reported among workers handling it. The maximal allowable concentration in air (MAC) is five parts per million. The MAC for formaldehyde is not a level which if exceeded would result in poisoning, rather it is a level which if exceeded will result in a nuisance and unpleasant environment.

Phenol

Phenol is a well known poison and is not only a skin irritant, but is a local anesthetic as well so that burns may not be felt until serious damage has been done. It can be absorbed through the unbroken skin and appear in the urine to which it imparts a smoky color. Therefore, besides being capable of causing dermatitis, it can do organic damage to the body. The maximal allowable concentration in air is five parts per million.

Hexamethylenetetramine

This material is not known to cause organic poisoning. It is, however, a primary skin irritant which can cause dermatitis by direct action on the skin at the site of contact, if permitted to act in sufficient concentration and for a long enough time.

Furfuryl Alcohol

There have been no reports from industry of health hazards associated with the use of furfuryl alcohol. Daily doses of one gram to dogs were without effect, and a dose of 150 milligrams administered orally to man caused no disturbance. However, as with other alcohols, it will defat the skin and therefore contact with it should be avoided as much as possible. It reacts with mineral acids (even dilute) and some strong organic acids with explosive violence. Therefore, great care should be taken to avoid accidental mixing with such acids.

Ethyl Alcohol

Ethyl alcohol is practically nontoxic and relatively nonirritating to the skin. However, continuous daily contact with it will produce cracking of the skin. Its vapors are highly irritant to the eyes. The MAC is 1000 parts per million.

Methyl Alcohol

Methyl alcohol is sometimes used instead of ethyl alcohol. The former is poisonous. Systemic poisoning can occur from absorption through the unbroken skin or from prolonged inhalation. It has a particular effect on the optic nerve. The oxidation and removal of methyl alcohol from the body requires a greater period of time than for ethyl alcohol. Consequently, there is not only a prolonged effect following a single overexposure to methyl alcohol vapor, but also a tendency for it to accumulate in the body.

The systemic effects are due to the conversion of methyl alcohol to the more toxic products of oxidation, formaldehyde and formic acid. It should be noted that methyl alcohol can generate vapor concentrations in air greater than twice those of ethyl alcohol. Because of this difference in their rates of evaporation, any given vapor concentration of methyl alcohol will be generated more quickly than the same vapor concentration of ethyl alcohol.

Hence, because of its toxic nature and greater volatility, methyl alcohol is much more hazardous than ethyl alcohol and therefore much more effective and extensive ventilation is required for methyl alcohol. It is also insidiously toxic, because of its virtual lack of warning properties as contrasted with those of ethyl alcohol. Therefore, in the case of methyl alcohol, ventilation sufficient to maintain vapor concentrations below 200 parts per million (the maximal allowable concentration) is required. Whereas in the case of ethyl, ventilation sufficient to eliminate a fire hazard is all that is necessary. This will be described later. Obviously, any horseplay with poisonous materials should not be tolerated.

Urea

Urea decomposes to carbon dioxide and ammonia. Ammonia has adequate warning properties and is intolerable in toxic concentrations.

Silicones

The nonhydrolyzable types of silicones used as mold release agents are of a low order of toxicity. From a practical standpoint the hazards of handling them are minor. The hydrolyzable types, however, are highly corrosive and can cause severe burns, but they do not possess the physical properties required for shell operations and therefore are not likely to be used in the foundry.

Carbon Monoxide

Carbon monoxide is given off during pouring operations. The MAC for an 8 hr exposure is 100 parts per million. The atmospheric concentration of toxic dusts can be averaged for an 8 hr day to arrive at the MAC. Thus, peak concentrations far in excess of the MAC can be cancelled out by those concentrations which are far below the MAC and no deleterious effects will result.

This is not true for carbon monoxide. For example, an exposure to carbon monoxide of 400 parts per million for one hr is the maximum tolerable without noticeable effects even if the exposure for the rest of the day is zero. Tubich, et al,* found peak breathing zone concentrations of 600-700 parts per million during pouring of shell molds. The lethal effects of even short exposure to high concentrations of carbon monoxide are well known.

Smoke

Smoke is an atmospheric contaminant resulting from incomplete combustion, and consisting predominantly of small gas borne particles of carbonaceous material. It is given off during baking and pouring of shell molds. Smoke, per se, from shell molds or cores is innocuous, and only in heavy concentrations is it a nuisance.

Silica Dust

Silica dust from shell operations has the same effect on the lungs as that from any other foundry operation, and is therefore capable of producing silicosis under certain conditions. However, in order to produce silicosis there must be sufficient exposure in terms of time and concentration, to free crystalline silica dust of particle size below five microns. It usually requires two to 20 years (average 10), and then only when dust concentrations greatly exceed the maximal allowable, to produce a case of silicosis.

The maximal allowable concentrations of silica-bearing dust are:

Dust	MPPCF*
Above 50% free silica	5
5 to 50% free silica	20
Below 5% free silica	50

*Millions of particles per cubic foot of air.

It may be stated that the silicosis risk from the shell process is no different than the risk in conventional foundry operations.

*A.M.A. *Archives of Industrial Health, vol. 21* p. 424 (May 1960).

Dermatitis — Prevention and Precautions

Predisposing Causes

These are the principal factors concerned with predisposition to dermatitis.

(1) **Nature of the skin.** Persons with red hair or fair skin are more susceptible than those with dark complexions. Oily skins withstand solvents better than dry skins. Hairy skins are more apt to develop oil folliculitis than dry skins.
(2) **Age.** Young workers are usually more susceptible than older workers.
(3) **Sex.** There are less cases of dermatitis among women; probably because of cleaner habits, and because they ask for treatment for the slightest skin irritation.
(4) **Season of the year.** Dermatitis is more prevalent in warm weather than in cold.
(5) **Perspiration.** One who perspires excessively is more susceptible to dermatitis than one who does not.
(6) **Skin diseases.** Workers with open skin lesions are more likely to be affected.
(7) **Allergy.** Despite all precautions, dermatitis will occur in those persons allergic to resin bonded sand.
(8) **Uncleanliness.** This is probably the most important factor in predisposing to dermatitis.

Prevention

An unusually extensive dermatitis under conditions of proper cleanliness, subsiding on removal from exposure, and flaring up after return to use of resin, indicates that the person involved has become allergic. Further work with this material by this person is not recommended. The wearing of rubber or latex gloves over a pair of throw-away cotton gloves has been found to give effective protection.

Protective hand creams are of some benefit, especially when used as an adjunct to other personal protective equipment. Adequate facilities for washing, showering and changing work clothing should be provided. A simple safety rule would be: "Avoid contact as much as possible by any feasible means and observe personal cleanliness."

Treatment

Treatment of dermatitis should be given by a physician, or a nurse acting under his orders. Treatment by nonmedical personnel should not be permitted.

Foundry Control

Carbon monoxide. In general, local exhaust systems generally used on mechanized pouring lines will be adequate for controlling carbon monoxide during pour off.

Silica dust. Silica dust from shell operations usually occurs in significant quantities during shakeout and dry mixing. However, because of the excellent casting peel from the shell and absence of burn in, silica dust exposures in the cleaning room are far less than in other types of casting cleaning. Methods for control of foundry dusts are adequately described in the AFS Engineering Manual for Control of In-Plant Environment in Foundries.

Acids and acid salts. Acids and acid salts should be handled in such a way as to avoid spattering or contact with the body. Depending on the type of exposure for operations involving the use of these materials, consideration should be given to the need for corrosion resistant devices such as hoods, face shields, sleeves, boots, aprons, leggings, spats and protective creams.

Alcohols. The alcohols are highly flammable, and should never be used near open flames or other sources of ignition. Containers should be periodically inspected for leaks. Clothing accidentally saturated with alcohol should be immediately removed and dried out. In one plant, a man was burned to death when he approached an open flame with alcohol saturated clothing.

Explosion hazards. Blending the resins, sand and alcohol in a muller is dangerous unless the vapors rising from the muller are properly diluted with air. A safe dilution is 3 cfm/lb of sand capacity. This exhaust volume prevents escape of dust and vapor, and keeps the atmosphere inside the mixer below 25 per cent of the LEL (Lower Explosive Limit) for air-ethyl alcohol mixtures. These exhaust volumes are confirmed by using this standard dilution formula.

$$Q_{LEL} = \frac{388 \times 100 - (\%\ \text{of LEL})}{\text{Mol. Wt. of Liquid}}$$

Where

Q_{LEL} = Dilution air required per lb ethyl alcohol evaporated.
388 = cu ft vapor occupied by mol. wt. in lb of any vapor.
LEL = 4.3% for ethyl alcohol (ethanol).
Mol. Wt. = 46 for ethanol.

Substituting:

$$\frac{388 \times 100 - (25\% \times 4.3)}{46} = 843 \text{ cu ft}$$

A 1000 lb sand batch in which 3 lb ethanol are added and evaporated in 10 min:

Air required for safety

$$3 \text{ lb ethanol} \times \frac{843 \text{ cu ft}}{\text{lb}} = 2523 \text{ cu ft}$$

Air actually supplied

$$10 \text{ min} \times 1000 \text{ lb sand} \times \frac{3 \text{ cu ft}}{\text{lb sand}} \text{ or } 30{,}000 \text{ cu ft/lb}$$

As far as explosion hazard is concerned, this is enough air even for an open type mixer. It is also enough from a toxicity standpoint, as shown by the formula for the maximal allowable concentration (MAC) of ethanol is 1000 parts per million:

$$Q_{MAC} = \frac{388 \times 1{,}000{,}000 \times K}{\text{Mol Wt Liquid} \times \text{MAC}}$$

Where

Q_{MAC} = cu ft dilution air required per lb ethanol.
K = An experience factor varying from 3 to 10.

Substitution (using lowest K factor):

$$Q_{MAC} = \frac{388 \times 1{,}000{,}000 \times 3}{46 \times 1000} = 25{,}300 \text{ cu ft/lb}$$

Assume as before 3 lb ethanol are evaporated in 10 min.

Then:

$$\frac{3 \text{ lb ethanol}}{10 \text{ min}} \times \frac{25{,}300 \text{ cu ft}}{\text{lb}} = 7590 \text{ cfm required}$$

Air actually supplied:

$$\frac{3 \text{ lb ethanol}}{10 \text{ min}} \times \frac{30{,}000 \text{ cu ft}}{\text{lb}} = 9000 \text{ cfm}$$

Sometimes methyl alcohol (methanol) is used instead of ethanol. In such event, 9000 cfm would be sufficient to prevent explosion, but approximately five times more would be required from a toxicity standpoint. In either case, the amount of dilution air is large, so that the use of a closed top muller exhausted to 25 per cent of the lower explosive limit is indicated.

Resin dust is explosive also, as are other finely divided organic or metallic dusts such as hexa, magnesium and the like. In one case, maintenance men, working overhead, disturbed a three year accumulation of resin sand dust on the rafters. The dust cloud was ignited by the gas flame in the shell curing ovens causing an explosion. The practice of blowing down dust with compressed air may create explosive dust clouds. Settled dust should be removed by wet or vacuum methods.

General

The irritating atmospheric contaminants such as phenol, formaldehyde, ammonia and the like, arising from shell operations are a nuisance. The amount and type of exhaust ventilation required for good working conditions will depend on the local situation. Experience to date shows that hazards involved in making castings in shell are no more serious than those related to other foundry methods.

PATENTS

It is normal for any new process or development to attract many investigators, and it is through their efforts in many cases that improvements and refinements are made. The tremendous amount of effort that has been expended in the refinement of the shell process has brought about many changes in the methods, materials, and equipment used. Many of these innovations were new, novel, and useful, therefore, patentable and a number of patents have been issued, and other applications are pending.

The following are several of the more important patented improvements that have been made.

Chester W. Fitco, U.S. Patent No. 2,706,163 — (April 12, 1955), *Coated Sand and Method of Producing the Same.*

Chester W. Fitco and John S. Horn, U.S. Patent No. 2,706,188 — (April 12, 1955). *Production of Resin Coated Particle Material.*

Chas. F. Froherger, U.S. Patent No. 2,751,650 — (June 26, 1956). *High Strength Shell Molds.*

X. L. Bean, U.S. Patent No. 2,914,823 — (Dec. 1, 1959). *Casting Mold and Pattern and Process.*

Frank W. Less et al., U.S. Patent No. 2,965,514 — (Dec. 20, 1960). *Process for Coating Particles With a Thermosetting Phenolic Resin.*

John R. Lewis, U.S. Patent No. 2,990,594 — (July 4, 1961). *Shell Molding Composition and Process.*

X. L. Bean, U.S. Patent No. 2,991,267 — (July 4, 1961). *Coated Sand and Method of Making the Same.*

Chas. F. Froherger, U.S. Patent No. 2,997,759 — (Aug. 9, 1961). *Shell Molding Mixture.*

Chas. F. Froherger, U.S. Patent No. 3,004,312 — (Oct. 17, 1961). *Process of Shell Molding.*

F. W. Less et al., U.S. Patent No. 3,020,254 — (Aug. 9, 1955). *Phenolic Resin and Molding Composition.*

John Abanese et al., U.S. Patent No. 2,888,418 — (Oct. 22, 1953). *Production of Coated Sand.*

F. W. Less et al., U.S. Patent Re. 25661 — (Oct. 13, 1964). *Process for Coating Particles With a Thermosetting Phenolic Resin.*

Chapter 22

SILICATE BONDED CORES

GENERAL PRINCIPLES AND APPLICATION

Silicate bonded cores are used because of their accuracy and simplicity. They may be blown or rammed by any of the usual means. The metal, size of core, or type of core box is not critical. Special equipment is limited to gassing probes or cups and a source of carbon dioxide gas (CO_2). Curing is complete in a few seconds in the core box and at room temperature, after which the core may be drawn and used immediately.

One published list of the favorable attributes of the silicate process is as follows.

(1) Cores without driers.
(2) Smoother cores for the same grain size.
(3) Exact size.
(4) Cores can be ready in 5 minutes after core box arrives.
(5) Very low gas.
(6) Rods and wires limited to lifting hooks on large cores.
(7) Dry sand, rigid wall molds.
(8) Reduced shrinkage of metal.
(9) No limit to size.
(10) Low equipment investment.
(11) Minimum operating skill required.
(12) No ovens required.

The drawbacks of the process are: occasional lower collapsibility than oil cores; the necessity of keeping the mixed sand well covered; a somewhat softer surface than with resins or oil; and the necessity of studying and understanding peculiarities of silicates.

Some of the most common applications are small blown cores and stack molds in high production, facing medium-sized jobbing work, and the making of large dry sand cores on the floor. Skeleton core boxes may be strickled with the aid of a little clay in the mix. Figures 22.1 — 22.5 show the range of castings and cores that have been made successfully in CO_2 hardened silicate sands.

Many foreign foundries have reported complete conversions to silicate bond in the core and in the mold. The process depends on the ability of CO_2 gas to harden a viscous water solution of sodium silicate in the thin films which exist on the sand grains in as little as 10 sec.

By using hollow tube probes, gas holes in the core box, or gassing boards, the hardening is easily done while the core is still in the box. Air and oven drying also develop a high strength. About one per cent or 2 per cent of bentonite may be used to allow green stripping, although in this case, the exactness of hardening in the core box is lost.

A very slight shrinkage of the sand occurs on gassing, which aids release. Alcohol also appears to harden the binder, but actually leaves a supercooled liquid

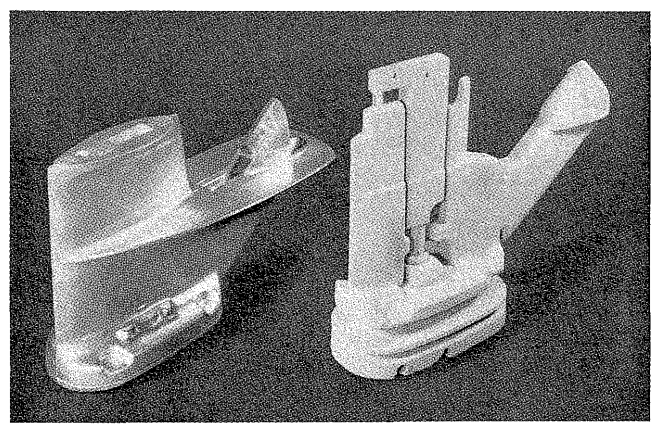


Fig. 22.1 — Casting and core for outboard motor.

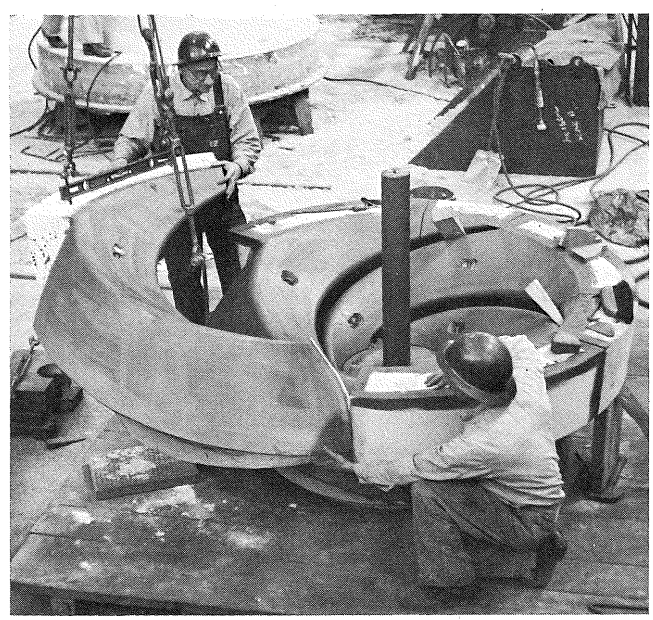
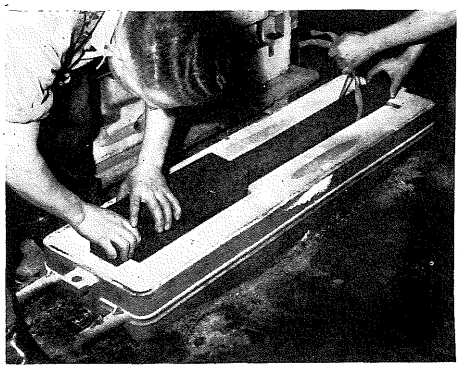


Fig. 22.2 — Bronze propellor core in silicate sand.



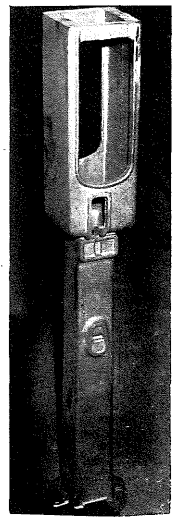
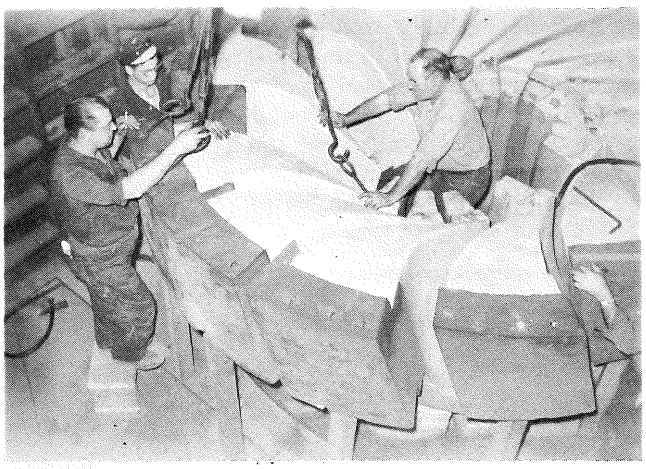


Fig. 22.3 — Scale housing (right) and its CO_2 core being set (above).



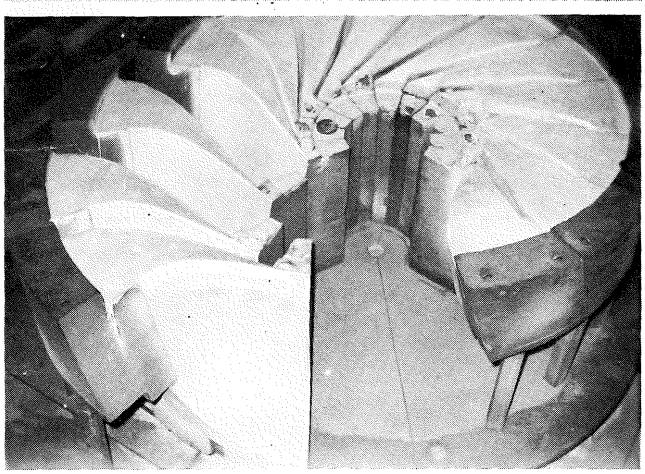


Fig. 22.4 — CO_2 cores being assembled for a large turbine.

that will allow the core to distort slowly if it is not supported. Solutions of calcium chloride or most acids will permanently harden the silicate, but are not feasible in the core room.

One equation given for the hardening effect is as follows:

$$Na_2\,SiO_3 \cdot xH_2\,O + CO_2 \rightarrow SiO_2 + Na_2\,CO_3 \cdot xH_2\,O$$

The exact chemistry is somewhat hazy. Bonding may be partly due to the sodium carbonate crystals themselves, as well as the silicic acids and gels which are formed. The one fact that should always be borne in mind is that the strength of a silicate core is almost always changing after the initial gassing, either up or down, depending on how much it was gassed and on the type of silicate used.

HISTORY

Sodium silicate is a very old foundry binder. The first record of its use is in a British Patent of 1898 issued to Hargreaves and Poluson, Chemists. Some sources claim that there were no foundry trials made at that time, while others claim that Poluson used the process at a foundry in Widnes. Their patent reveals using a silica gel which was previously made with silicate and an acid salt or by mixing sodium bicarbonate into the sand with the silicate. Gassing with CO_2 is not mentioned in the patent.

Foundry trials using sodium silicate as a core binder and alcohol as a hardening agent were made at the Dow Chemical Foundry in 1943. The type of bond produced and the lack of organic collapse ingredients made it impossible to remove the core from a magnesium casting. Trials with exothermic salts were also unsuccessful as were those with silicates and detergents which could not then be hardened.

The use of CO_2 and the use of organic collapse ingredients seem to have been developed in 1947 in a steel foundry in Czechoslovakia by L. Petrzela and patented in England in 1948.

Introduction of the process into Germany occurred in 1952. First trials in England were in 1954 in South Wales. It was brought to the United States soon after that from Germany as the Schmidt-Philipp Process.

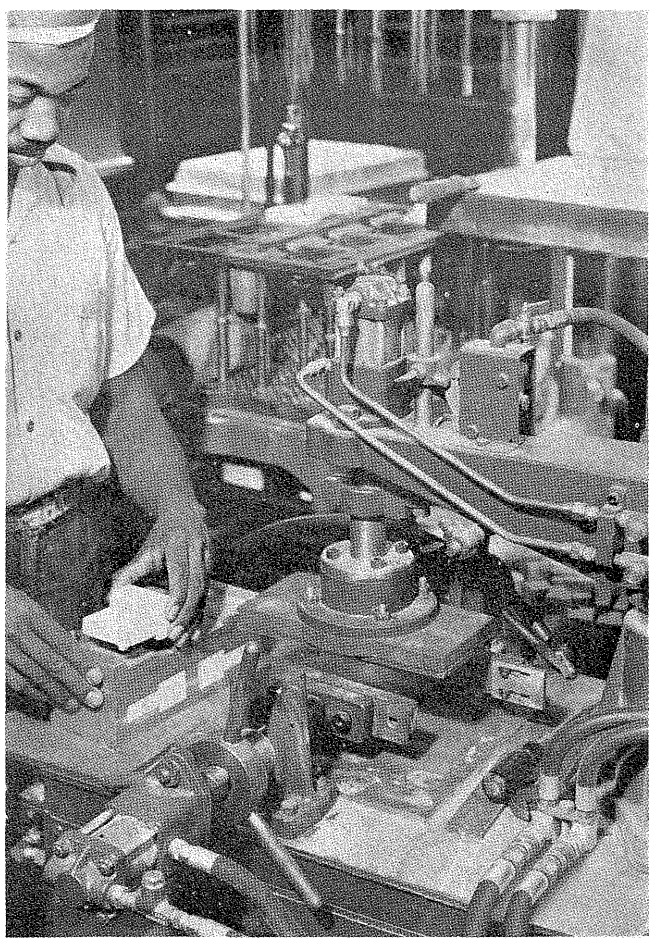


Fig. 22.5 — Small CO_2 cores blown and gassed.

Many Americans saw the process demonstrated for the first time during the 1955 AFS Convention in Houston, Texas. Further refinements in the binders and process are described in a 1956 United States Patent issued to F. S. Brewster.

Formulated binders ranging from very high collapsibility (high organic content) to almost plain silicates are available. One producer lists seven grades. It is feasible to compound silicate binders at the time of mixing the sand, providing adequate technical supervision and controls are available.

BINDER

Sodium silicate is made by fusing soda ash and silica sand in the ratio of one part Na_2O to 3.22 parts of sand on a per cent by weight basis. The molten glass is cast into small pigs which are later dissolved by heat and pressure to make the water glass of commerce. Foundry binders are made from silicates which have had sodium hydroxide added to the above water glass to get various ratios as low as one part Na_2O to 1.6 parts SiO_2. The more alkaline varieties are more soluble and allow the handling of more concentrated solutions and also will tolerate more organics such as sugars, etc., to be included. The more alkaline the binder, the slower they gas and the more the tendency for the core to be rubbery instead of firm. Potassium silicates are also made for special adhesive uses. The ratios are stated as molecular percentages in this case.

The most useful silicates for foundry cores are from the 1:2.2 ratio to 1:2.6. A typical silicate having a Baumé of 52 degrees can accept up to 30 per cent solid sugar or its equivalent, and still be flowable. Liquid organics such as molasses may be used, although the silicates are very touchy about water being added or subtracted. Soft and weak cores result in either case.

The binder is not corrosive and can be handled in steel drums. A little oil on top prevents troublesome skins from forming. Core binder contents as low as 2½ per cent are used with clean, dry sand and good core room practices. In other cases, 6 per cent or 7 per cent may be advisable for fine sands or those having clay in them, either accidentally or for the purpose of green stripping.

The better commercial binders are made almost to the limit of pourability viscosity for quality reasons. Figure 22.6 is a temperature viscosity curve for one such binder.

Figure 22.7 shows a chart correlating the amount of binder with the fineness of the sand. Powdered anhydrous sodium silicates are available, but are difficult to dissolve and quite expensive. The powdered grades are also available with 17 per cent of moisture, which makes them readily soluble. They are also more expensive than liquids and are only used in special cases.

The famous Antioch Process uses sodium silicate with gypsum, sand, talc and asbestos. The slurry is piped into core boxes and hardens in 5 to 10 min. Precision castings are made in this manner.

SAND REQUIREMENTS

Sands for the process should always be dry which means not more than the usual .15 to .25 per cent moisture held in equilibrium with the air. Almost any sand can be used, which includes silica sands, bank sands, lake sands, etc. Zircon, chrome ore, and olivine are also acceptable. Angularity of the grain increases the binder content, as usual. Normally, the best collapse is obtained by using clean sand and a minimum amount of binder. Lime contamination can have a special meaning by reacting with the binder to harden it.

MIXING AND HANDLING

Unless silicates are allowed to get too cold in the winter, they may be mixed in a slow speed mixer for from 3 to 5 min. The least mixing that produces uni-

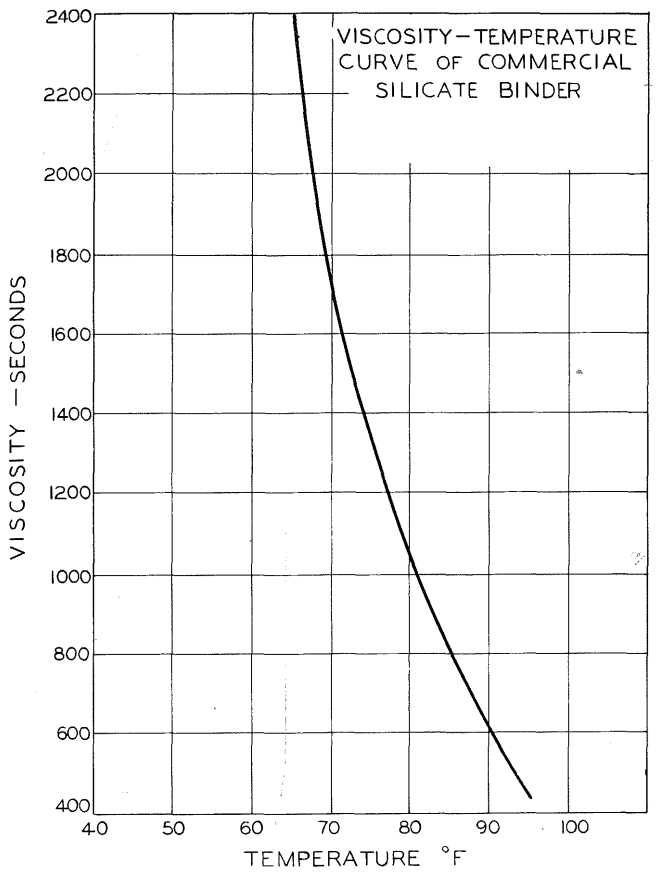


Fig. 22.6 — Viscosity-temperature relation for a silicate binder.

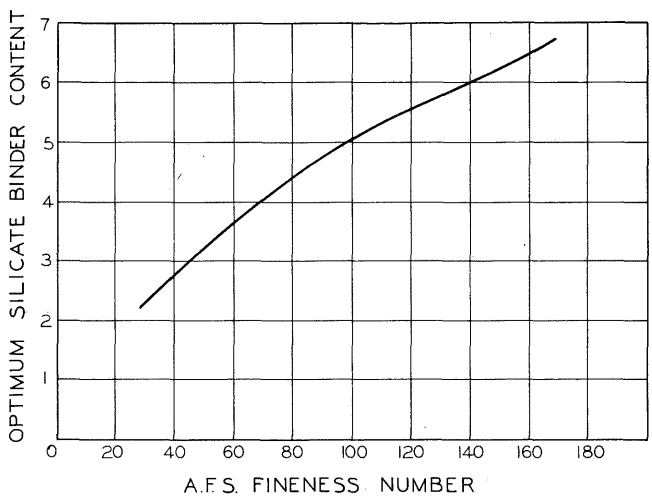


Fig. 22.7 — Fine sands require more binder.

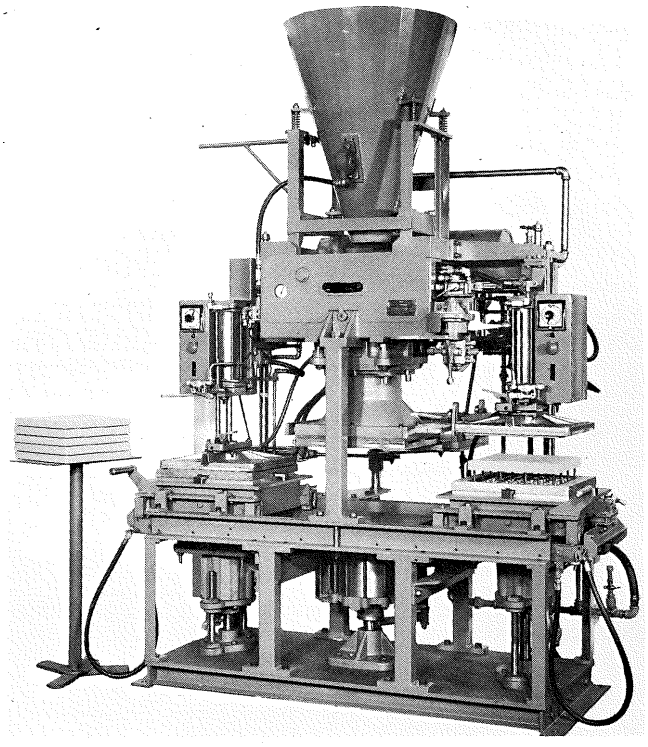


Fig. 22.8 — CO_2 core blower with twin gassing stations.

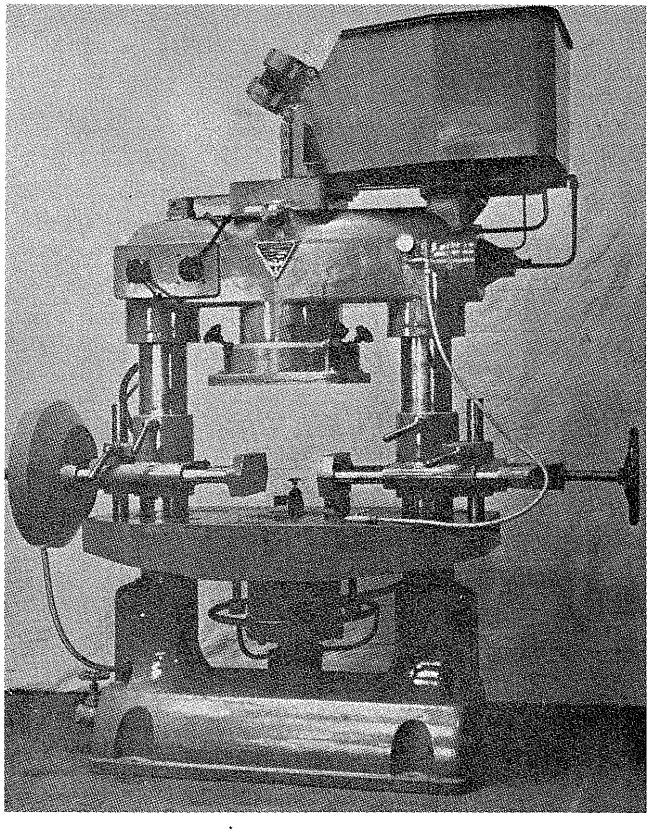


Fig. 22.9 — Core shooter for silicate sands.

form dispersion is the best. Overmulling can quickly produce a dry, crumbly mix which is not usable.

A little sand conditioning oil (internal parting) in the amount of 4 to 6 oz per 100 lb of sand may be mulled with the dry sand for 2 min before adding the binder. This shortens the mulling time about 25 per cent and makes the sand flow considerably better. No damage is done to other properties.

Some additives assist collapse without interfering with properties. These include one to 2 per cent pitch (pelleted or otherwise) or seacoal. The use of 2 per cent iron oxide seems to give a harder, sharper core. In the unlikely event that extreme moisture resistance is required, zinc oxide and other heavy metal salts lend waterproof resistance. Outdoor statuary falls in this category. Wood flour is not entirely satisfactory, but is tolerable if used with equal weights of water — not over one per cent.

The collapse agents mentioned above are, of course, in addition to the 20 per cent to 30 per cent organic material already present in a high grade binder. The percentages for pitch, iron oxide, etc., are percentages of the total batch weight. Bentonite in the order of 2 per cent allows the core to be stripped from the core box green for hardening under a gassing hood or in an oven. The use of 1½ per cent bentonite, plus a few hours maturing is recommended for hand work such as skeleton core boxes. A small amount of phenolphthalein is sometimes used to color the batch red. This color fades upon gassing and gives a rough indication of the completion of hardening.

When making magnesium cores, about 2 per cent sulfur is included to prevent the metal from burning. Boric acid reacts with the silicate and cannot be used. There is a likelihood that some of the more insoluble protective agents such as potassium fluoborate can be used.

English research has developed the use of one to 1½ per cent pelleted ammonium chloride as a breakdown additive. Another European development is to include some sodium silicate in it with the regular no bake resins. A short gassing gives enough strength to strip the core and let it cure by itself, thus, longer working times can be scheduled for the no bake sand and the core box is immediately released for further production. Too many so-called collapse agents merely lower the gassed strength, which could have been done better by reducing the binder content.

If only moderate gassed strength can be tolerated, the higher ratio silicates such as 1:2.9 will give very low retained strength in the 1000 F (538 C) area and excellent core knockout. Gassing time for these ratios is quite short, but the storage life of the core is poor as is the storage life of the mixed sand. Hardening surface sprays are especially desirable in these cases.

COREMAKING AND EQUIPMENT

A great deal of the success of silicate coremaking comes in how well the mixed sand is protected against evaporation. Close scheduling of mixing and coremaking is highly desirable as in the case with the cold cure and cold set binders. Blow magazines with dead pockets allow some sand to get old and dry and plug blow holes much the same as with hot box resins.

When one batch of dyed sand precedes the main flow of uncolored sand, these dead spots may be observed on opening the magazine and can then be filled in with metal pieces. In this way, straight through sand flow is obtained. Tightly covered bins and hoppers at the coremaking station are almost a necessity. The same coremaking procedures can be used for silicates as for oil or resin. Silicates will blow, sling, jolt, squeeze and butt ram very much the same as a typical

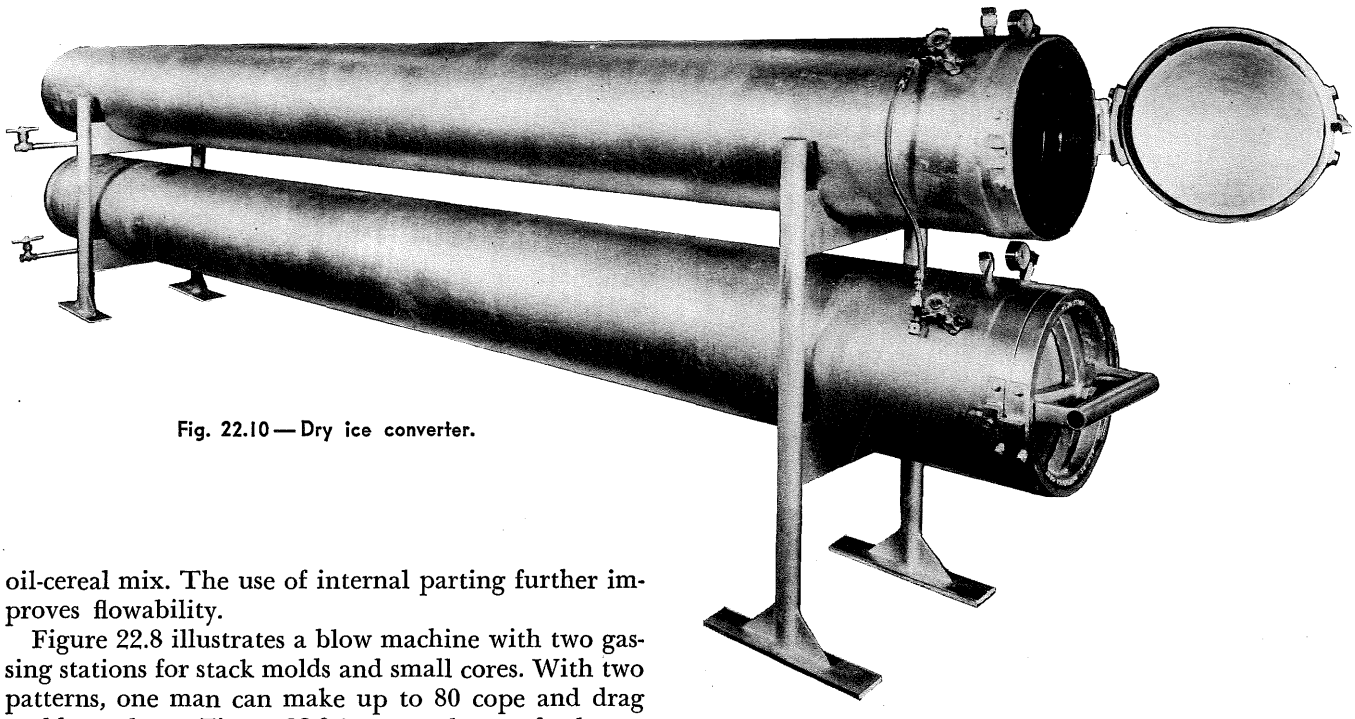


Fig. 22.10 — Dry ice converter.

oil-cereal mix. The use of internal parting further improves flowability.

Figure 22.8 illustrates a blow machine with two gassing stations for stack molds and small cores. With two patterns, one man can make up to 80 cope and drag molds per hour. Figure 22.9 is a core shooter for larger cores.

CORE CURING

Soft ramming and failure to tuck pockets will result in soft, penetrated areas on the cores as with any other binder. One probe can harden a 6 in. cylinder of sand in a reasonable time (20 sec). Thus, holes must be punched on 6 in. cylinders before starting to gas a core. Either single or multiple probes may be used.

Serviceable probes can be made of $\frac{3}{16}$-in. steel tubing. Flare fittings and quick disconnectors are used on the one end, while the other end is closed by squeezing it in a three jaw drill chuck. The closed end is then drilled twice at right angles, just above the closure. The rubber cups for hydraulic cylinders make good gassing cups with the addition of a quick disconnector held on with a drilled pipe cap. Gassing boards are generally made of plywood and a gasket of sponge rubber. The core box may in some cases be ventilated to admit CO_2 gas.

The gas pressure at the probe is usually in the order of 5 to 50 lb, depending on the job. It is the time in contact with the gas that matters — the pressure only serving to send the gas a reasonable distance. The amount of gas used is always less than the formula would indicate, since the reaction is never brought to completion. In some cases, however, gas is wasted so that it is difficult to calculate how much reacts with the sand. Dilution of the CO_2 with air is practical where the gassing is liable to be wasteful.

One pound of CO_2 gas will harden 50 to 100 lb of sand. Thus, to cure 600 to 1200 lb of cores per hour, 6 cylinders of 50 lb each would be connected to a double manifold which allows the use of three cylinders at a time and the exchange of the empty cylinders without halting production.

The gas from the cylinder is at 850 psi at 70 F (21 C) and must be heated in the manifold to 170 F (77 C) before it reaches the reduction gage. Each of the three cylinders furnish 4 lb for a total of 12 lb per hour. A 570 watt heater is required. Without heating, the gas would cool to −30 F and freeze the regulator as it expands from 800 psi to the 30 psi working pressure.

Sponge rubber and plywood muffle boards can readily be made to cure a wide range of cores. A reasonable economy of production is obtained by using devices that allow the coremaker to continue ramming while his previous cores are gassing. This requires some scheduling of production and the use of more than one core box at a time.

Carbon dioxide may be purchased as dry ice, usually in 50 lb blocks. In this case, it is necessary to have a twin pressure chamber so one can be recharged while the other is on the line. If such a chamber is filled with dry ice and left for 12 hr, the entire contents will be liquid and gas existing at 70 F (21 C) and 850 psi pressure. Some controllable heat source, such as a hot water jacket or electric blanket, will reduce the time for liquification to ½-hr. As the gas is used, the liquid will finally be all evaporated and shortly thereafter, the pressure will drop. When the pressure has reached about 75 psi, the one container is cut off the line, exhausted and open for charging. Figure 22.10 shows a converter with one side open. Figure 22.11 illustrates various gassing arrangements.

VARIATIONS

A variation is called the Nishiyama Process. A typical mix used would be: 6½ per cent sodium silicate with a molecular ratio of 1:2 sodium to silica SG 1.3; 2 per cent 300 mesh, 75 per cent ferrosilicon; and 91½ per cent silica sand.

Calcium silicide can be used instead of the ferrosilicon. The reaction given is as follows:

$$Na_2 \cdot nSiO_2 + mSi + 2mH_2O$$
$$Na_2OmSiO_2 + nSiO_2 + 2mH_2 + \text{heat}$$

The sand is said to be superior to a gassed core in strength, refractoriness and collapsibility. Setting time of the ferrosilicon mix is 20 min to 2 hr, depending on the amount and fineness of ferrosilicon.

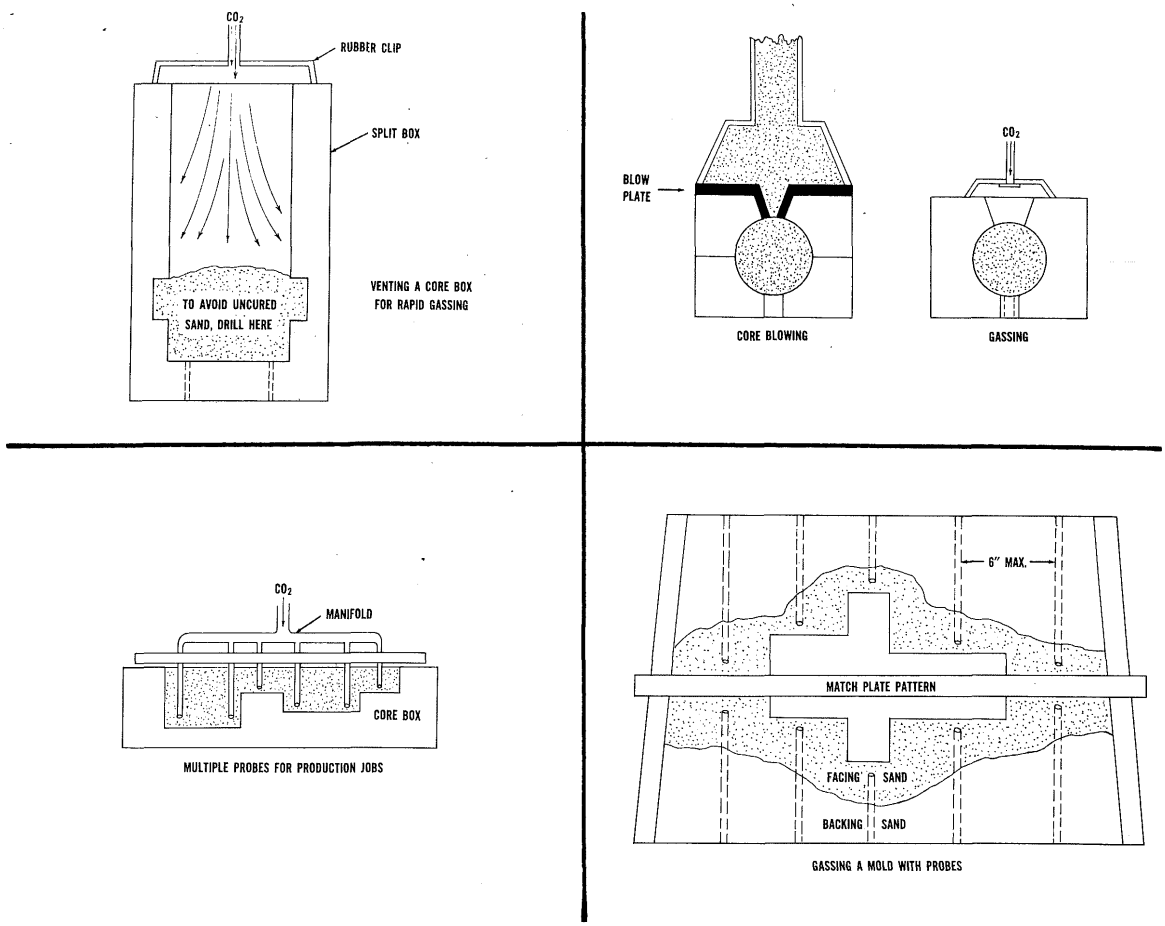


Fig. 22.11—Various gassing arrangements.

A sodium silicate based binder (exobond) is recommended for use at the 3½ per cent level with ¾ to one per cent ferrosilicon, 75 per cent and 325 mesh. Strengths of 300 psi are said to result from setting times of 20 to 120 min. Working time can be regulated to some extent by varying the percentage of ferrosilicon.

Fluid sand is another variation of the silicate process. Essentially, foaming agents are used to capture any gas produced or whipped in to make a self-hardening silicate core. Sand, however, is said to have something like the consistency of yogurt and is pumped around the foundry in pipes from which it flows into the core box.

One process described by Vorsouk and Liass uses 70 per cent sand, 28 per cent water glass with a specific gravity of 1.1 and 2 per cent of either nitric hydrochloric or sulfuric acid. The gel-like plastic mass first forms, which can readily be drawn from the core box. The residual 20 per cent water must be baked out before use.

Another CO_2 hardened fluid mix is as follows.

6 per cent water glass
Specific gravity 1.49
1.75 per cent water
0.4 per cent foaming agent
Remainder silica sand

The fluidity is controlled by additions of fatty alcohol which eventually destroy the foam. Foam may persist from 15 to 40 min. Vibrations of 0.5 to 2 millimeter amplitude and 1750 to 2500 vibrations per sec frequency may also be used to destroy the foam.

This process involves the following operations: vibrate one to 2 min; let set 67 min; vibrate one to 1½-in; gas with CO_2 10 sec; vibrate 8 to 10 min; gas with CO_2 one min.

A self-hardening fluid silicate sand is the subject of a French Patent by Liass and Borsouk. The mixture is as follows.

0.3 to 0.5 per cent foam producer
6 to 7 per cent sodium silicate
Specific gravity 1.49
7 to 10 per cent nepheline tailings (dicalcium silicate)
Remainder silica sand
1.5 to 1.75 per cent moisture

This mix is slurried and piped around the foundry, although the mixer shown shows an exit trough similar to a concrete mixer. Setting begins in 15 min as the calcium reacts with the silicate. A foam destroyer is sometimes necessary.

All of these practices seem to take more time than the regular CO_2 silicate procedure but may be better suited to huge cores which are difficult to gas. A shortage of −300 mesh, 75 per cent ferrosilicon has hampered development somewhat.

SURFACE TREATMENT

There is a tendency for silicate cores to have a softer surface than an equivalent oil core when the binder is kept at a figure consistent with good knockout. This is often remedied by spraying the working surface with an alcohol solution of resin. The alcohol is burned off to set the surface and at the same time, remove mois-

ture. The resin solution should be quite dilute (say one gal liquid resin in 20 gal of alcohol) to avoid possible peeling of the surface. The alcohol spray also serves to eliminate the necessity of oven drying to get rid of the last one per cent of moisture in the case of magnesium cores or any core totally enclosed in metal, such as a jacket.

Improvements in the surface finish may, of course, be made by using regular alcohol base core washes. It should be remembered that alcohol has a hardening effect on the silicate as against the softening effect of water base washes which also require oven drying. The use of 2 per cent iron oxide has an unexplainable strengthening effect. The choice of pigment in the wash such as silica, zircon, carbon, etc., lies more with the metal than with the binder.

CORE STORAGE AND STRENGTHS

Silicate cores should not be stored in humid areas for any length of time. They are, however, no worse in this respect than many of the resin binders in common use. If the approximate storage time is known at the time of gassing, adjustments in the amount of gassing can be helpful.

A normal silica sand with 5 per cent of a high collapse binder was tested in compression for the combined effect of gassing time and aging on collapse with the following results.

	15 sec gas time	80 sec gas time
As gassed	191 psi	237 psi
3 days old	281 psi	110 psi
3 days old, heated to 800 F (427 C) ½-hr, cooled and broken	85 psi	30 psi

Collapsibility at three days is almost three times as good as a result of long gassing, but the room temperature strength is also about one-third.

Figure 22.12 shows the progress of strength with age in a typical mix containing 5 per cent of a high collapse, commercial binder and silica sand. Short gassing gives a weak, as-gassed core which grows stronger with time. This is the air-dry effect which eventually will produce double the gas strength. This type of strength, however, is not too good for collapse. Medium gassing time gives reasonable as-gassed strengths and still stores well. Long gassing times give the highest immediate strengths, but cause a continual weakening of the core thereafter.

Thus, for cores that are liable to be stored for some time, the gassing time should be short to medium, and for those cores that are to be used within a few hours, the gassing time can be quite long for the benefit of both handling and collapse.

Since air and oven dried strengths are higher than gassed strengths, the poorest collapse is obtained by short gassing. Heat of the metal will finish the hardening before collapse sets in. If a core has been brought to peak strength by gassing, the only way it can go is down when the metal surrounds it. Furthermore, the structure obtained by gassing is more heat sensitive than that produced by oven drying.

The standard retained strength test has been shown to be the true measure of collapsibility. There has been a great deal of confusion in the published values between hot strength and retained strength of these sands.

Figure 22.13 shows the hot strength (soaked at temperature and broken hot) and the retained strength (soaked at temperature, cooled and broken). These

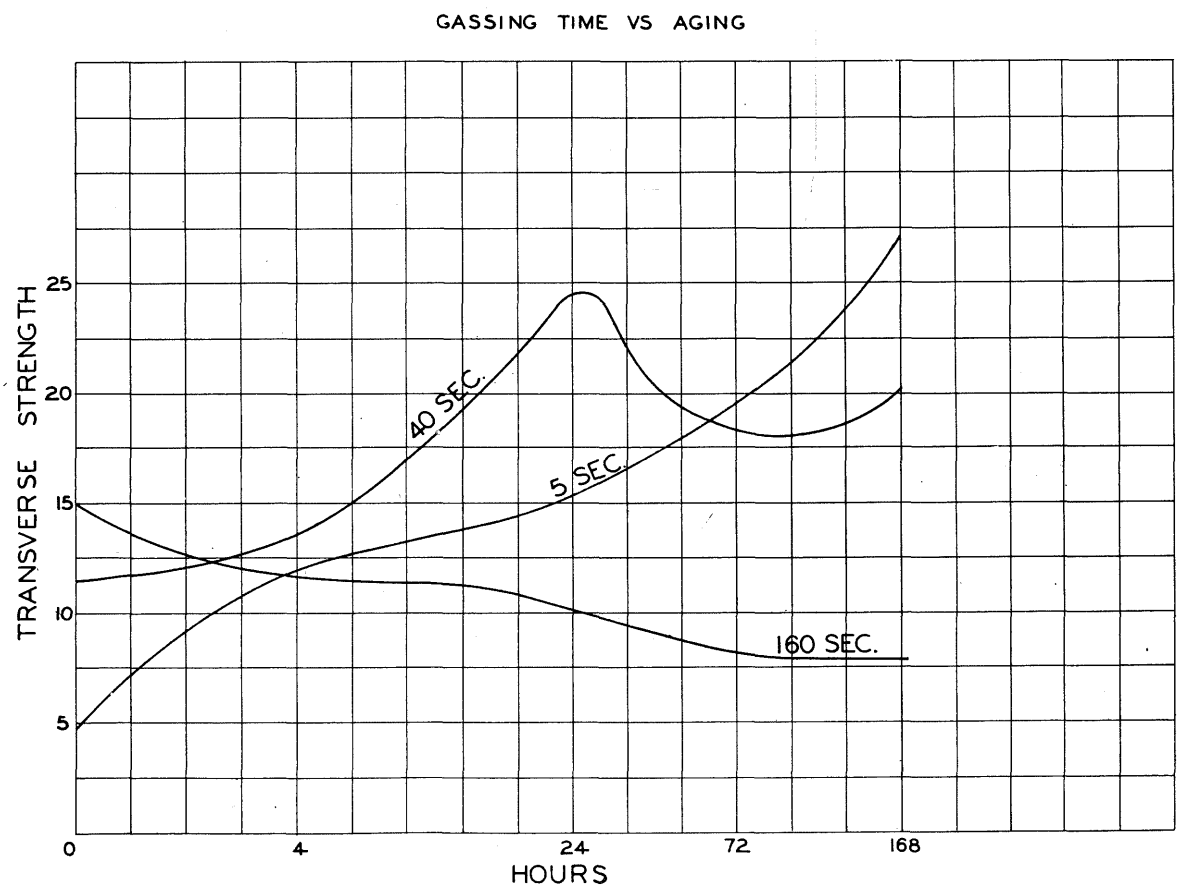


Fig. 22.12—Combined effect of gassing time and aging on strength.

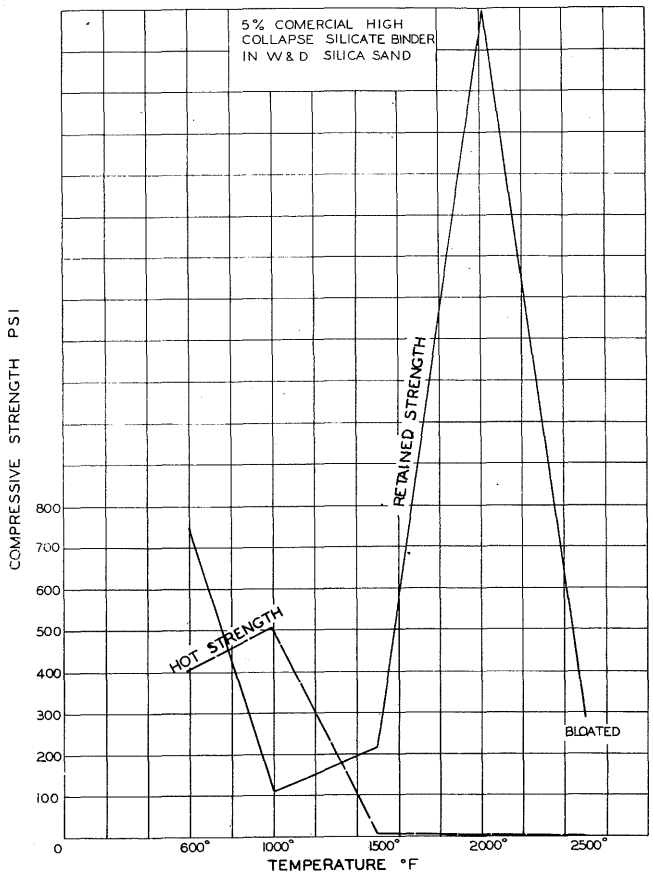


Fig. 22.13 — Hot and retained strength of a silicate sand.

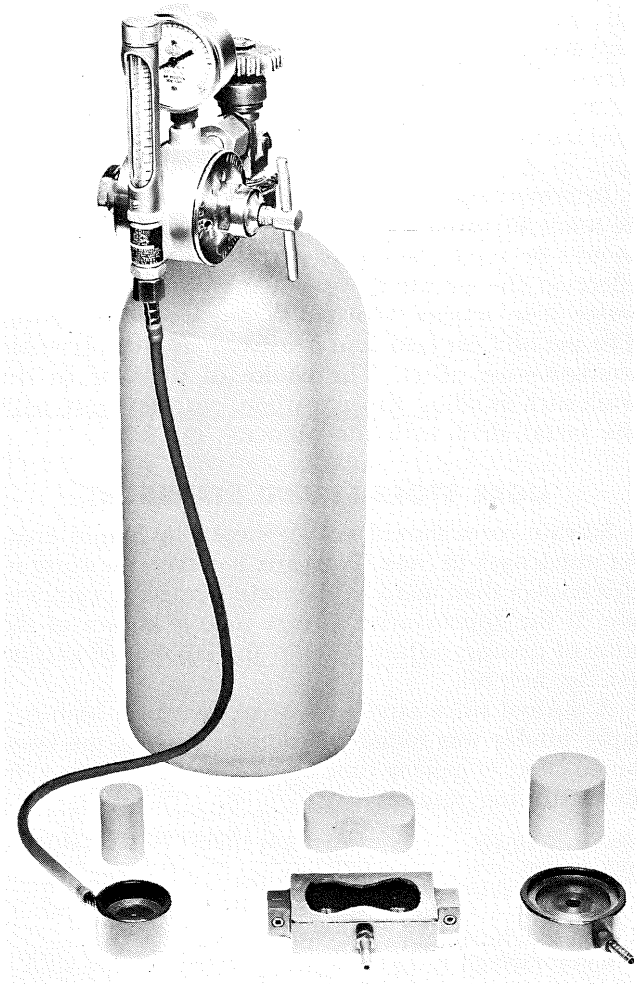


Fig. 22.14 — Test equipment for silicate sands.

two strengths are entirely different. As in the case of bentonites, the highest hot strength of silicates occurs at 1000 F (538 C) which is also the lowest retained strength point. The bentonites, of course, have 1850 F (1010 C) as the inversion point. Beyond 1000 F (538 C), the hot strength of silicates falls on account of incipient plasticity and finally, softening. The retained strength rises to a maximum at 2000 F (1093 C) by virtue of a sintering process and then finally falls at a higher temperature because the release of gas into the fused structure causes bloating. The low point of retained strength at 1000 F (538 C) explains the success of this type of binder with the light metals.

TESTING METHODS

Strength tests on silicate binders are made either by tensile, transverse or compression at room temperature and by compression in the dilatometer. Figure 22.14 shows a group of gassing fixtures together with cylinder, regulator and flowmeter. The specimens are rammed in the standard rammer and gassed in these fixtures. The inclusion of a timer and solenoid valve increase the convenience and accuracy of gassing. When gassing the 2 in. diameter permeability specimen, the shrinkage that takes place on gassing evidences itself by shooting the specimen out of the tube unless care is taken. The gassing fixture for the AFS Tensile Specimen and for the 1⅛-in. diameter dilatometer specimen are also included. The specimens are broken or tested on regular core sand testing equipment as in the case of oil or resin cores.

Other properties of the core such as gas, hardness, moisture, etc., are measured in the same laboratory equipment as that used for other types of sand. The silicates, in general, are lower gas producers than the organic core binders and especially so, if time or heat is allowed for the removal of the last one per cent of moisture.

The surface finish of the casting will be comparable with other binders using the same base sand. One outstanding advantage of a silicate core is that it is almost impossible to produce a vein or other expansion defect, due to a wide range of plasticity and the fact that plasticity starts at 1000 F (538 C), somewhat before the isothermal expansion of silica takes place at approximately 1063 F (573 C).

Chapter 23

OIL OXYGEN PROCESS OF COREMAKING

INTRODUCTION

In 1954 the oil oxygen process was introduced into the U.S.A. Heretofore, cores and molds were made from conventional type sand mixes either naturally bonded or synthetically formulated. These mixes were composed of various additives of fireclay, bentonite, wood flour, cereal, dextrines, oils, etc. Oils had been used for many years as binders in sand mixes but required additives to give strength to the sand mix in its green state. This meant ramming, high degrees of rodding for support and long oven curing cycles. With the advent of the oil oxygen process these problems were either alleviated, or eliminated.

PRINCIPLES OF PROCESS

The oil oxygen process is based upon the principle of auto oxidation. Auto oxidation is a form of oxidation by which drying oils absorb oxygen, isomerize to the conjugated form and then polymerize to the solid state. Auto oxidation is accelerated by metallic driers, by light and heat, and by the oxidation decomposition products that are being formed concurrently. The oil oxygen process might best be defined as one that utilizes both oxidation and polymerization mechanics on a combination of oils containing chemical additives so that the final product when activated with oxygen bearing materials will gel or set in a predetermined time.

A typical sand mix for the oil oxygen process would be as follows:

Sand
2% oil oxygen binder
5% to 15% activator (based on the amount of oil)

To date almost all types of sands have been found feasible to use with the oil oxygen oils. It is only necessary that the sand be dry and not over 100 F (38 C) in temperature so that control of set times can be dependable and reproducible.

The amount of binder required is dependent on the surface area to be coated. Approximately 2 per cent binder will coat sands of an AFS fineness of 45–55. Finer sands or more angular sands will require more binder and conversely coarser sands or less angular sands will require less binder.

The activators in the oil oxygen system are oxygen bearing materials such as perborates, percarbonates, permanganates, and peroxides. The amount of activator added to the sand mix will determine the working time or set time of that particular mix. The sand when mixed is extremely free flowing having no green strength. As the activators react with the base oils the oils partially gel or harden. This rate of hardening or gelling is controlled by increasing or decreasing the amount of catalyst or oxidizing agents. When the sand mass has partially hardened it is stripped from the core box or pattern as the case might be.

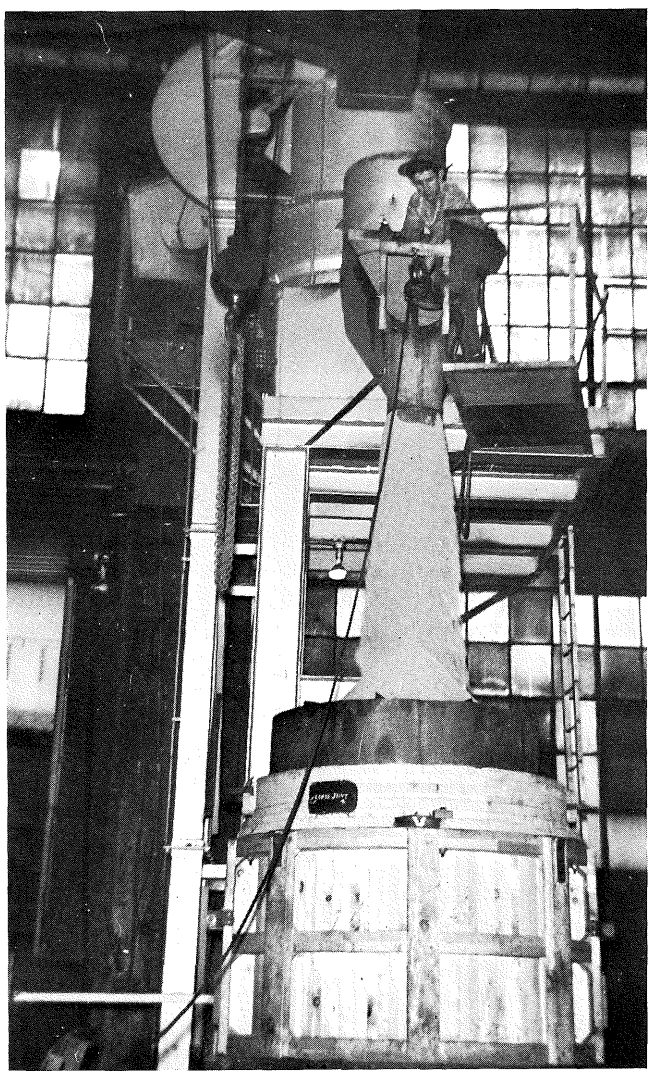


Fig. 23.1 — System for delivering sand directly to core box from muller.

OIL OXYGEN DAILY CONTROL CHART

No. of Mills	Weight	Temp. In (F)	Temp. Out (F)	Per Cent Binder	Per Cent Act.	Mulling Time		Time Out	Set-up Time (Min)
						Binder	Act.		
1	1000	60	66	2	0.25	5	2	8:00	30
2	1000	62	68	2	0.25	5	2	8:15	25
3	1000	62	68	2	0.20	5	2	8:25	40
4	1000	62	68	2	0.20	5	2	8:37	35
5	1000	64	70	2	0.20	5	2	8:45	30
6	1000	70	76	2	0.15	5	2	8:55	30
7	1000	68	76	2	0.15	5	2	9:04	30
8	1000	68	76	2	0.15	5	2	9:15	30
9	1000	92	98	2	0.025	5	2	9:26	30
10	1000	72	82	2	0.15	5	2	9:37	30
11	1000	82	88	2	0.075	5	2	9:45	30
12	1000	78	86	2	0.10	5	2	9:58	25
13	1000	84	90	2	0.075	5	2	10:05	30
14	1000	72	82	2	0.15	5	2	10:15	30
15	1000	78	86	2	0.10	5	2	10:26	30
16	1000	84	90	2	0.075	5	2	10:37	25
17	1000	80	88	2	0.075	5	2	10:45	35
18	1000	84	90	2	0.075	5	2	10:55	25
19	1000	84	90	2	0.075	5	2	11:05	25
20	1000	70	80	2	0.15	5	2	11:15	30
21	1000	70	82	2	0.15	5	2	11:24	30
22	1000	94	96	2	0.025	5	1	11:35	25
23	1000	90	94	2	0.025	5	1	11:45	25
24	1000	93	96	2	0.025	5	1	11:55	30
25	1000	98	100	2	0.012	5	1	12:02	30
26	1000	96	98	2	0.012	5	1	12:30	25
27	1000	90	98	2	0.012	5	1½	12:40	25
28	1000	80	90	2	0.10	5	2	12:50	30
29	1000	80	84	2	0.10	5	2	1:00	30
30	1000	84	88	2	0.075	5	2	1:00	30
31	1000	92	94	2	0.05	5	2	1:20	25
32	1000	84	94	2	0.075	5	2	1:30	25
33	1000	90	94	2	0.05	5	2	1:40	25
34	1000	90	94	2	0.05	5	2	1:55	25
35	1000	84	92	2	0.075	5	2	2:05	30
36	1000	84	94	2	0.075	5	2	2:15	30
37	1000	84	94	2	0.075	5	2	2:30	30
38	1000	88	96	2	0.05	5	2	2:42	25
39	1000	84	94	2	0.075	5	2	2:57	25
40	1000	82	93	2	0.10	5	2	3:05	20
41	1000	90	96	2	0.05	5	2	3:15	25
42	1000	86	92	2	0.075	5	2	3:26	25
43	1000	93	98	2	0.025	5	2	3:35	20
44	1000	94	97	2	0.025	5	2	3:45	20
45	1000	92	97	2	0.05	5	2	3:55	20
46	1000	90	96	2	0.05	5	2	4:02	25
47	1000	85	92	2	0.075	5	2	4:15	25
48	1000	84	90	2	0.075	5	2	4:25	25
49	1000	82	88	2	0.075	5	2	4:55	30
50	1000	80	87	2	0.10	5	2	4:47	30

It is necessary to control the working life of the sand mix so that core production schedules are maintained. A good workable range in sand life is 30 minutes. It is possible to maintain this established set time by adjusting the following conditions.

(1) Adding activator before or after the oil oxygen binder. Activator added at the beginning of the mulling cycle will result in faster set times then if added at the end of the cycle.

(2) Varying the amount of activator.

(3) Changing the mulling cycle (adjust the length of time with activator added).

These adjustments are made by determining the sand temperature before it is added to the muller. Records should be kept on each batch of sand mixed. Referring to these records enables the muller operator to control the set-up time rather easily. The table shows how the percentage of activator or the mulling cycle is changed to compensate for changes in sand temperatures.

All types of mixers and mullers have been used with this process. Normal mixing times are as follows.

	Slow Speed	High Speed
Oil oxygen	3–5 min	60 sec
Activator	1–2 min	15–30 sec

The oil oxygen process lends itself readily to continuous type screw mixers. The activator is blended into the trough by means of a vibrating chute or a screw type feeder. The liquid is measured into the system by pump. Since only mixing is required for coating purposes and the mixed sand is used immediately, it is possible to work with faster setup time than is possible in batch type mixing.

EQUIPMENT REQUIRED

To utilize the process, all that is necessary is a means of weighing the ingredients, a muller or mixer, a means of delivering prepared sand to the core boxes or patterns, and a core box or mold. However, to make

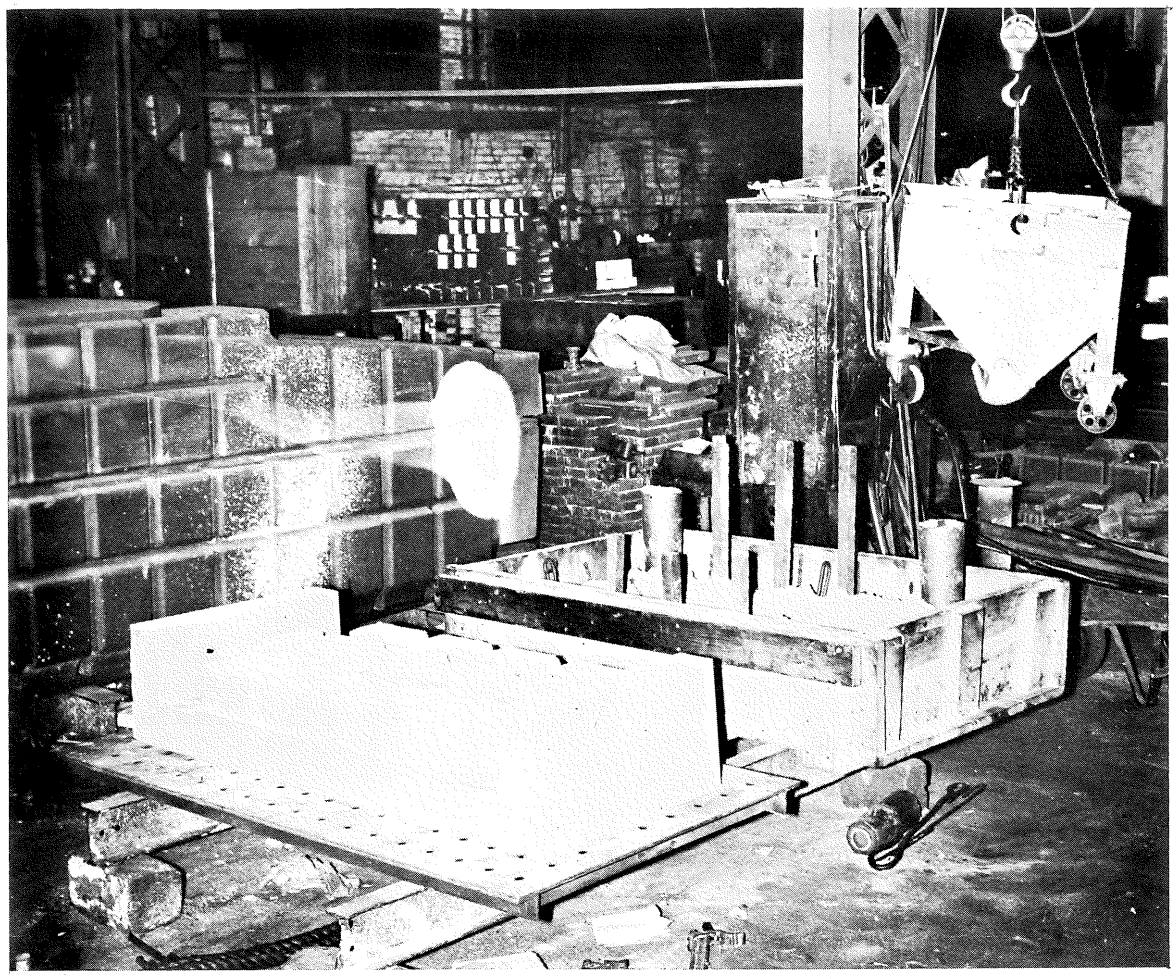


Fig. 23.2 — Sand transported by small hopper and delivered by bottom discharge.

the process more efficient it is advisable and sometimes more economical to mechanize some parts of the operation.

An efficient means of transporting and dumping sand should be provided. Hoppers can be installed on a monorail so that the sand is moved easily to the core boxes. The core boxes can be on rollers so that they can be moved quickly out of the way after being made. Bumpers can be installed in the rollers so that maximum density can be imparted to the sand masses. Vibrators may be used to increase the density of the sand. Rollover draw machines can also be used to an advantage.

Figure 23.1 shows a system of delivering sand to the box directly from the muller. Figure 23.2 shows a means of transporting sand by a small hopper and delivering the sand by means of a bottom discharge. Figure 23.3 shows a bottom discharge hopper that can be installed on a monorail or the sand can be transported by means of belts to the hopper. Figure 23.4 shows a continuous type mixer.

OPERATING AND PRODUCTION PRACTICE

The prepared oil oxygen sand is delivered to the core boxes. Because it is so free flowing it requires no air ramming. The prepared mix is hand tucked, bumped or vibrated. Even though these mixes are free flowing, good coremaking techniques must be followed to insure maximum density.

It is only necessary to add enough rods to support overhang areas and to anchor hooks. When the box is

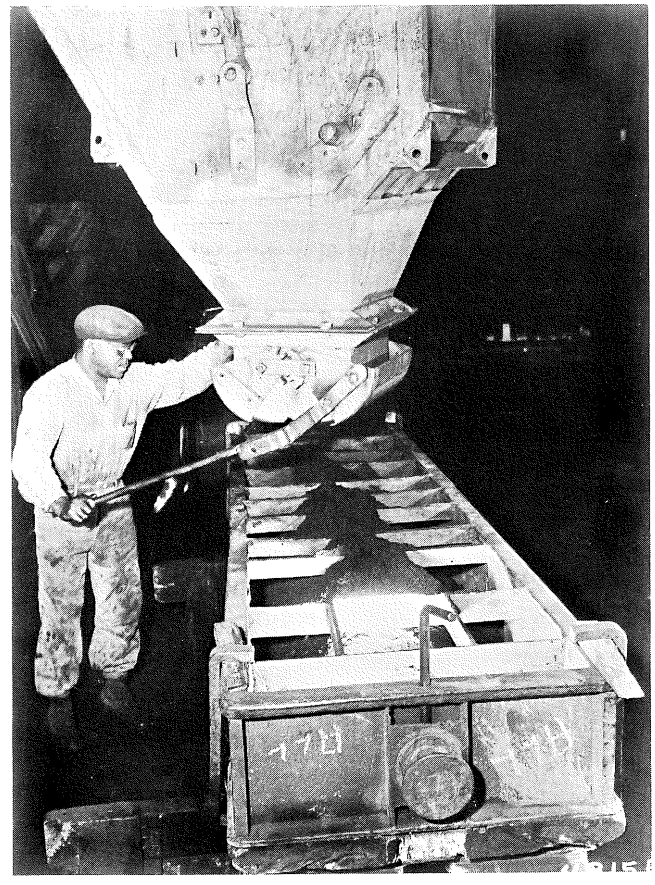


Fig. 23.3 — Bottom discharge hopper that can be installed on a monorail.

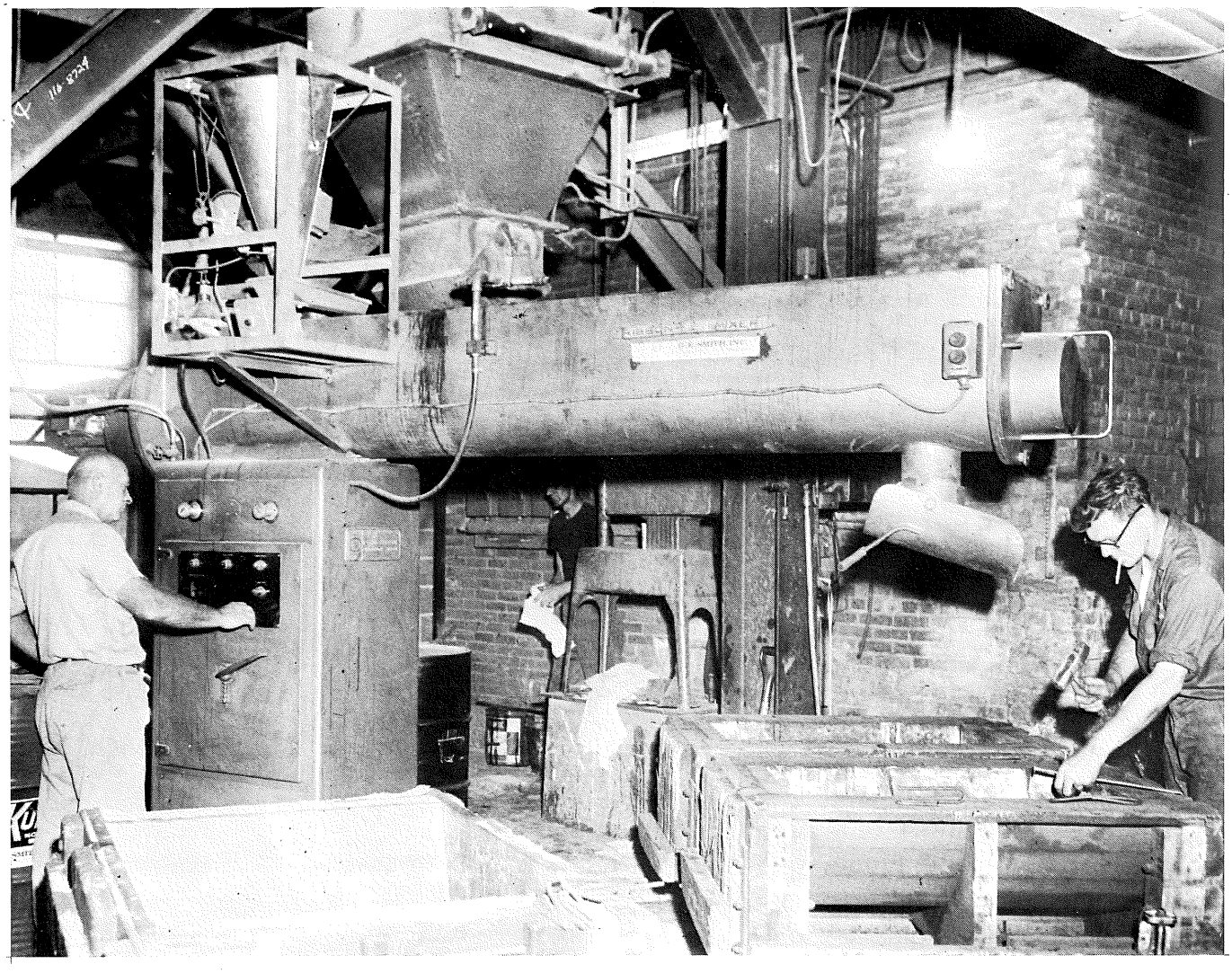


Fig. 23.4 — A continuous type mixer.

filled it is struck off and the core is completed. The core is permitted to stand until the activator has reacted with the oil oxygen oil to partially set the oil films. This time interval depends principally upon the amount of activator added to the sand mix. When the mix has set it is removed from the core box or mold. Core finishing and core washing is best done at this stage.

Chill nails, paste cores, etc., can be easily nailed or pasted to the parent core. Core washes are just as important with this process as with any other process. All types of washes can be used including the solvent-based types. Good wash practice not only reduces burn on but enhances eye appeal. Better surface finishes result from good wash practice.

When the core finishing is completed the oil oxygen cores or molds are then baked or oven cured long enough to complete the polymerization of the oils. Curing temperatures are from 400 F to 450 F (204 to 232 C). Curing time is dependent on core sections, efficiency and type of oven. Since there is no water in the system it is not necessary to remove moisture in baking before the curing begins. A 12 in. cube of oil oxygen sand baked three hours at 450 F (232 C) in a circulating type oven will bake clear through and produce a scratch hardness in excess of 90. Conventional core sand mixes baked the same length of time at the same temperature dried in only 3 in. from all sides. Usually baking cycles are reduced 30 per cent to 50 per cent with the oil oxygen process depending upon the type of oven.

ADVANTAGES

There are many advantages when using the oil oxygen process.

(1) The oil oxygen process utilizes a simplified sand mix. Only three ingredients are necessary: sand, oil oxygen oil, and an activator.

(2) Due to the free flowing characteristics of the mix, air ramming is eliminated.

(3) Skilled coremaking labor is reduced.

(4) At least 50 per cent of the rods can be eliminated as compared to use in conventional practices.

(5) Cores maintain the dimensions of the core box. This results in better dimensional accuracy of the final castings and in increased production in closing molds. The cores fit the prints and require no rubbing.

(6) There is less patching and core and mold finishing.

(7) There is a reduction in oven baking cycles.

(8) There is better shakeout. Since the binders are organics they pyrolyze at about 500 F (260 C). Therefore, the sand pours from the casting at shakeout. This is a great savings in rough chipping.

(9) There is a reduction in layout and in machining costs. Castings run true to size from casting to casting. Closer tolerances on the finished castings are also possible, resulting in less machining.

DISADVANTAGES

(1) There is a one time use life to the sand mix. Once the mix sets it is no longer usable.

(2) The process is limited to core production that normally requires no more than 6 to 8 cores per box in an 8 hour period. This means it lends itself best to jobbing type work rather than to production runs.

FIELD OF APPLICATION

The oil oxygen process has found its greatest application in the larger ferrous type jobbing foundries. Large cores and molds can be produced rapidly and feasibly. All types of metals are cast successfully in the oil oxygen sands. Steel, gray iron, ductile iron, meehanite iron, brass, bronzes, aluminum, and aluminum alloys all have been cast in production. However, the use of this process is most prevalent in the ferrous foundry industry.

TESTS FOR OXYGEN SETTING OILS

These cure binders are heavy bodied oils accelerated with a peroxide type compound. From 1½ to 2 per cent of oil is mixed with the sand followed by one to 5 per cent of peroxide salt (based on the oil weight). Prepared tables available from the supplier show the correct amount of peroxide for each temperature and type of sand. Cold sands are best warmed up in the

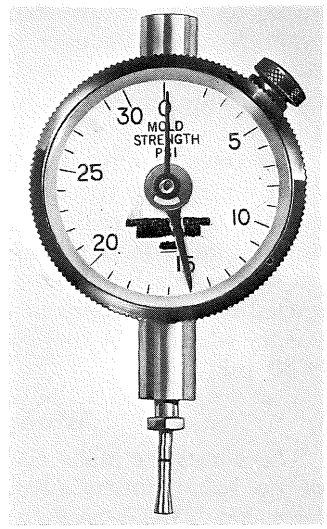


Fig. 23.5 — Mold strength tester.

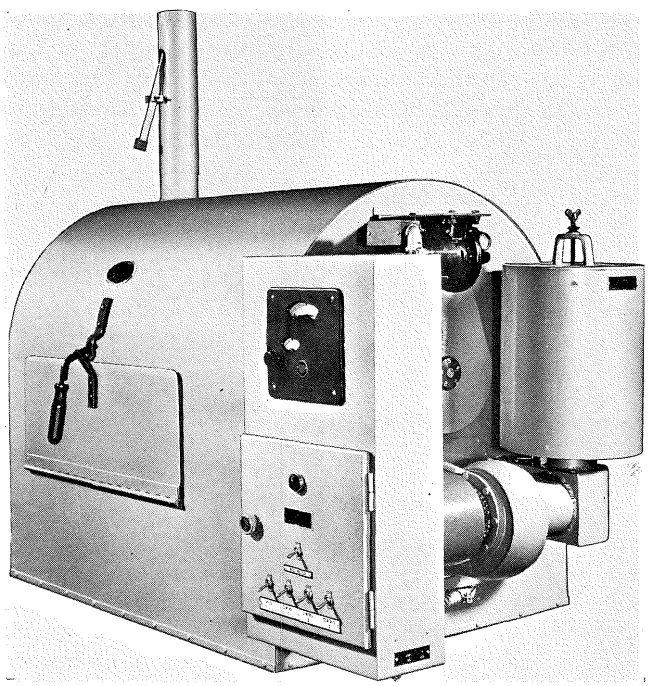


Fig. 23.6 — Test core oven.

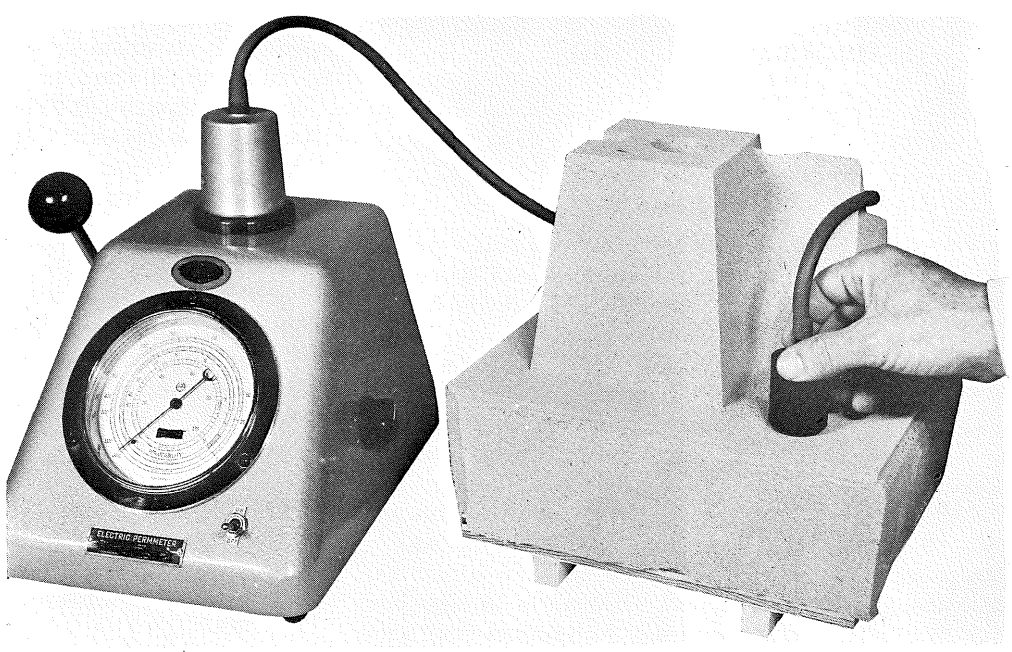


Fig. 23.7 — Electric permmeter.

muller as with the no bake resins. See Chapter 24, FURAN NO BAKE PROCESS, *Control of No Bake or Cold Cure Core Sand.*

A working time of ½-hr and strip time of one hr is normal.

The cores finally are baked at 425 F (218 C) for about one-half to three-fourths the time required for an ordinary oil-cereal core. These binders allow easy ramming and do not attack shellac, fillets, etc. They can be drawn safely from a chipped and slightly backdrafted box on account of the somewhat rubbery consistency when set. A mold strength tester will show 20 to 30 psi.

Work Time

These tests are made essentially in the same way as for no bake binders except that the mold strength tester, Fig. 23.5, is used to determine the set strength of the core after stripping in place of the scratch hardness tester.

Strip Time

A rod is used in the same way as for no bake.

Cure Time

Core tensile specimens rammed from fresh sand, air set for the strip time, are baked at 425 F (218 C) for 30, 45, 60, 75, 90 min. Strength and hardness of the cooled cores show the optimum bake time. The results are, of course, relative since larger cores will need more time just as in the case of oil-cereal cores. The core oven, Fig. 23.6, provides precisely reproducible baking conditions.

Core Permeability

While it is possible to make the regular 2 in. x 2 in. dry permeability specimens, the most desirable way is to use the mold permeability accessory attached to the electric permmeter, Fig. 23.7, on the cured specimen or core.

Chapter 24

FURAN NO BAKE PROCESS OF COREMAKING

DESCRIPTION

A natural trend of research with the oil oxygen process would be the elimination or the further reduction of oven baking. If this could be accomplished and still maintain the benefits of the oil oxygen process then this would certainly be an improvement over the existing art. The result of this research is called the furan no bake system.

Certainly the idea of a no bake binder was not new. Binder systems such as silicates and cement would be in the no bake category. However, the no bake binder system most prevalent today is the furan no bake system. The first question is, "Why use a furan derivative to create a binder system?"

(1) Furfuryl alcohol at this time was readily available and was cheaper than most plasticizers that might be used for this work.

(2) Resins using this type binder can be varied in formulation and can be processed to varying degrees. The binders can be manufactured so that they can be converted from liquid to solid at room temperature or by means of heated core boxes.

(3) These resins are nontoxic and essentially nonflammable, and therefore, can be handled easily.

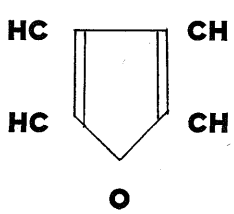
DEFINITION OF TERMS

No Bake Binders

No bake binders are that class of materials that are converted from liquid to solid at room temperature. To define these materials as never requiring any oven drying or curing is a misnomer. There are many cores that cannot produce a casting successfully unless some drying is predicated due to the configuration of the casting design and the type and temperature of the metal poured.

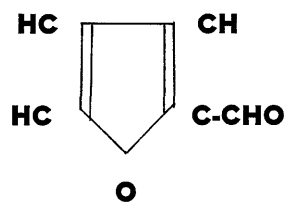
Furan

This is only a generic term that denotes the basic structure of a class or family of chemical compounds. There is no furan used in producing resins. The chemical radical for furan is as follows.



Furfural

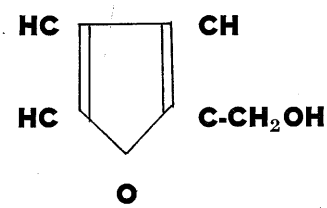
Furfural is prepared from a large number of cellulose products. Commercial production in this country is based primarily on the distillation of corn cobs and oat hulls with dilute sulfuric acid. In appearance this is an oily liquid with a very aromatic odor. Its chemical structure is as follows.



There is no furfural in the resins as manufactured currently.

Furfuryl Alcohol

This is the prime material used in the formulation of furan resins. Furfuryl alcohol is prepared by the catalytic hydrogenation of furfural. In appearance this is a mobile amber-colored liquid. Its chemical radical is as follows.



Chemistry

The resins produced for the no bake category are composed basically of furfuryl alcohol, ureas, and formaldehyde. The differences in competitive resins are in various binder formulations and in methods of manufacturing. These binders are all liquid synthetic resins that when catalyzed with acidic materials form a tough resinous film. The reaction is exothermic and forms a thermosetting resin.

The reaction is denoted by the following equation: Liquid Resin + Catalyst → Solid Resin + H_2O + Heat.

The speed of the reaction is influenced by the temperature of the sand, the type of sand, the speed and type of muller, the binder formulation, and the type and amount of activator used.

A typical sand mix for the no bake process is as follows.

Sand – washed and dried
2 per cent no bake furan resin
40 per cent activator (based on the amount of resin)

Base Sand

The base sand will influence the speed or rate of conversion. Impurities in the sand such as clay, or carbonates, lime, etc., that react with acid in a basic-acid reaction will neutralize the effects of the catalyst. These impurities are not necessarily related to the pH value of the sand. The pH value is only a measure of the reciprocal of the hydrogen ion concentration of a solution. There are many materials that are insoluble in water and are therefore not measured in pH testings that are still reactive to acids. Therefore the acid requirement of the sand has more value than the pH factor when determining the effects of various sands with acid activators.

Sand temperature is also a factor in rate of conversion. High sand temperatures are to be avoided. Sands in excess of 95 F (35 C) are difficult to work with. The resins are sensitive to heat and this excess temperature can result in premature set. The opposite is true when sand temperatures are low. The reaction is arrested when the system is chilled. This can happen easily in the winter with outside sand storage and by using cold metal arbors or mold metal core boxes and flasks.

No Bake Furan Binder

The amount of binder necessary for coating will depend upon the surface area to be coated. Different formulations of binder will react faster or slower depending upon the amount of furfuryl alcohol in the formulation. Usually resins containing higher amounts of furfuryl alcohol react slower than those with lesser amounts.

Activator

The activator used in the no bake furan system is phosphoric acid. Two grades are available differing only in concentration. One grade is 85 per cent and the other 75 per cent phosphoric acid. The basic difference between the two concentrations is in the crystallization point of phosphoric acid. A concentration of 85 per cent will crystallize at 70 F. A concentration of 75 per cent will crystallize at 0.5 F. Therefore, in cold weather, 85 per cent phosphoric acid should be stored in a warm area to avoid crystallization.

The basic reaction between phosphoric acid and furanic resins result in an acid dehydration of the binder. Water is formed in the reaction, therefore, there are some atmospheric effects. This is most readily noticed with high humidity conditions in conjunction with a low catalyst addition. The surface of the core wll harden before the interior due to the evaporation of water at the surface.

Mixing Equipment

All types of mullers can be used successfully in this process. The muller should be clean to insure good results. The cycle will depend upon the type and condition of the muller. A normal cycle would be as follows.

	High Speed	Regular Speed
Catalyst	30 seconds	2 minutes
Resin	60 seconds	4 minutes

The continuous screw type mixers are also advantageous with the furan no bakes. It is feasible to make and strip cores in 10 to 15 minutes using this mixing procedure.

Low strength cores are produced from sand that is insufficiently mulled or mixed. The catalyst is usually added first. This is for two reasons.

(1) This precludes the possibility of causing any localized polymerization, as might be the cause when it is added last.

(2) The sand grains are wetted, and it is therefore easier to disperse the resin.

However, it is advantageous in some instances to add the catalyst last. As mentioned before this is dependent upon the acid requirement of the sand. By adding the resin first it is possible to coat the materials that will react with the activator, so that when the activator is added, it is used solely in the polymerization of the resin. When the activator is added in this manner it must be added slowly and evenly or small areas of localized polymerization will result. These are a source of gas defects and are to be avoided.

The prepared sand is introduced into the core box in the same manner as for the oil oxygen process. However, rodding is even less critical than with the oil oxygen process. The oil oxygen process showed an area of savings in rodding. The furanic no bake made it a reality.

The set time is dependent primarily once again on the amount of activator or catalyst. When the core has set completely, it is either lifted from the core box or rolled and the core box drawn from the core. The core is finished and washed at this stage. If drying is required the drying temperature should be about 300 F (149 C). The drying or oven curing is to remove the water present in the system.

Operating and Production Practices

Parting Agents

Shellacs used to paint core boxes and patterns are soluble in furfuryl alcohol. This fact, coupled with the heat generated by the polymerization of the resin can and does cause sticking. Dry partings have been used with only a minimum of success. A good parting can be made from graphite and kerosene. The kerosene is wiped onto the core box surface and then the graphite materials are rubbed onto this surface. Mica is also good for this application.

Core Boxes

The cores can only be as good as the core boxes. Old core boxes that are full of nicks and indentations or boxes that have back draft will prove difficult to draw. Take down boxes are ideal. Using good core boxes with graphite kerosene parting will produce cores that can be drawn with little difficulty.

Patching

If patching is necessary, it can be done very simply. Apply a little air drying paste on the area to be patched and complete the patching with freshly prepared no bake sand. A light torching for a few moments will convert the binder and patching is complete. In coring up and closing the mold, no bake sand should be used to patch hook areas and core joints.

Chilling

When chilling is necessary, such as is the case many times to promote directional solidification, the following procedures should be used.

If chill plates are used they should have some air drying paste applied and be molded in the core. When chills such as coils or horseshoe nails are used the core should be drawn from the box as soon as possible, before the maximum hardness develops and the chills inserted immediately. If the core has reached its maximum hardness then it will be necessary to drill the holes and paste the chills into place.

Washes

To take the maximum advantage of the no bake feature it will be necessary to use alcohol or rapid evaporating solvent type washes. However, this does not preclude the use of water-based washes, but when using either type wash, core should be tested to be sure that the solvent is removed from the sand surface. In some cases it might be advisable to dry the wash for a short period of time.

An effective film of wash will reduce the tendency of the sand to burn on, therefore enhancing peel, and an effective film of wash will reduce erosion caused by molten metal flowing over a given area.

Molding

In molding the pattern is faced with 4 to 5 in. of the furan no bake sand. The sand is allowed to set completely and the flask filled with conventional backup sand or, as the sand becomes tacky, the backup sand is added with the slinger. If ramming energy is applied before the sand sets then the density of the sand mass at the pattern surface is increased. This is reflected in better casting finish. Figure 24.1 shows the slinger filling the mold after it was faced. Figure 24.2 shows the resulting casting.

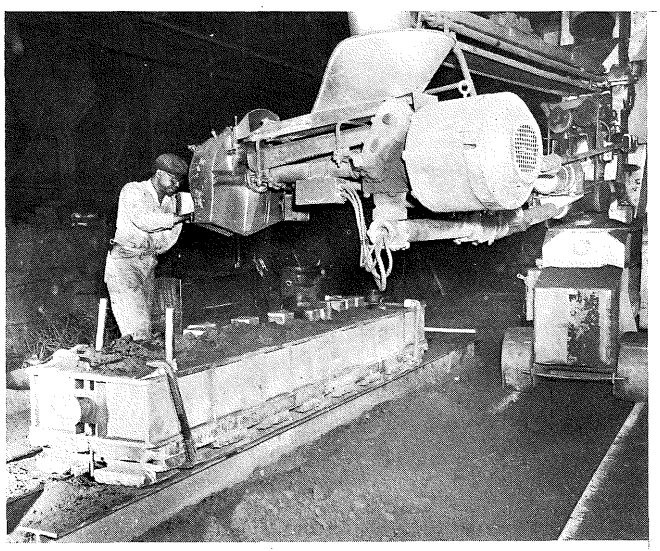


Fig. 24.1 — Slinger filling mold after it was faced with no bake sand.

ADVANTAGES AND DISADVANTAGES OF THE FURAN NO BAKE PROCESS

Advantages

(1) *Simplified sand mix.* Only three additions are necessary. That is, resin, activator, and sand.

(2) *Excellent flowability.* Due to the good flowability, there is no air ramming. It is only necessary to hand tuck. A vibrator attached to the box will also be of benefit. This is directly reflected in increased core and mold production.

(3) *Reduced rodding.* Due to the high tensile strengths developed, it is only necessary in many cases to install and tie the lifting hooks. In any case, a minimum amount of rods is now a reality.

(4) *Skilled coremaking is reduced.*

(5) *There is less core and mold finishing.*

(6) *There is a uniform hardness throughout the core.* Since this is a chemical reaction, the core is homogenous. This is not true of cores that have been oven baked.

(7) *There are exact dimensions.* Cores maintain the dimensions of the core box.

(8) *It takes less time to close the molds.* The cores fit.

(9) *There is better shakeout.* The collapsibility of the cores is excellent.

(10) *There is a reduction in rough cleaning.*

(11) *There are reduced machining and layout costs.*

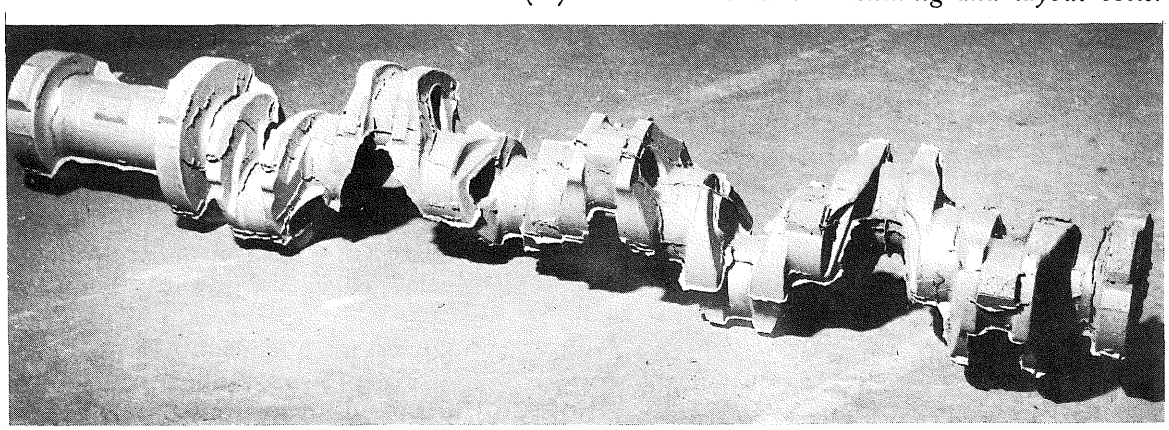


Fig. 24.2 — Casting from mold shown in Fig. 24.1.

(12) *Baking is either eliminated or reduced appreciably.*

(13) *Cores do not develop thermal cracks in the no bake process.*

Disadvantages

(1) *There is a sand life to the mix.* Once the mix sets, it is no longer usable.

(2) *The process is limited to core production that normally requires no more than six or eight cores per box in eight hours.* This means it lends itself more profitably to jobbing work, rather than to production runs.

(3) *High sand temperatures (+95 F) are more critical.* Since heat influences polymerization of the resin, or the oil, this could result in premature set.

(4) *There is no retained flexibility in the no bakes.* Many types of cores can prove difficult to draw. Old core boxes that are full of nicks, where splinters of wood have been removed, or boxes with back draft or loose pieces with no draft will be difficult. A pattern change, in some cases, to take down boxes may become a necessity.

(5) *There is a slight odor of synthetics with the no bakes.* This may be objectionable, particularly at the muller.

CONTROL OF NO BAKE OR COLD CURE CORE SAND

These binders harden solely by time at room temperature. So, as in the case of hot box cores, control is a matter of timing. There are three distinct periods.

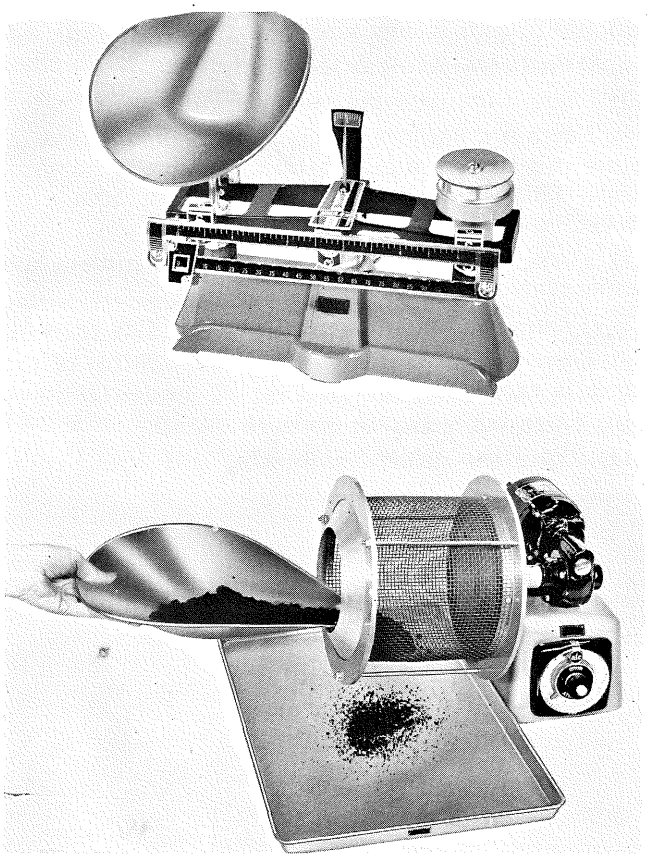


Fig. 24.3 — Moldability index test equipment.

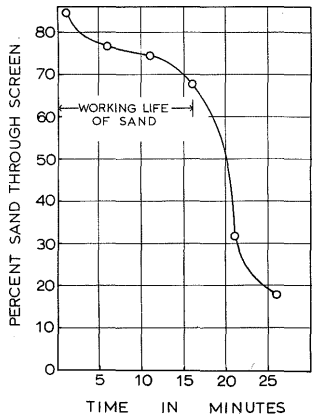


Fig. 24.4 — Typical curve of results from moldability index test.

(1) Work time is the period during which a good core may be made with the low ramming energy so typical of these binders.

(2) Strip time is the time at which the core can be drawn from the core box for further air hardening.

(3) Cure time is the number of hours before a core can be set and poured.

These times as well as the magnitude of strengths will be affected by resin type and quality, strength and per cent of the phosphoric acid or equivalent, temperature of sand and surroundings, mixing time and sand quality. Manufacturers of resins can supply charts showing the amount of acid to use for various temperatures and sands. Resin contents of 1½ per cent to 2½ per cent of the sand weight are most common, with the amount of phosphoric acid (85 per cent) varying from 25 per cent to 50 per cent of the weight of the resin. Work times of 15 to 60 min, strip times from 45 to 240 min and cure times of 2 to 8 hr are most common. The object is to have enough work time to utilize an entire batch without tying the core boxes up too long with a long strip time.

One practice that reduces the need for juggling the acid as the day progresses is to run the sand alone in the mixer until it gets to some chosen temperature, for instance 80 F (27 C). The least mixing time (after resin and acid have been added) that will eliminate segregated spots is the best.

Work Time

(1) **Work Time Testing** — The gradual stiffening of the mixed sand may readily be followed by making moldability index tests at 5 min intervals. Fig. 24.3 shows the equipment. The entire test takes less than one minute. Two-hundred grams of sand are weighed out, transferred to the tester, run 10 seconds and the portion falling through weighed on the special balance reading directly in moldability index. A typical curve of results is shown in Fig. 24.4. The surface quality of a core made with sand after it has gone below 65 moldability index is visibly inferior (Fig. 24.5).

(2) **Research Method, AFS** — The core box and jolter of Fig. 24.6 are recommended by the AFS Core Test Committee report. The box and upset are poured full

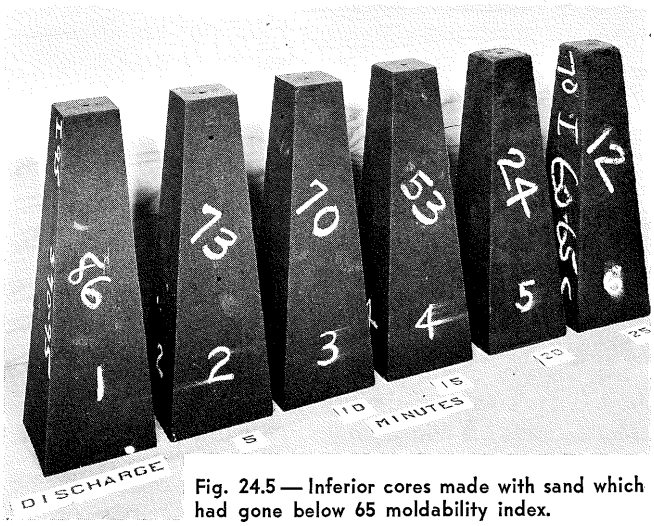


Fig. 24.5 — Inferior cores made with sand which had gone below 65 moldability index.

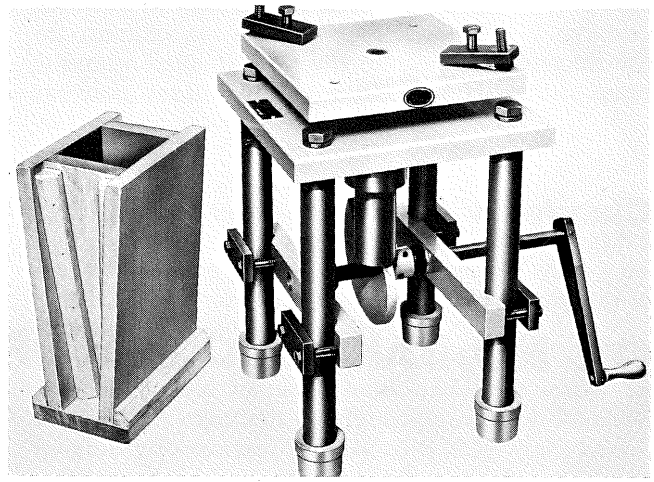


Fig. 24.6 — Core box and jolter.

(with no tucking) jolted four times, after which the upset is removed and the box struck off. About six cores are made at 5 min intervals. A rod is inserted in each core almost to the full 12 in. depth. The cores are checked for scratch hardness and appearance at about 2 hrs after discharge. The age of the sand from which the last acceptable pyramid was made is the working time. Subsequent cores will show low scratch hardness, supervoids and missing corners.

Stripping Time

The rod inserted in the pyramid core (4 in. x 2 in. x 12 in.) is gently tamped at 10 min intervals after about ½-hr. The change from a tough mushy feel to a firm hard structure occurs very quickly and is easy to detect. This is strip time as recommended by the AFS Core Test Committee report.

Cure Time

It is not always necessary for these cores to attain peak strength before pouring, but they must have a substantial tensile strength and hardness to hold up. Tensile strength specimens should be rammed up as fast as possible after discharge for pulling at 1, 2, 4, 6, and 8 hr or any special schedule desired. Three specimens are enough at each time, being careful not to ram all of any group first or last. For production cores, the course of hardening may be followed with scratch hardness tests. A high strength tensile tester is required for breaking these tensile specimens. The time at which the cores acquire maximum strength is the theoretical cure time, although they can be set sooner.

High Temperature Properties

The core collapse test as outlined under hot box resins (Chapter 26, Hot Box Process, *A Test Program for Hot Box Cores)* applies to the no bake resins as well. The same applies to gas problems.

In evaluating base sands it is well to remember that the cleaner sand which requires less resin also has the advantage of less gas, although it will probably collapse sooner because there is less resin to burn.

Humidity Effect

After tensile cores have cured for 24 hr, they then may be tested before and after an 8-hr stay in a controlled humidity cabinet. Storage in a reasonably tight cabinet over water is the method generally used. Thermostatic control of the water temperature is a refinement.

Stickiness

Most no bake resins contain furan and will attack some core box finishes, fillets, etc. There are lacquers that will overcome this. Flat, low cores can often be drawn immediately, as in the case of the tensile cores, without sag or sticking. There is an interval later where a surface layer of sand will adhere to the box if an attempt is made to draw the core.

Chapter 25

OIL NO BAKE PROCESS OF COREMAKING

DESCRIPTION

The oil no bake process is one of the most significant binder developments for medium size and large work since the development of the no bake concept. It is a synthetic oil binder which, when mixed with basic sands and chemically activated, produces cores and molds that can be cured at room temperatures.

The oil no bake process is unique because it can be used as either a fast baking oil oxygen type material or a furanic type no bake material. It differs from the oil oxygen process (which is primarily an oxidation reaction) and the furan no bake process (an acid dehydration or condensation reaction) in that it is a polymerization reaction affording many advantages in the setting-up and thru-set operations.

ADVANTAGES

The following are the primary advantages of the oil no bake process as opposed to the oil oxygen and/or the furan no bake process.

(1) *Excellent flowability.* Because of its oil base, the oil no bake process achieves the optimum in flowability.

(2) *Better depth of set.* Because the oil no bake reaction is chemical, no auxiliary air source is needed to partially set cores. This enables better control of set times in deep boxes and pockets, and allows a substantial savings in air costs.

(3) *Less influence of sand impurities.* All types of sands have been used successfully with the oil no bakes, including olivine, zircon, and chromite sands.

(4) *Faster baking at reduced temperatures.* Use of the oil no bake process can reduce baking cycles by 50 per cent, and baking temperatures by 20 per cent.

(5) *Easier draw.* Because the oil no bake process goes through a stage of plasticity in the polymerization process, the drawing of cores and molds is a relatively simple task.

(6) *Less stickiness.* Tests with all types of box finishes have proved that the lubricity of the oil no bake process minimizes stickiness.

(7) *Better casting finish.* Because of the complete absence of water in the system and the absolute polymerization of the oils better casting finish is possible.

(8) *Minimum scorch or burn possibilities.* The oil no bake process minimizes the possibility of mold and core edge scorching during the torching operations because of the inherent overbake characteristics of the system.

(9) *Elimination of tramp elements.* An oil no bake produced casting is free from undesirable elements such as boron, nitrogen or phosphorus.

(10) *Less waste.* In batch mixing with the oil no bake process there is less buildup in the mixing equipment. When continuous mixers are employed, initial sand can be recycled into the mixing trough. In both cases, less sand waste becomes a reality.

(11) *No objectionable odor.* There is no free formaldehyde odor as in the no bake furan process.

(12) *Less pattern and core box maintenance.* Minimum damage to both pattern and core box during the drawing operation.

(13) *Substantially reduced rodding.* The oil no bake process, because of its complete and uniform conversion throughout the sand mass, almost eliminates the need for rodding.

(14) *Lower production costs.* The oil no bake process reduces coremaking costs because of its excellent flowability and no bake characteristics.

OPERATING AND PRODUCTION PRACTICES

Mixing (General)

All types of mullers and mixers have been used with the oil no bake process. All that is necessary to insure good results is clean, dry sand, well mixed with the oil no bake ingredients in a clean muller or mixer.

The oil no bake ingredients can be furnished as either a three-component system or as a two-component system.

Typical sand mix for a three-component oil no bake system will contain the following.

1,000 lb sand, washed and dried
14 lb Oil no bake binder
11.2 oz Oil no bake cross-linking agent

The formula upon which this mixture is based is as follows.

Oil no bake binder part I, 1.4 per cent (based on sand weight)
Oil no bake drier part II, 5 per cent (based on weight of the oil no bake oil)
Oil no bake cross part III linking agent, 20 per cent (based on weight of the oil no bake oil)

When three components are supplied, Parts I, II, and III are furnished separately requiring the following mixing procedure.

Parts I and II are first mixed together
This mixture is added to the sand
Part III is then added

Typical sand mix for a two component oil no bake system is as follows.

1,000 lb sand, washed and dried
14.7 lb oil no bake binder and drier
2.8 lb oil no bake cross-linking agents

When two components are supplied, Parts I and II are supplied premixed. The amount of Part II added affords a tailor-made predetermined set time. A system such as this enables a foundry to use only two additions.

Mixing (Batch)

Average batch mixing times at various muller speeds are as follows.

Components	Regular Speed	High Speed
Oil no bake and drier	2–3 min	1 min
Oil no bake cross-linking agent	1–2 min	½ min

Set time is controlled by the amount of Part II included and the type and length of the mulling cycles employed.

Mixing (Continuous Mixers)

The oil no bake process lends itself readily to continuous type mixing equipment. The premixture of Parts I and II are added at the rear end of the mixing trough. Part III is added into the area where the binders are normally discharged. A uniform and homogenous sand mixture is delivered at the discharge point. Set times are even more easily controlled than in batch type mixing equipment.

When using continuous mixers the pumping units used for Part III should be flushed before changing to or from the acid catalyst of furan no-bakes, and the mixer must be kept clean to avoid contamination.

Making Cores and Molds

Flowability of the sand is excellent and will require about the same handling as used in the making of an oil oxygen core. The degree of flowability, as in the oil oxygen process, will depend largely on the fineness of the sand.

After the cores have been made, it is a simple matter to slick off the top. A cloth wet with kerosene will serve as an excellent dressing for the trowel and will enable finishing the strike-off side of cores without tool drag.

On smaller type boxes, rapping the box while the sand is in a plastic stage will permit easier draws. This will free the corners and any areas that may have a tendency to hang up. On large, heavier type cores, the weight of the sand will be sufficient to free the cores with ease. Depending on the size and shape of cores or molds, they can be drawn ten to fifteen minutes after a solid state has been attained.

As a general rule of thumb, cores made with the oil no bake process can be drawn with greater assurance of complete set than cores made with oil oxygen or furan no bake, because the oil no bake polymerization reaction results in a complete and uniform setting of the sand mass.

Patching

Patching, if necessary, can be done very simply by applying a small amount of rapid, air-drying paste and completing it with freshly prepared oil no bake sand. A light torching for three or four minutes will convert the binder.

In coring up and closing the mold, oil no bake sand should be used to patch hook and joint areas. This type sand is excellent for these applications because of its ability to convert rapidly with only slight heat.

Finishing, when necessary, should be done following normal procedures and whenever possible prior to the washing operation.

Washing Cores and Molds

Proper washing procedures are as important with the oil no bake process as they are with any other process and will always be necessary except when very small cores are being produced. Proper wash applications can be an effective means of not only reducing cleaning costs, but also of enhancing the finish and eye appeal of the castings produced.

Both water-base and alcohol-base washes can be used; but in either case, cores and molds should cure for a reasonable amount of time (minimum of two hours) before the wash is applied. If oil no bake sand masses are washed immediately upon stripping from the boxes, problems such as the following might occur.

(1) Alcohol-base washes will soften the surfaces of the core or mold.

(2) Water-base washes will react with the uncured oil no bake cross-linking agent, Part III to form ureas — products of rapid decomposition and are a possible source of wash peeling and/or burn on.

When a water base wash is utilized, a short oven bake (approximately 90 min) is recommended to remove the solvent. Cores that are completely covered with metal should have a 1½ to 2 hr oven bake at between 400 and 450 F (204 and 232 C).

TENSILE DEVELOPMENT

Figure 25.1 depicts the rate of tensile development of the no bake furan, the oil no bake and the oil oxygen processes. The comparison is based on mixes as follows.

Furan — 2% resin
Oil no-bake — 2% total binder
Oil oxygen — 2% binder
Sand — 55 AFS silica

The furan system initially attains greater tensile strength because of the amount of catalyst that can be used. However, if samples are left overnight — or until room temperature cure is realized — the oil no bake system will attain a higher tensile strength. If the furan curve is extrapolated, the curve will peak and then fall to a lower level as is shown in Fig. 25.2.

The amount of tensile loss is proportional to the

amount of acid activator in the system — the more the activator, the faster the rate of initial tensile development, but the greater the tensile drop after peaking. If the oil no bake curve is extrapolated, the curve will level off as is shown in Fig. 25.3.

Using 65 AFS Wedron sand, and 1.6 per cent combined binder, the following air set tensile strengths are representative of the ranges achieved by the oil no bake system.

30 to 60 psi — after 2 hours
80 to 160 psi — after 4 hours
150 to 210 psi — after 6 hours
225 to 375 psi — overnight

The oil oxygen process requires baking to polymerize the oils, which, of course, affects ultimate tensile strength.

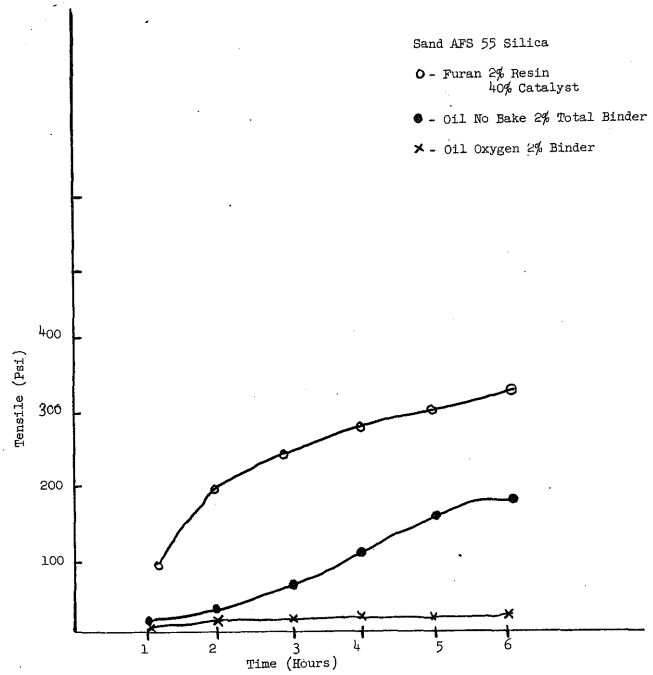


Fig. 25.1 — Tensile development of various processes.

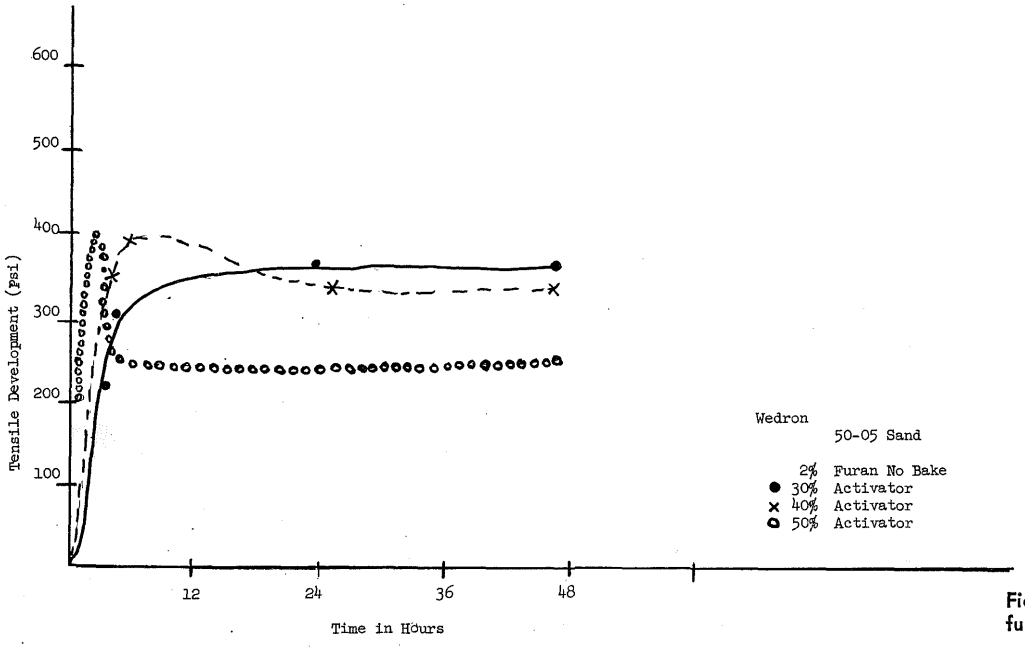


Fig. 25.2 — Tensile development — furan no bake at room temperature.

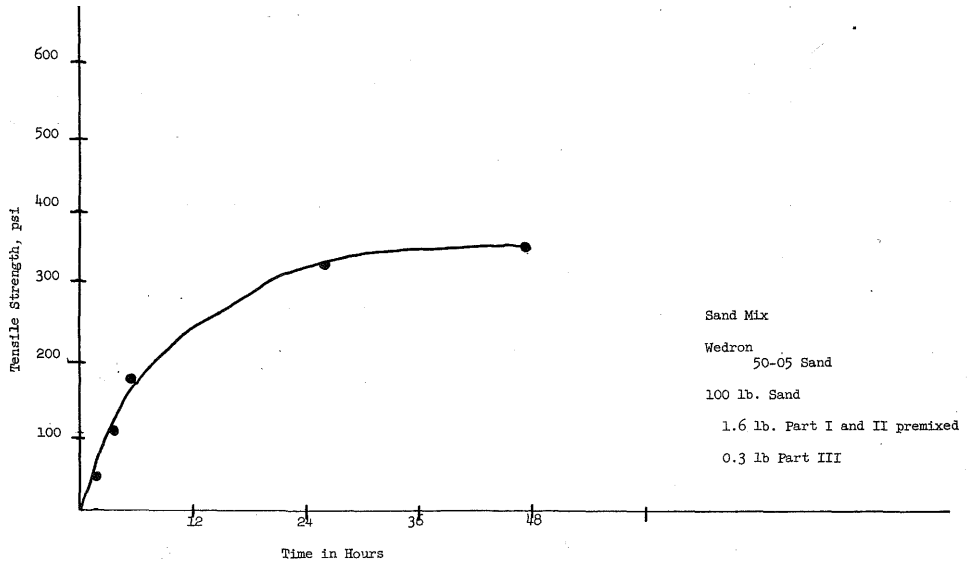


Fig. 25.3 — Tensile development of oil no bake at room temperature.

CONVERSION TIME WHEN BAKED

Baking times can be reduced by 50 per cent and baking temperatures by 20 per cent when the oil no bake process is utilized. This can best be seen by examining the graph, which shows tensile development at various baking temperatures in Fig. 25.4.

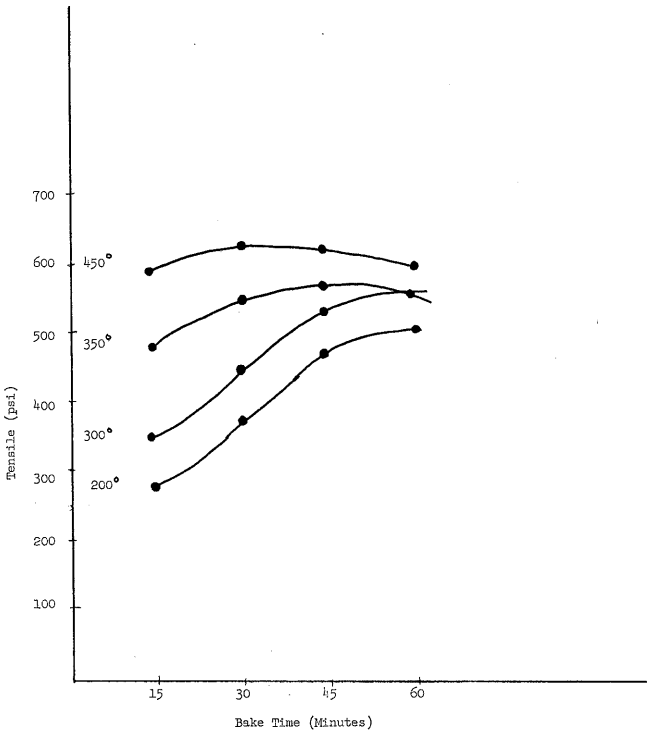


Fig. 25.4 — Effects of baking at various temperatures.

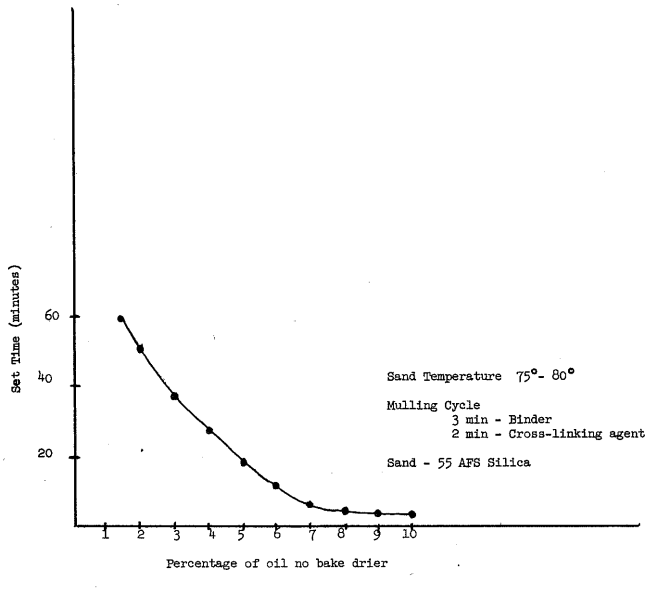


Fig. 25.5 — Effects of set time with various percentages of drier.

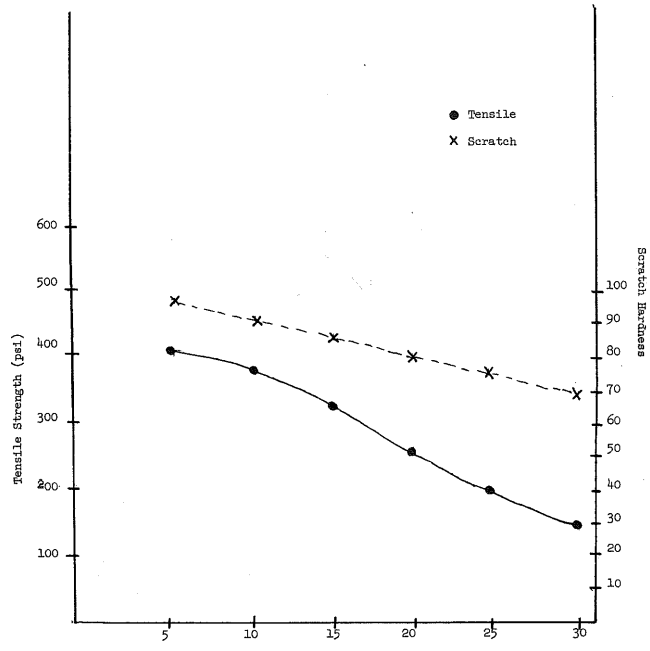


Fig. 25.6 — Tensile development and scratch hardness.

EFFECT OF ADDITIONAL OIL NO-BAKE PART II

Figure 25.5 depicts the effects of various additions of oil no bake drier Part II. Note that as the amount of Part II is increased, the set time of the sand mix is accelerated.

TENSILE DEVELOPMENT AND SCRATCH HARDNESS

Figure 25.6 shows the results of tests conducted to determine tensile development and scratch hardness inherent at various time intervals during the polymerization process. Note that as the sand life of the mix decreases, the tensile strength and the scratch hardness also decreases.

After discharge from the muller, tensile cores were made at 5 min intervals until sand life was finished (30 min). Cores were allowed to stand for 24 hr before tensile and scratch hardness were recorded. The following are the results in chart form.

Time Intervals	5 min	10 min	15 min	20 min	25 min	30 min
Tensile psi	410	395	320	250	190	165
Scratch	98	94	86	80	78	70

The foregoing data show how the strength of prepared sand declines upon standing. This effect is most noticeable when using large amounts of sand in batch type muller operations. When an appreciable amount of time is taken to use all the sand, the cores made from the last of the sand will be weaker than the first cores made from the same batch.

The data is also indicative of the efficiency of the continuous mixers. Since the sand used from the mixers is used immediately, then the resulting cores or molds are always at their optimum strengths.

RECOMMENDED FORMULAS

All types of washed and dried sand can be used with the oil no bake process. Sands containing clay can also be used but this may require additional binder. The following are the most commonly used sand types, along with the required amount of binder and cross-linking agent to achieve best results.

1. 1000# — Portage #5
   17# — Oil no bake binder
   3.5# — Oil no bake part III

   Sand life — 30 min
   Drawing time — 45 min

2. 1000# — 50-05 Wedron
   12.5# — Oil no bake binder
   2.5# — Oil no bake III

   Sand life — 30 min
   Drawing time — 45 min

3. 1000# — Lake Sand 55 AFS
   15# — Oil no-bake binder
   3# — Oil no-bake III

   Sand life — 30 min
   Drawing time — 45 min

4. 1000# — New Jersey 35
   15# — Oil no bake binder
   3# — Oil no bake III

   Sand life — 30 min
   Drawing time — 45 min

5. 1000# — 70 New Jersey
   17# — Oil no bake binder
   3.5# — Oil no bake III

   Sand life — 30 min
   Drawing time — 45 min

Note that the above formulas are based upon utilization of a slow-speed muller: 3 min with an oil no bake binder; 2 min with oil no bake III.

Chapter 26

HOT BOX PROCESS OF COREMAKING

DESCRIPTION

The term furan resin is receiving worldwide attention today within the foundry industry because of its universal acceptance as a core and mold sand binder. As mentioned previously, the word "furan" is generic in nature and denotes the basic structure of a family of chemical compounds.

Research and development with furanic type binders has been twofold. As explained in previous chapters one class of furanic type binder is the furanic no bake binder. The second class is the hot box furanic type binder. Whereas, the furanic no bake binders find their greatest application in jobbing type and semiproduction type foundries, the furanic hot box binders have found their greatest acceptance in the production type foundries.

Hot box binders are liquid synthetic resins. This liquid resin when reacting with acidic chemicals forms a tough resinous film around the sand grains. The reaction is greatly enhanced by heat, a factor which is the basis for greatly increased production rates.

Heat is supplied either by normal procedures such as ovens, infrared lamps, dielectric ovens or by heated core boxes. Heating core boxes is the most common means of introducing heat into the process. Heat obtained by gas, electricity, or heated air for heating core boxes is constantly being lost during each operating cycle and must be replaced as uniformly as possible, at a rate that will constantly maintain the desired operating temperature. Temperature control of core boxes is important because over- or undercuring of cores is adverse to uniform quality control.

The reaction is explained as follows.

Liquid Resin + Catalyst + Heat → Solid resin + H_2O + Heat. The reaction is exothermic, forming water and a thermosetting resin.

The original hot box techniques were developed using furan binders. Recently phenol has been substituted for all or part of the furfuryl alcohol in some formulations. This has made available several binder systems for the hot box process.

Name	Formulation
Furan hot box	Furfuryl alcohol urea-formaldehyde
Phenol hot box	Phenol urea-formaldehyde
Phenol modified hot box	Phenol, furfuryl alcohol urea-formaldehyde

SAND PREPARATION

All types of mullers and continuous mixers have been used with the process. All that is necessary to insure good results is a clean dry sand at room temperature, well mixed with activator and hot box resin in a clean mixer.

A typical sand mix for the hot box application is as follows.

Sand, washed and dried
2 per cent hot box resin
20 per cent activator (based on the weight of resin)

The activator is added first and mulled long enough to be evenly distributed throughout the sand. This precludes any localized polymerization as might be the case when the activator is added last. The hot box resin is then added and mulled an additional period of time to insure proper coating of the sand grains. Average times for various mullers are as follows.

	Regular Speed	High Speed
Sand and catalyst	2 min	30 sec
Hot box resin	4 min	60 sec

The continuous mixers are extremely efficient with this process, for with this method of mixing it is possible to always use freshly prepared sand.

The most common error which may not be immediately apparent is incomplete mixing of sand, catalyst and resin. This error results in low strength sand mixes. Properly coated sand will have a useful sand life of four to six hours.

The catalyst and resin are essentially nonreactive at room temperature, but there is a gradual reaction over a period of time. This gradual reaction coupled with the evaporation of water from the sand mass determines sand life. Prepared sand that is covered with a damp cloth or stored in closed containers to inhibit water evaporation has been observed to have a sand life in excess of 24 hr.

SAND INTRODUCTION

There are two means of introducing sand into the heated core box: core blowing and core shooting.

Core Blowing

Core blowing is the most common means of introducing prepared sand into core boxes in the U.S.A. With this method air is mixed with the prepared sand

and propels it into the core box cavity. Blow pressures are from 70 to 100 lb.

Core Shooting

This is a means of extruding prepared sand by releasing extremely high air pressure at a given instant. Core shooting has been adapted to some of the smaller hot box machines. This method of sand introduction has the benefit that core box venting is not quite as critical as is the case with core blowers.

CORE CURING

Heat from the core box triggers an exothermic reaction which cures the thermosetting resin. Cure times depend upon core sizes, core configuration, core box temperature and production requirements. For maximum production, the prepared sand should be introduced into the core box as quickly as possible and the semicured core ejected in the shortest possible time in which the core can be handled without distortion. When this practice is employed it is usually necessary to make provisions for a secondary cure, which is usually 10 or 15 min through a tunnel oven or continuous oven at 400 F (204 C). Where maximum production is not a requirement, the core is left in the box for enough time to be sure that it will cure completely.

Most cores can be removed from the core box in 5–20 sec. At this time the curing reaction will have penetrated $\frac{3}{16}$-in to $\frac{5}{16}$-in. The surface will be hard with no indication of thermoplasticity. Cores cured to this depth can be safely handled, or set on racks or plates until needed. Additional internal curing will take place during the 10 to 20 min after the cores have been ejected.

The completeness of the cure is dependent on several factors.

Temperature of Core Box and Dwell Time

The core box is operated from temperatures of 350 to 550 F (177 to 288 C). At lower temperatures it will be necessary to cure for a longer cycle and at higher temperatures, a shorter cycle.

Sand

Sands containing appreciable amounts of alkaline reacting materials will affect the resin catalyst reaction. As the activator systems employed in the hot box process are only mildly acidic, the effects of these materials can be highly detrimental. The pH value of the sand is not indicative of the final acid requirements of the sand mix. The pH value is measured by adding the sand to distilled water and measuring the hydrogen ion concentration of the water layer. If alkaline reacting materials are present in the sand that are insoluble in water, then these materials have no influence on the final pH value. If these materials are reacted with acidic activators, then a portion of the catalyst is no longer available for the requirements of the resin. Therefore in some cases, it is necessary to adjust the catalyst system to fit the requirements of the sand.

A better method, however, for determining the catalyst requirements of the sand is to measure the acid requirements of the sand. This can be done as follows.

Acid Requirement Test

Mixture 50 gm sand
50 ml 0.1 N HCl
50 ml distilled water

Instructions

Stir and let set 1½-hr. (The materials that are alkaline will react with the acid.)

Back titrate the mixture to neutralize the excess HCl with 0.1 N NaOH to determine the original amount of HCl that had been used in the reaction with the alkaline materials.

For example. . . .

Original amount added 50 ml. 0.1 N HCl
Used in back titration 40 ml. 0.1 N NaOH
10 ml. material reacted

Sand has an acid demand of 10. (As the acid demand increases, the acidity requirements of the catalyst system also increases.)

The chart below shows a comparison of pH to acid requirement for different base sands, depicting how erroneous pH values can be.

Sand	pH Value	Acid Requirement
Silica Sand	6.9	2
Lake Sand	6.7	4
Bank Sand	6.5	40

Note that the pH factor can show more acidity for bank sands yet have a far greater acid requirement value.

Humidity

The evaporation of water is slowed by high humidity. This results in lower tensile strength and the need for longer dwell times. It has been found by laboratory and field tests that the dwell time is lengthened about 5 to 8 sec and the tensile strength reduced about 50 psi when the relative humidity is in excess of 90 per cent.

The Thickness of the Core Sections

One-inch sections will cure completely through upon cooling in most sands when subjected to a temperature of 350 F (177 C) for 10 sec. For sections over 2 in., the exothermic reaction of the resin cannot be depended upon to effect a complete cure. In these cases, a secondary heat source is necessary, such as post-oven cure. This will usually consist of oven drying for an additional 5 to 10 min, depending on the oven temperature. It is preferable to put these cores through the secondary cure immediately after stripping from the heated box.

The Temperature of the Base Sand

Cold sand will slow the resin catalyst reaction, and hot sand will accelerate the reaction. Sand temperature, in excess of 90 F (32 C), will result in shorter sand life in the mix.

CORE FINISHING

Core wash coatings are advisable in most cases. Cores are usually dipped, but care should be taken that the curing of the interiors of the cores is not arrested due to the chilling action of the wash solvent. Water base washes are commonly used and a loss in tensile strength is noticed immediately after dipping.

TABLE 26.1 — COMPARISON OF TENSILES — Blown with 80 lb at 425 F (218 C)

	Hot-Box Without Inhibitor				Hot-Box With Water Inhibitor				
Time	10 Sec	20 Sec	30 Sec	50 Sec	Time	10 Sec	20 Sec	30 Sec	50 Sec
3 Hr	356	473	506	510	3 Hr	420	515	575	570
24 Hr	425	468	475	425	24 Hr	440	520	570	565
48 Hr	440	464	460	406	48 Hr	448	530	565	570
6 Days	428	470	420	420	6 Days	460	535	575	570

The percentage of tensile loss is related to the amount of water absorbed during the washing operation. Even after drying the tensile loss is still evident.

Proprietary materials are now available that inhibit water absorption into the core mass. These materials not only aid in the wash practices but have several other advantages in the process.

(1) Less moisture pickup in the core in storage.
(2) Better sand flowability.
(3) Higher core density.
(4) Shorter bake cycles on secondary cures.
(5) Less odor.

Table 26.1 depicts a comparison of tensile strengths with and without a water inhibitor.

EQUIPMENT REQUIRED

Sand Mixing Equipment

Mullers suitable for mixing oil sand are quite satisfactory. Preparation of the sand mix is simple and requires no special equipment. Since the chemical activity of the catalyst is important to the cure of the resin, it is vital that the contamination of the sand mixture be avoided. A clean muller is the best assurance that contamination will be minimized.

Hot Box Machines

Practically all equipment manufacturers have designed machines especially adapted to the hot box process or have designed adapter kits to fit the shell machines that are currently being used. The newer machines have also been designed to give faster cycles, so as to derive maximum benefits of the process. Equipment is now available to make cores weighing from a few ounces to about 100 lb.

Since the mix used for this process is wet, blowing pressures from 70 to 100 lb are commonly used. Also, since the mix is sensitive to heat, the blow plates on the core blowers are water cooled to minimize heat transfer from the heated box to the sand in the blow holes and in the sand hoppers. Water flows continually through the water jacket while the machine is in operation. Blow holes for the hot box mix are the same size as for tempered sands or for oil sand mixes. Blow tubes in the upperhalf boxes are tapered to facilitate the ejection of cores. The trend has also been to water cooled blow tips. Figures 26.1–26.3 show various hot box machines.

Core Box Equipment

The cores made by the hot box process will only be as accurate as the core box in which they were formed. Cast iron is the preferred metal for core box equipment. The walls surrounding the core cavity are made uniformly to 7/8-in. thickness, where practical, to achieve uniform heating.

Ribs are placed on the outside of the box to keep it in shape when exposed to the heat. Copper-base alloy inserts are not generally used because of the corrosive action of the binder ingredients. Hardened steel is used for locating pins, bushings, and wear pads. Strip-

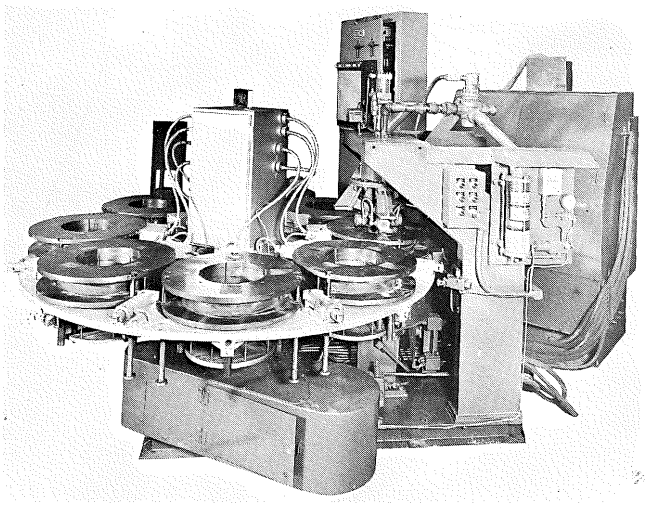


Fig. 26.1 — Hot box indexing machine.

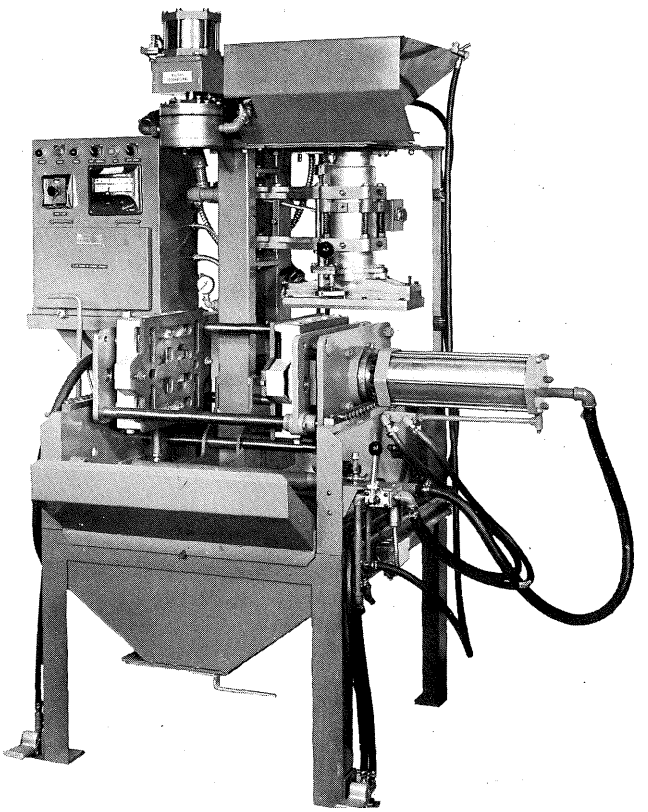


Fig. 26.2 — Single hot box machine.

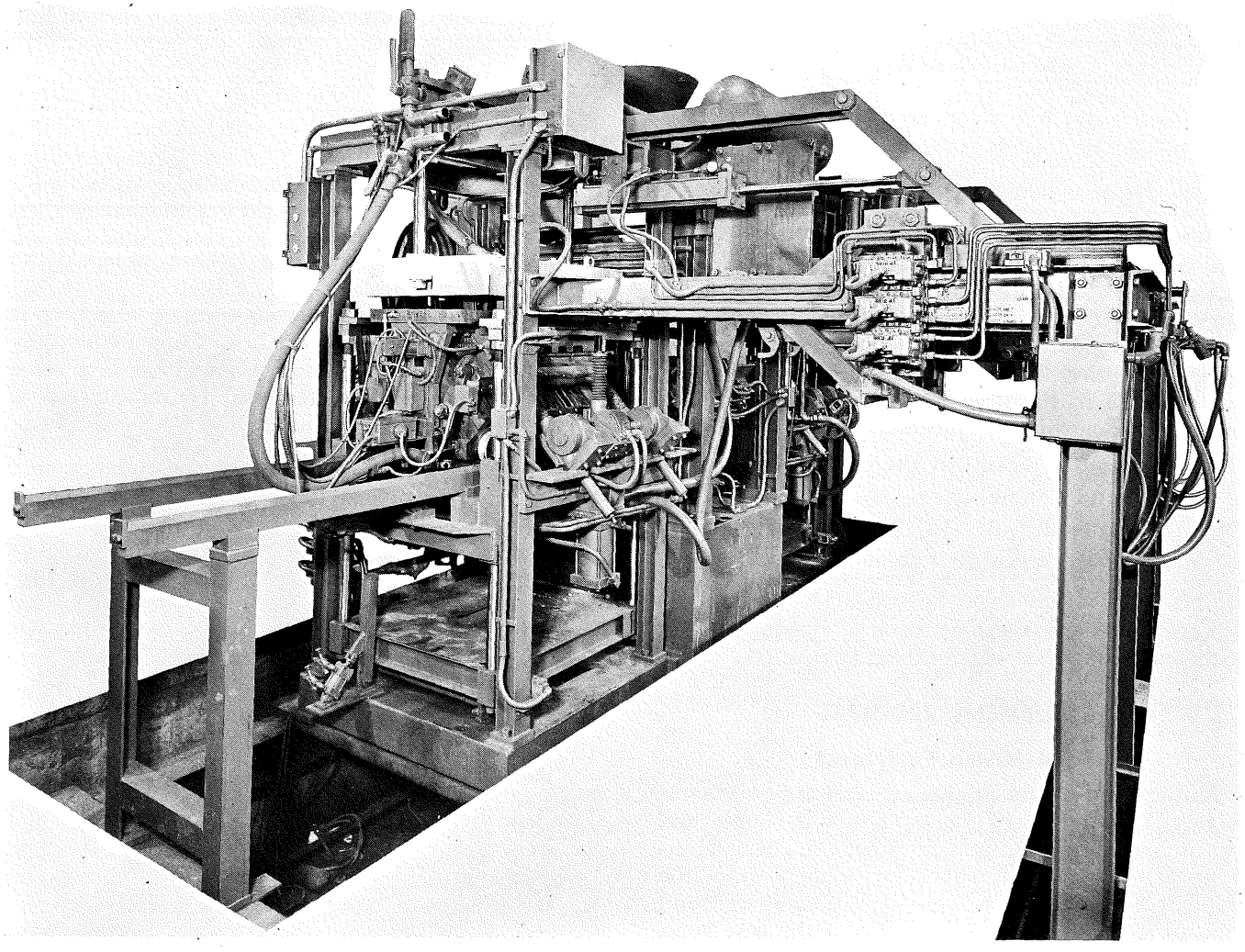


Fig. 26.3 — Cylinder block hot box machine.

ping pins have a clearance of as much as 0.008 in. This clearance also acts as a vent. Since the hot box mix is wet and is blown at 70 to 100 lb pressure, provision must be made for exhausting the air from the core box. Venting practice is comparable to that of an oil-cereal bonded mix. Slotted steel vents are preferred. The opening between the slots is usually from 0.010 in. to 0.018 in. Vents are usually plugged by silicones and parting agents rather than by hot box resin. Parting line venting is good practice when blowing through the parting line and should be a milled cavity about 0.005 in. deep by one in. wide.

FIELD OF APPLICATION

All types of metals have been cast in hot box. Binder formulations are changed for various metals. For instance in aluminum castings the furfuryl alcohol content of the binder is decreased to aid collapsibility. In steel castings, the furfuryl alcohol content is increased in the binder formulation. Since the process has been pointed toward the high production shops its greatest application has been in automotive and plumbing industries. Typical cores are for water jackets, head jackets, manifolds and other cores related to automobile engines. In the plumbing and fixture industries such things as elbows, tees, valves, faucets and miscellaneous plumbing fixtures are common things made in the hot box process. Figures 26.4–26.6 show various automotive cores.

ADVANTAGES

There are many advantages inherent to the hot box process.

(1) No special mixing equipment or heating systems required to coat sand.
(2) Fewer machines and less space required.
(3) No special sand additives required.
(4) High degree of core stability prevents warping.
(5) Lower temperatures and less heat required during curing cycles.
(6) Laminations near core surface eliminated.
(7) Cores produced in a fraction of the time required by conventional practices.
(8) Increased core strength reduces handling breakage.
(9) Core wires are eliminated.
(10) Core driers are not required.
(11) Shakeout efficiency greatly improved because of high collapsibility properties.
(12) Closer dimensional tolerances.

(13) Lower casting costs.
(14) Higher production.

DISADVANTAGES

As is the case with most sand binders, hot box binders have several critical factors that will be encountered if put to use. These factors are listed as follows:

(1) Sand sections are limited to about 2½-in.
(2) Blow heads must be water cooled.
(3) Venting is more critical than it is with the shell process.
(4) Base sand temperatures are critical.
(5) Sand mix has a definite bench life.
(6) An odor of free formaldehyde is present in the work area.

SAFETY

During the curing of cores in a hot core box, some formaldehyde vapor escapes to the atmosphere. As a result, work stations should have adequate ventilation.

Hot box resins will harden in the presence of acid or hydrogen ions. This reaction is rapid and is accompanied by the evolution of much heat. Therefore hot box resins should be kept out of any container having an acid residue and the reaction should never be permitted or caused to occur in a closed container.

A TEST PROGRAM FOR HOT BOX CORES

The development of the hot box process has been so rapid that it has been difficult to design tests and equipment fast enough to keep up. At present, it is possible to state some of the problems associated with the hot box process, the factors involved, the sensitive properties, and how to test for them. Complete knowledge on how to control all the variables and eliminate difficulties is gradually being assembled. The problems seem to be, in general.

(1) Short bench life.
(2) Plugging of blow holes by dry lumps.
(3) Slow curing and long ejection times.
(4) Fast curing causing plugged blow holes.
(5) Low hot tensile strength.
(6) Variable cold tensile strength.
(7) Too rapid collapse causing cuts, washes and veins.
(8) Pinholing or other gas defects.
(9) Occasional susceptibility to high humidity.

The variables which seem to have a bearing on the above problems are as follows.

(1) Quality and type of resin and accelerator.
(2) Cleanliness, pH, temperature and moisture of the sand.
(3) Storage and conveying conditions for the mixed sand.
(4) Mixing cycle and equipment.
(5) Rate of gas evolution from the core and presence of gas in the metal or its susceptibility to absorb gas.

The bench or storage life of a hot box mix can be as much as several days or as little as a few hours. This is the length of time during which a core of usable tensile strength can be blown. Aside from the choices of resin and accelerator, the gain or loss of a little moisture is critical. In fact, additional accelerator can slow up the reaction on account of the extra water it introduces. The possibility of interference by impurities in

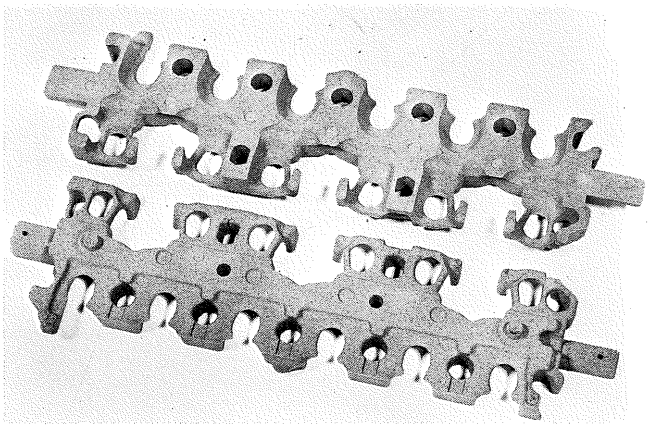


Fig. 26.4 — Hot box cylinder head core.

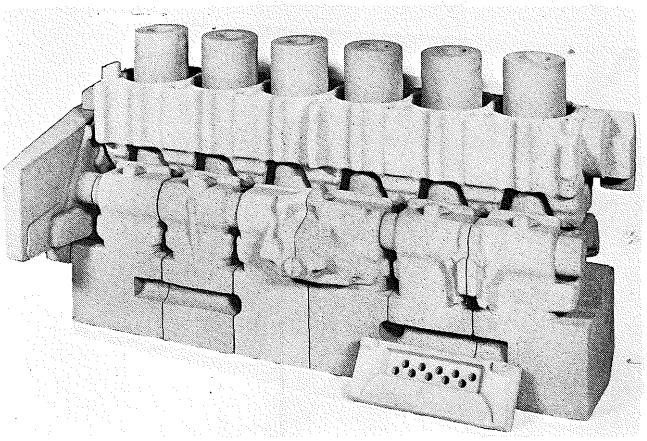


Fig. 26.5 — Six cylinder hot box core.

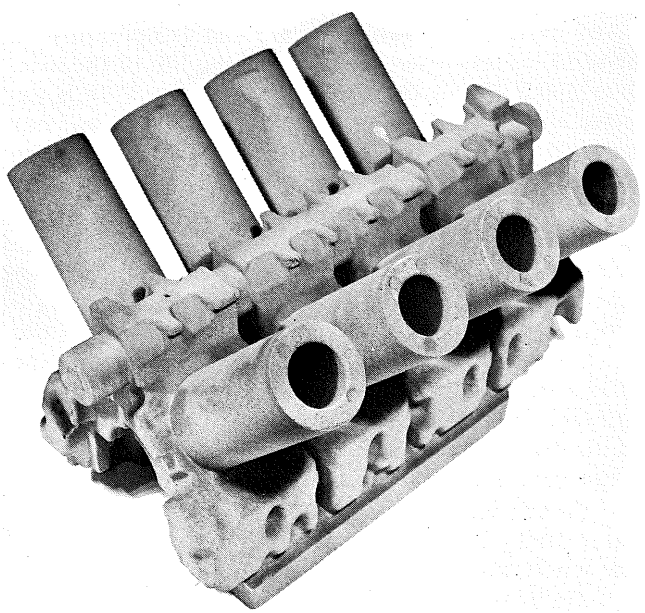


Fig. 26.6 — Hot box block core with single barrel core.

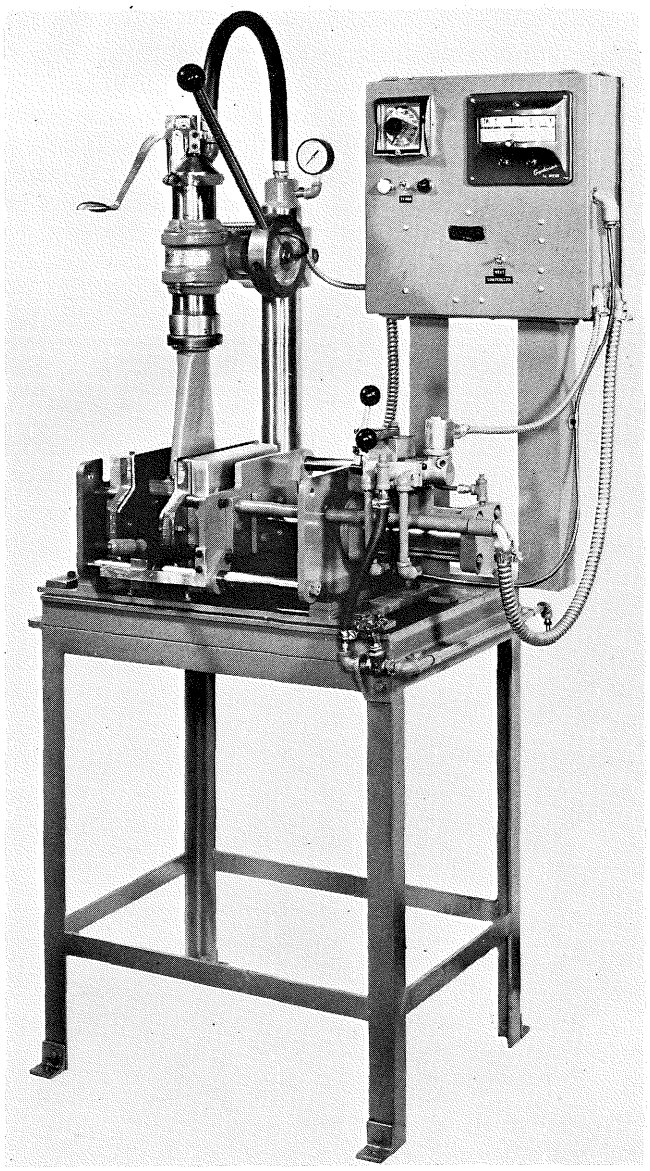


Fig. 26.7 — Hot box tensile curing machine.

the sand is still under study. Fines and clay are at least as harmful as with other resins and oils.

Any excess temperature over room temperature in the sand, mixer or storage shortens the life of the mix. Over 100 F (38 C) the action is very rapid. It is expected that the following tests will be able to sort out the good from the bad even if they don't explain the reason. The progress of deterioration in a mix can be followed by making tensile specimens at intervals in the hot box tensile curing machine (Fig. 26.7). Three specimens at a time are blown, cured and ejected automatically. The same machine is used to make regular quality control and research tensile tests on hot box mixes. A pressure sensitive switch in the air line starts a timer as the blow is made. When the set time runs out, the core box opens and the cores are ready to lift out on a fixture.

The core box temperature is controlled by a pyrometer. A special straight flow magazine is furnished. The 3-cavity box is cast iron with ample blow holes. The whole unit is complete with bench blower ready to make cores.

Another way to keep track of the deterioration process is to run a moldability index test (Fig. 24.3) at selected time intervals. The results of such a series of tests is shown in Table No. 26.2. Sand at 108 F (42 C) was charged into the mixer to simulate hot weather conditions.

TABLE 26.2

Age, hr.	Sand Temp. F (C)	Moldability Index	Green Compression	Tensile Strength, psi.
0	100 (38)	79	0.37	383
1	88 (31)	47	0.47	322
2	80 (27)	30	0.45	309
3	75 (24)	23	0.44	192
4	74 (23)	15	0.54	Would not blow

It is apparent that the green compression is not always sensitive enough to be useful. The results show that the mixed sand deteriorates rapidly at normal temperatures if it has once been warm. The moldability index does change widely and even provides a warning before the actual refusal of the sand to blow. It is surprising how uniformly different batches test about 80 moldability index if mixed, and also start to show a drop in tensile strength at about 25 moldability index. The final refusal to blow is almost always caused by a sudden hardening in the magazine and involves repeated exposure to air along with the effects of time and temperature.

The only solution to the air hardening problem is to be very exact in the design of blow magazines so that there are no corners or dead spots where sand can be sidetracked until it gets to the stage where one more blow will turn it into a dry, crusty lump which can easily break off and lodge in the blow holes. The transportation of mixed hot box sand by air gives it a

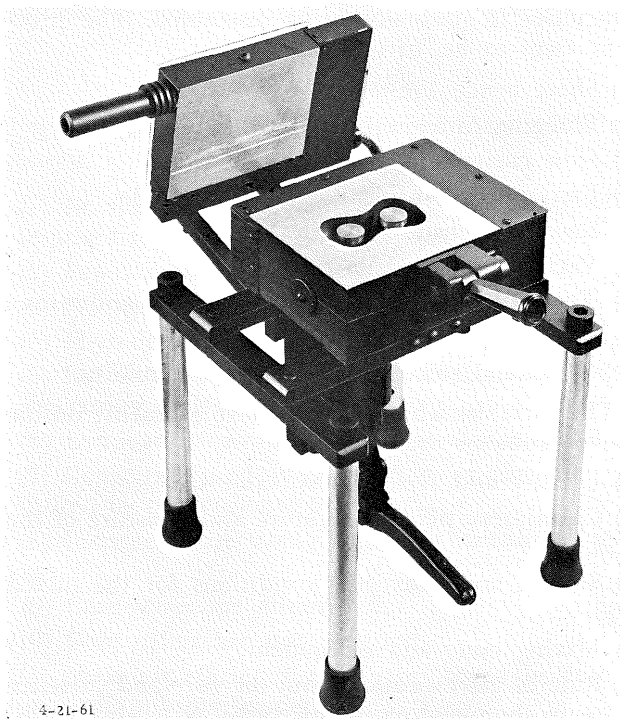


Fig. 26.8 — Tensile specimen curing and stripping accessory.

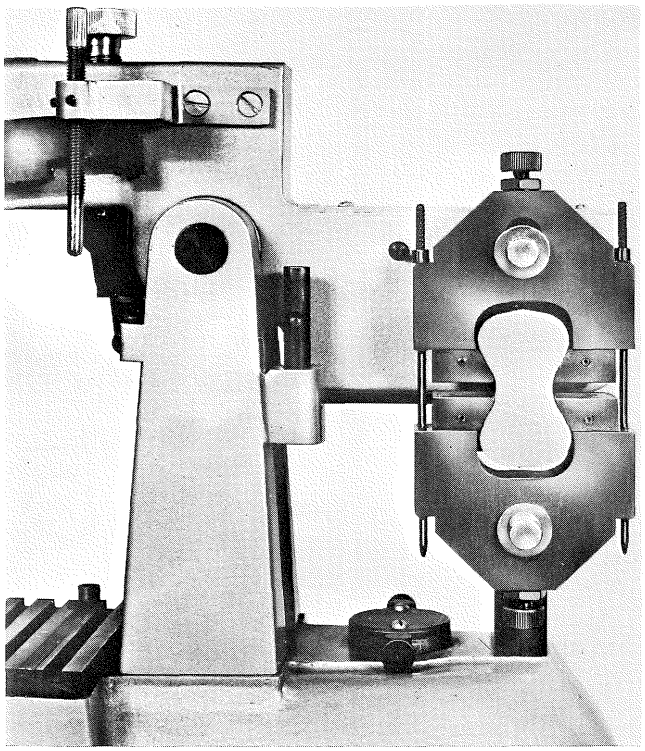


Fig. 26.9 — Universal sand strength machine.

start toward air hardening so that where this method is used, special care should be taken to design straight flow magazines. It is possible to design a test to show the effect of air on aging, but since the problem is largely mechanical, the solution is obvious.

The tensile specimens may be produced one at a time with the tensile specimen curing and stripping accessory (Fig. 26.8). This unit produces a single one in. thick tensile specimen in a thermostatically controlled core box which surrounds the specimen on all sides. The core box is split along the long axis and is also provided with push-out pins to facilitate removal of the specimen. The sand cartridge with an extended blow tube is supplied so that the box need not be opened to be blown. A screen vent is also supplied. After the sand has been blown into the core box and cured for the desired time, the top heating block is swung back, the core box halves separated and the specimen ejected by two stripping pins. After curing, hot box tensile specimens should be laid on their side on a wooden or other nonmetal surace until they are air cooled before breaking. A desiccator is not used.

The universal sand strength machine (Fig. 26.9) may be used to break the specimens up to 620 psi. This well-known machine is of the dead weight type with a constant rate of loading in accordance with AFS Specifications. The motor returns to zero at double speed to save as much time as possible.

For cores up to 1200 psi, and for rapid work, the tensile tester shown in Fig. 26.10 is preferable. This specialized machine is suitable for high strength laboratory work or rugged "out in the shop" control. The unit features uniform spring loading to 1200 psi in 40 sec and has long contact grips which are swivelled to insure true axial stress. All connections have been pinned and dowelled except for one necessary grip clearance adjustment. The specimen is dropped into the grips and the loading started by push button. After the specimen breaks, the motor returns to zero leaving the maximum tensile reading visible until reset. Brittle materials such as sand cores are somewhat sensitive to the rate of loading so that while tensile results on either machine will be consistent, they will not always check between machines closely, due to the difference in rate of loading. Tensile tester is very fast and is the only reasonable way to make a large number of tensile tests each day.

The production possibilities of hot box resin cores hinge on their ability to be ejected in the shortest possible time without being punctured by the ejection pins. The development of strength in the first few

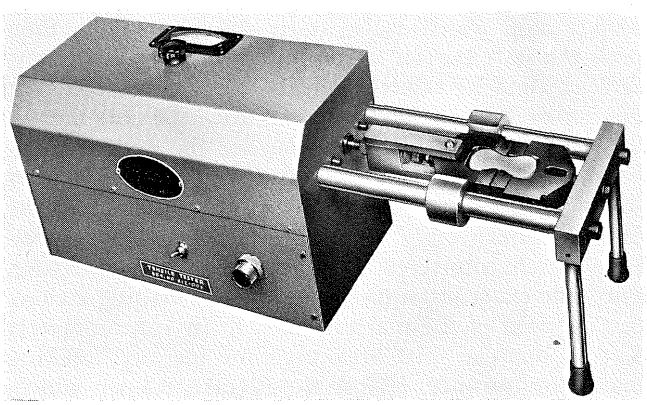


Fig. 26.10 — Tensile strength tester.

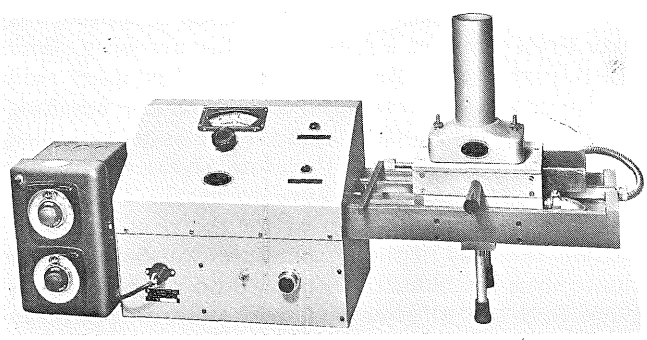


Fig. 26.11 — Hot box stripping strength tester.

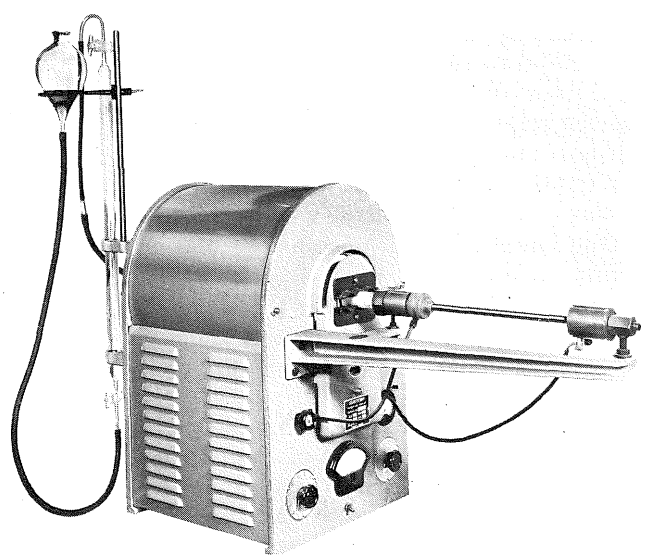


Fig. 26.12 — Gas volume determinator.

seconds is, therefore, more critical than the final tensile strength which is usually more than adequate.

The full one in. tensile specimen is thick enough to develop the same hard skin and soft center structure which exists in production cores. The rate of strength development in the first 5 to 30 sec is the most useful information. To get this data accurately, the specimen must be blown, cured and broken in place. The hot box stripping strength tester (Fig. 26.11) fits under a bench core blower and has its own magazine with a blow tube which goes through the top heater plate. Thus, the entire core is surrounded by heaters on all sides during blowing and curing. Two thermostat controls handle the heating elements. Timing can be handled in three different ways.

When the tester alone is used, the operator must snap a stop watch as he starts the blow time, then push the start button to commence loading at whatever cure time he selects. For the total cure time, the operator allows the watch to run until the core breaks. When the timer is used, it is set for the desired number of seconds at the end of which time the timer starts the breaking load, stops itself and resets to the original time setting. The timer is started by a pressure switch connected to the air line and therefore, starts the exact instant of the blow. By making a chart of the speed of the machine (200 lb in approximately 33 sec), one can read breaking time for any breaking load. For instance, 50 psi would take 8.3 sec which, together with a preset cure time of 10 sec, would make a total curing time from blow to break of 18.3 sec.

If greater accuracy and convenience is desired, the dual timer may be used. With this accessory, both timers start as the core is blown. The first timer runs out to zero, stops, resets and also starts the breaking mechanism. The second timer continues to run until the specimen breaks and, therefore, shows on its face the total cure time from blow to break. This timer then has to be manually reset for the next test. It is obvious that any of these procedures are far more accurate than the older transfer method where a core is cured in a heated blow box, removed and placed in another machine for breaking. The speeds currently being used in the hot box practice prohibit the use of this method.

Variations in resin type, moisture, accelerator, age and temperature of the sand and, possibly, the type of sand itself all have a bearing on cure rate as well as the temperature itself. The operation of the hot box strength tester is rapid enough to be used in the shop as a quality control test as well as in the laboratory for research and development work.

One interesting trait of some hot box mixes is their ability to break and rebond again when the motor reverses and brings the halves together. This property may exist for a variable length of time, probably depending again on some of the variables mentioned above.

While the effect of hot box binders in regard to pin hole formation may be one of composition as well as amount, the rate of gas evolution and total volume are still factors. The gas volume determinator (Fig. 26.12) is the standard equipment for this work. Certain refinements in procedure will help to make the test more useful. A full 3 gm sample of core should be cut out of the surface making it about ¼-in. square. Rubbing or filing from a core to get a sample can easily break off binder from the grains causing segregation and poor checks. A test temperature of not more than 1850 F (1010 C) is recommended so that an accurate measurement of rate in the first few seconds can be obtained. A light, thin boat such as nickel is the best to minimize momentary drawback of liquid in the burette.



Fig. 26.13 — Thermolab.

Core collapse is often the cause of dirt, cuts, washes and veins. The thermolab (Fig. 26.13) is the best place to study collapse of various binders and additives. The time of collapse at 50 psi load and 800 F (427 C) may be used as a measure of collapsibility.

Humidity has a weakening influence on hot box cores. A normal hot box mix was used to produce tensile cores cured at 450 F (232 C) for 20 sec. After cooling they were stored in 100 per cent humidity at room temperature. Strengths were as follows.

Time Hours	Tensile Strength, psi	Temp. F
0	350	70
1	225	70
2	150	70
4	75	70
6	50	70
8	40	70

While these conditions are more severe than ever met in the foundry it is evident that humid days may give trouble. The warm, 110 F (43 C) storage room so useful in magnesium foundries might be a good investment in other foundries as well.

Chapter 27

BIBLIOGRAPHY

The first section of the Bibliography is composed of references to AFS Transactions listed chronologically.

1922 (Vol. 30)

C. F. Mayer, "A Study of Insulated Core Oven Design and Performance," p. 680.

1923 (Vol. 31)

C. S. Kock, "Core Mixtures for Light Steel Castings," p. 236.

1925 (Vol. 33)

H. L. Campbell, "The Qualities of Commercial Core Oils," p. 72.

A. A. Grubb, "Selection and Blending of Core Sands," p. 808.

J. F. Harper and W. J. Stevenson, "Methods of Testing Core Sand Mixtures," p. 817.

1926 (Vol. 34)

H. L. Campbell, "Methods for Determining the Properties of Cores Made with Cereal Binders," p. 558.

C. A. Hausen, "Some Properties of Core Oils," p. 577.

I. Lamoreaux, "Core Supports in Large Castings," p. 1032.

1927 (Vol. 35)

H. L. Campbell, "The Effects of Moisture Absorption on the Properties of Dry Sand Cores," p. 158.

E. R. Young, "Characteristics of Some Steel Molding and Core Sand Materials," p. 202.

1928 (Vol. 36)

H. L. Campbell, "The Surface Conditions of Castings as Affected by Core-Sand Mixtures," p. 461.

1929 (Vol. 37)

H. L. Campbell, "Baking Practice for Oil-Sand Cores," p. 289.

V. A. Crosby and R. D. Wysong, "Uniformity in Core Oil—How Obtained," p. 526.

Report of Subcommittee, "Core Testing," p. 558.

1930 (Vol. 38)

J. A. Gitzen, "Value of Analysis and Specifications for Core Oils," p. 97.

D. B. Hill, "Core Room Conveyers," p. 273.

T. D. Stay, E. M. Gingerich and H. J. Rowe, "Stronger Aluminum Castings by Improved Foundry Practice," p. 65.

1931 (Vol. 39)

H. Fawcett, "Molding Practice for Heat Treated Aluminum Alloy Castings," p. 297.

W. M. Saunders and W. M. Saunders, Jr., "Effect of Heat on the Permeability of Sea Coal Facing Sands and Core Sand Mixtures," p. 440.

Report of Nonferrous Committee on Recommended Practices, p. 39, p. 43, p. 46.

1932 (Vol. 40)

A. V. Leun, "Sand Control in the Steel Foundry," p. 273.

1934 (Vol. 42)

G. Batty, "The Relation of Molds and Cores to Porosity in Steel Castings," p. 339.

1935 (Vol. 43)

J. A. Gann and M. E. Brooks, "Founding Magnesium Alloys," p. 591.

Report of Nonferrous Division Committee on Recommended Practices, p. 1.

1936 (Vol. 44)

H. A. Bedworth and V. P. Weaver, "Sand Castings of Copper-Silicon Alloys," p. 193.

Report of Nonferrous Division Committee on Recommended Practices, p. 33.

1937 (Vol. 45)

H. W. Dietert and E. Woodliff, "A Study of Core Hardness," p. 545.

1938 (Vol. 46)

J. Willsea, "What Happens to a Core in a Core Oven," p. 739.

1939 (Vol. 47)

D. O'Connor, "Production of Bronze Pressure Castings," p. 769.

E. Pragoff, Jr., "The Properties of Resin Bonded Cores," p. 97.

Recommended Practice for Sand Cast High Lead Bronzes, p. 195.

Recommended Practice for Sand Cast Manganese Bronze, p. 562.

1940 (Vol. 48)

J. A. Duma and S. W. Brinson, "Application of Directional Solidification to Steel Castings," p. 225.

1941 (Vol. 49)

E. J. Brady, "Cooperation of the Engineer, Patternmaker and Foundryman," p. 749.

Report of AFA Cost Committee, "Classification of Foundry Cost Factors," p. 298.

1942 (Vol. 50)

R. F. Lincoln, "The Arrangement of Cores, Blow Holes and Vents for Blowing Purposes," p. 1134.

F. B. Riggan, "The Use of the Hot Strength Test as a Tool for Controlling Core Mixtures," p. 1185.

O. A. Van Sickle, "Blowing Machines, Design of Core Boxes and Driers for Core Blowing Machines," p. 260.

1943 (Vol. 51)

F. S. Brewster, "Magnesium Foundry Sand Control, " p. 180.

S. W. Brinson and J. A. Duma, "Making Cores for the Steel Casting," p. 563.

M. V. Chamberlin and A. T. Peters, "Temperatures Developed in Sand Cores During the Casting of Magnesium Alloys," p. 155.

D. L. Longueville and O. J. Myers, "Core Sand Reclamation at Elevated Temperatures," p. 198.

A. V. Lorch, "Molding and Core Sand Characteristics in Light Metal Foundry," p. 183.

Z. Madacey, "Core Blowing as a Factor in a Semi-Production Factory," p. 593.

E. Pragoff, Jr. and C. P. Albus, "Elevated Temperature Studies of Foundry Cores and Coremaking Materials," p. 935.

1944 (Vol. 52)

W. C. Morgan, "Thermosetting Plastic Core Binders for Ferrous and Nonferrous Metals," p. 1317.

1946 (Vol. 54)

J. J. Clark, "Malleable Foundry Core Sand Practice," p. 634.

W. G. Ferrell, "Cores for Automotive Malleable Castings," p. 210.

H. E. Linsley, "Core Ovens," p. 803.

H. Louette, A. E. Murton and H. H. Fairfield, "Core Sand Purchasing Factors," p. 303.

D. F. Sawtelle, "Malleable Foundry Coremaking Practice," p. 691.

V. Volenik, "Measurement and Investigation of Gases Escaping from Oil Cores," p. 86.

E. C. Zirzow, "Malleable Coremaking Practice," p. 316.

1947 (Vol. 55)

AFS Committee Report, "Evaluation of Core Knockout," p. 313.

1948 (Vol. 56)

H. L. Campbell, "Designing Strainer Cores," p. 574.

H. W. Dietert, H. H. Fairfield and F. S. Brewster, "Surface Gas Pressures of Molding Sands and Cores," p. 528.

H. J. Jacobson, "Core Box Designing and Rigging for Core Blowing," p. 602.

1949 (Vol. 57)

AFS Committee Report, "A Study of the Workable Green Strength of Core Mixtures," p. 386.

C. A. Barnett, "Modern Foundry Core and Mold Ovens," p. 181.

H. K. Salzberg, "Plastic Binders for Foundry Sand Practice," p. 357.

1950 (Vol. 58)

B. H. Booth, "Controlled Sand Produces Quality Castings," p. 52.

S. L. Gertsman and A. E. Murton, "An Investigation of Metal Penetration in Steel Sand Cores," p. 595.

F. E. McMillan and J. A. Wickett, "Phenolic Resin Core Binders," p. 439.

O. J. Myers, "Effect of Moisture on Core Sand Mixtures," p. 557.

R. B. Wagner and J. E. Wiss, "Cold Formed Flexible Precision Patterns and Core Boxes," p. 675.

H. R. Williams, "Standard Data for Bench Coremaking," p. 503.

1951 (Vol. 59)

E. A. Blake, "Design of Core Boxes and Driers for Use on Core Blowing Machines," p. 216.

J. W. Cable, "Recent Advances in Dielectric Core Baking," p. 159.

R. H. Greenless, "Modern Core Sand Practice," p. 412.

E. J. Jory, "Core Practice as Related to Malleable Foundry Losses," p. 300.

A. E. Murton, H. H. Fairchild and B. Richardson, "Core Oil Evaluation Method," p. 276.

H. W. Zimnawoda, "Mechanical Equipment for Medium Size Gray Iron Foundry," p. 56.

1952 (Vol. 60)

AFS Sand Division Committee, "Veining Tendencies of Cores," p. 218.

J. N. Mathias, "Core Boxes for Core Plugs," p. 466.

G. Ulmer and M. DeCrop, "Influence of the Nature of Oven Atmosphere on Drying of Molds and Baking of Foundry Cores," p. 234.

1953 (Vol. 61)

AFS Sand Division Committee, "Veining Tendencies of Cores," p. 150.

C. T. Marek and R. J. Wimmert, "Induced Flow Process of Baking Oil-Bonded Cores," p. 279.

L. L. Martin, "Developing Standard Data Tables for Core Finishing," p. 355.

1954 (Vol. 62)

AFS Sand Division Committee, "Metal Penetration Tests on Dry Sand Cores and Core Washes," p. 78.

W. H. Buell, "What Is Stickiness in Core Sand Mixtures?" p. 131.

A. A. Evans, "Fluidity vs. Core Blows in Automotive Gray Iron," p. 492.

R. B. Fischer, "Some Factors Affecting Metal Penetration of Navy 'M' Bronze in Cores," p. 199.

J. A. Mescher, "Core Blowing Principles," p. 600.

R. W. Wendt, "Use of Blow-In Core Driers," p. 427.

1955 (Vol. 63)

R. F. Dalton, "Make Plastic Cores in Rubber-Lined Boxes," p. 442.

C. J. Gogek, "A New Foundry Core Sand Binder," p. 472.

R. H. Greenlee, "Coreroom Practice Pitfalls," p. 373.

G. J. Grott and H. F. Taylor, "Reactions During Core Baking," p. 493.

R. L. Olson, "Sealing Metal Coreboxes Against Blow-By," p. 325.

W. Schumacher, "Application of the Carbon Dioxide Process in the Foundry," p. 488.

C. H. Wyman, "Influence of Coremaking Materials on Development of Hot Tears," p. 203.

1956 (Vol. 64)

P. J. Ahearn, F. Quigley, J. I. Bluhm and J. F. Wallace, "Some Considerations on the Tensile and Transverse Strength Testing of Shell Mold and Core Sands," p. 125.

D. V. Atterton, "The Carbon Dioxide Process," p. 14.

A. M. Clark, "Principles of Core Blowing," p. 267.

J. E. Huss, "A Survey of the CO_2 Process," p. 98.

D. S. Mills, "Stickiness in Core Sand Mixtures," p. 344.

F. M. Scraggs, "Coremaking with the CO_2 Process," p. 333.

E. C. Zuppann, H. Putz, "Evaluating Green Properties of Cereal Core Binders," p. 267.

1957 (Vol. 65)

R. F. Dalton, "Intricate Small Diameter Coring of Aluminum and Magnesium Alloy Sand Casting," p. 483.

W. E. Mason, "Metal Core Box Equipment," p. 443.

R. L. Olson, "Engineering Aids for Sealing Core Boxes Against Blow-By," p. 471.

1958 (Vol. 66)

E. A. Lange and R. E. Morey, "Sodium Silicates for the CO_2 Process," p. 35.

G. Nestor, "Carbon Dioxide Cores in a Malleable Foundry," p. 252.

W. A. Wright, "Construction of Shell Mold Patterns and Core Boxes," p. 495.

C. E. Wulff, "Investigation of the Hardening of Sodium Silicate Bonded Sands," p. 91.

V. E. Zang, "Construction Hints and Wear Characteristics of Plastic Patterns and Core Boxes," p. 569.

1959 (Vol. 67)

AFS Sand Division Committee, "Stickiness in Core Sand Mixtures," p. 598.

R. J. Cowles, "Optimum CO_2 Molding," p. 553.

W. H. Miller, "Core Box Rigging for High Production," p. 629.

J. E. Stock, "Core Boxes for Shell Cores," p. 421.

1960 (Vol. 68)

Z. Madacey, "Pattern and Core Box Equipment for Blowing Foundry Sands," p. 193.

H. K. Salzberg and J. J. Greaves, "Phenolic Resin Bond in Solid Sand Cores," p. 387.

1961 (Vol. 69)

G. D. Haley and J. L. Leach, "The Carbon Dioxide Process," p. 189.

E. E. Harkess, "Hot Core Box Design and Engineering," p. 123.

P. Jasson, "Core Production in Hot Box Cores," p. 287.

1962 (Vol. 70)

R. J. Bossong and J. R. Jenkins, "Core Economics," p. 1278.

J. Pelleg, "Core Binder Properties," p. 57.

L. W. Smith and H. W. Noll, "Evaluation of Hot Box Furan Core Binders for Steel Castings," p. 924.

1963 (Vol. 71)

M. Granlund and G. Noren, "Loading Rate Effect on Tensile and Compressive Strengths of Various Binders," p. 167.

1964 (Vol. 72)

R. J. Cowles, "A Report of the Developments for Eliminating Deformation and Cracking in Shell Molds and Cores During Casting," p. 923.

1965 (Vol. 73)

M. D. Markarian, "Hot Boxes! Progression to Superheating of Air for Core Boxes," p. 84.

References from sources other than AFS Transactions.

Authors Anonymous

"Aluminum Foundry Rearranged," *Iron Age,* Vol. 121, No. 11, p. 726 (Mar. 15, 1928).

"Bureau of Standards Investigates Rubber Core Binders," *Foundry,* Vol. 56, No. 21, p. 892 (Nov. 1, 1928.)

"Cleanliness Stressed in Pressurized Coreroom," *Foundry,* Vol. 91, No. 7, p. 104 (July 1963).

"CO_2 Breakdown Agent," *Foundry Trade Journal,* p. 764 (June 16, 1960).

"Conditioning Air," *Canadian Foundryman,* Vol. 24, p. 27 (Aug. 1923).

"Core Baking by Electric Heat," *Iron Age,* Vol. 120, No. 1, p. 18 (July 7, 1927).

"Core Baking with Electric Heat," *Nat. Elec. Light Assn.,* Report No. 256-88 (Aug. 1926).

"Coremaking Equipment," *Zeit. fuer die Gesamte Giessereipraxis* (Berlin), Vol. 51, No. 6, p. 51 (Feb. 9, 1930).

"Core Production with Air-Setting Sand," *Foundry,* Vol. 88, No. 6, p. 106 (June 1960).

"Core Sand, Core Binders and Coremaking," *Canadian Foundryman,* Vol. 12, p. 21 (Dec. 1921).

"Economics in Core Production," *Foundry Trade Journal,* Vol. 31, No. 454, p. 372 (April 30, 1925).

"Fluid Sand," Editorial, *Foundry Trade Journal,* p. 527 (May 6, 1965).

"Forum on CO_2 Silicate," *Foundry Trade Journal,* p. 768 (Dec. 10, 1964).

"Further Notes on the CO_2 Process and Core Assembly," *The British Foundryman,* Vol. LVIII, No. 12, p. 487 (Dec. 1965).

"Gas Burning Equipment on Large Core Oven," *Iron Age,* Vol. 109, p. 342 (Feb. 2, 1922).

"Gas for Foundry Ovens," *Foundry,* Vol. 52, p. 116 (Feb. 1, 1924).

"Heater Sections Made in Quantity," *Foundry,* Vol. 50, p. 267 (April 1, 1922).

"Hints for the Core Room," *The Foundry,* Vol. 57, No. 19 (Oct. 1, 1929).

"Hints for the Core Room," *Foundry,* Vol. 58, Nos. 7 and 8 (April 1, 1930).

"Hints for the Core Room," *Foundry,* Vol. 57, Nos. 22 and 23 (Nov. 15 and Dec. 1, 1929).

"Hints for the Core Room," *Foundry,* Vol. 58, Nos. 1, 2 and 3 (Jan. 1, 1930).

"Hints for the Core Room," *Foundry,* Vol. 58, No. 4 (Feb. 15, 1930).

"Improved Core Making Practice," *Metal Industry* (London), Vol. 50, No. 15, p. 437 (April 9, 1937).

"Improved Core Output from Smaller Space," *Iron Age,* Vol. 108, No. 15, p. 927 (Oct. 13, 1921).

"Installation of Continuous and Batch Type Ovens Used for Baking Cores," *Fuels and Furnaces,* Vol. 7, No. 4, p. 601 (April, 1929).

"Intricate Castings Use Zircon Sand Cores," *Foundry,* Vol. 90, No. 12, p. 134 (Dec. 1962).

"Large Cores for Turbine Castings," *Iron Age* (July 28, 1921).

"Manufacture of Silicon Cast Iron," *Zeit. fuer die Gesamte Giessereipraxis* (Berlin), Vol. 50, No. 45, p. 381 (Nov. 10, 1929).

"Mechanized CO_2 Process Cuts Core Cost 30%," *Foundry,* Vol. 90, No. 7, p. 157 (July 1962).

"Molds Formed with Cores," *Metal Industry* (London), Vols. 26 and 27, Nos. 23, 25, 3, and 6, pp. 559, 607, 57, 123 (June 5, 19, July 17, and Aug. 7, 1925)

"Nishiyama and Fluid Sand Process," An Interim Report, *Foundry Trade Journal,* p. 14 (July 1, 1965).

"Oil Sand Cores," *Foundry,* Vol. 52, p. 72 (Jan. 15, 1924).

"Pastes and Gums as Core Binders," *Western Machinery World,* Vol. 16, No. 9, p. 371 (Sept. 1925).

"Plastic Saves Time in Corebox Duplication," *Foundry,* Vol. 89, No. 2, p. 152 (Feb. 1961).

"Pouring Gates Are Used as Risers," *Foundry,* Vol. 49, p. 696 (Sept. 1, 1921).

"Precision Production of Metal Patterns and Core Boxes," *Foundry Trade Journal,* Vol. 60, No. 1173, p. 133 (Feb. 9, 1933).

"Rate Fixing and Estimating," *Automobile Engr.,* Vol. 16, No. 213, p. 97 (March 1926).

"Recovers Core Sand from Sand Blast," *Iron Age,* Vol. 131, No. 24 (June 15, 1933).

"Remove Cores with Vibrator," *Foundry,* Vol. 51, p. 984 (Dec. 15, 1923).

"Requirements of Foundry Core Oils and Their Composition," *Zeit. fuer die Gesamte Giessereipraxis* (Berlin), Vol. 50, No. 5, p. 37 (Feb. 3, 1929).

"Rubber Core Binders for Foundry Cores," *Letter Circular 252,* Department of Commerce, Bureau of Standards (Sept. 4, 1928).

"Securing Cores in Molds," *Eng. Production,* Vol. 8, No. 150, p. 66 (March 1925).

"Self-Contained Heater for Foundry and Metallurgical Use," *Engineering,* Vol. 119, No. 3101, p. 700 (June 5, 1925).

"Significance of Removing Core Air in Manufacture of Gas Burners," *Kankl, Giesserei* (Dusseldorf), Vol. 16, No. 52, p. 1220 (Dec. 27, 1929).

"Specializes in Die Blocks for Automotive Industry," *Foundry,* Vol. 57, No. 19, p. 812 (Oct. 1, 1929).

"Spindles Are Molded in Cores," *Foundry,* Vol. 52, p. 445 (June 1, 1924).

"The Stock Core," *Research Group News,* Vol. 2, No. 1, p. 2 (April 1925).

"Testing of Core Binders," *Diepschlag, Giesserei,* Vol. 13, No. 40, p. 752 (Oct. 2, 1926).

"Thermotechnical Investigation of Core Drying Plant of Firm of Carl Schenk, Darmstadt Machine Shop and Iron Foundry," *Borissow, Giesserei,* Vol. 13, No. 35, p. 650 (Aug. 28, 1926).

"Thermotechnology of a Core Drying Oven," *Schlipkoter, Giesserei,* Vol. 13, No. 35, p. 648 (Aug. 28, 1926).

The following references are listed alphabetically by author.

C. W. Ammen, "Trouble Shooting (Core Plug Method)," *Foundry,* Vol. 87, No. 1, p. 178 (Jan. 1960).

Archer-Daniels-Midland Co., "Adcosil Technical Bulletin, No. 1."

A. Atherton, E. Roebuck and W. Herring, "The Relayout of a Jobbing Shop," *British Foundryman,* Vol. LIV, p. 421 (1961).

H. S. Austin and C. E. Schubert, "Eliminating Variables in Core Testing," *Foundry,* Vol. 68, No. 6, p. 42, 122 (June, 1940).

W. C. Babbitt, "Synchronization of Equipment Aids Material," *Foundry,* Vol. 59, No. 6, p. 51 (March 15, 1931).

R. Ballantine, "Development in the Production of Ingot Mold Castings," *Foundry Trade Journal,* Vol. 56, No. 1064 and 1065, p. 3, 25 and 32 (Jan. 7 and 14, 1937).

M. Barnardy, "Use of Core Oil in Coremaking," *Giesserei* (Dusseldorf), Vol. 17, No. 21, p. 512 (May 23, 1939).

C. A. Barnett, "Selecting the Core Oven Suited to the Work," *Canadian Foundryman,* Vol. 17, No. 5, p. 14 (May, 1926).

C. A. Barnett, "Oven Design Shows Advance," *Foundry,* Vol. 54, No. 6, p. 240 (Mar. 15, 1926).

E. W. Beach, "Bake Cylinder Block Cores in Continuous Ovens," *Foundry,* Vol. 58, No. 24, p. 55 (Dec. 15, 1930).

F. H. Bell, "Cores, Core Sand, Core Binders and Core Ovens," *Canadian Foundryman,* Vol. 13, p. 22 (Jan. 1922).

F. H. Bell, "Cores Play Prominent Part in Molding Turbine," *Canadian Foundryman,* Vol. 15, No. 10, p. 39 (Oct. 1924).

H. J. Bidwell, "Development of a CO_2 Process Molding Sand," *Foundry Trade Journal,* p. 383 (Oct. 29, 1959).

B. Bird, "Core Assembly," *British Foundryman,* Vol. LIV, p. 392 (1961).

P. O. Bobo, Jr., "New Techniques for Combining Baked Strength Core Binders," *Modern Castings,* Vol. 50, p. 53 (July 1966).

O. Brandt, "Core Drying in Nonferrous Foundries by Means of Exhaust Gas Utilization," *Giesserei* (Dusseldorf), Vol. 17, No. 48, p. 1152 (Nov. 28, 1930).

E. Bremer, "Continuous Ovens Increase Capacity and Speed Production," *Foundry,* Vol. 57, No. 2, p. 82 (Jan. 15, 1929).

E. Bremer, "Gas-Fired Horizontal Oven Bakes Cores Rapidly," *Foundry,* Vol. 58, Nos. 4 and 5, pp. 68 and 115 (Feb. 15 and March 1, 1930).

G. W. Brown and C. B. Searles, "Some Experiences with the CO_2 Process in the Production of Copper-Base Castings," *British Foundryman,* Vol. LIV, p. 205 (1961).

E. Bruehl, "Core Oils," *Chemiker-Zeitung,* Vol. 55, No. 4, p. 442 (June 10, 1931).

Brumley Donaldson Co., "DonCO_2 Binders and Sand."

N. F. Budgen, "Oil-Sand Cores for Nonferrous Castings," *Metal Industry* (N.Y.), Vol. 28, No. 8, p. 370 (Aug. 1930).

W. W. Burden, "Conveyer-Type Oven Used for Baking Cores," *Fuel and Furnaces,* Vol. 5, No. 12, p. 1661 (Dec. 1927).

R. S. Bushnell and E. Park, "The Production of Cores by a Cold Setting Nonstoving Method, Using Furan Resins," *British Foundryman,* Vol. LV, p. 325 (1962).

J. B. Caine and R. E. Toepke, "Gas Pressure and Venting of Cores," *Modern Castings,* Vol. 49, p. 91 (Feb. 1966).

H. L. Campbell, "Baking of Oil-Sand Cores," *Fuels and Furnaces,* Vol. 7, No. 5, p. 759 (May 1929).

H. L. Campbell, "Core Sand Mixtures Affect Castings' Surface," *Canadian Foundryman* (Toronto), Vol. 19, No. 11, p. 14 (Nov. 1928).

H. L. Campbell, "On the Use of Convected and Radiated Heat in Core Ovens," *Canadian Foundryman* (Toronto),

Vol. 21, No. 2, p. 15 (Feb. 1930).

H. L. Campbell, "The Selection of Fuels for Heating Core Ovens," *Gas World* (London), Vol. 92, No. 2394, p. 11 (June 21, 1930).

H. L. Campbell, "Heating Requirements for Core Baking Ovens," *Fuels and Furnaces,* Vol. 8, No. 7, p. 955 (July 1930).

Cardox Division of Chemtron Corp., "Cardox CO_2 Process."

E. J. Carmody and J. E. Olson, "Makes Diesel Engine Castings," *Foundry,* Vol. 65, No. 12, p. 30 (Dec. 1937).

Carver Foundry Products, "Carbon Dioxide Mold and Core Hardening Procedures," Instruction Booklet, 4th Ed.

C. H. Casberg and C. E. Schubert, "An Investigation of Core Oils," *Engineering Experiment Station Bulletin,* University of Illinois, Vol. 28, No. 28 (March 10, 1931).

C. H. Casberg and C. E. Schubert, "Investigation of Suitability of Soya Bean for Core Oil," *University of Illinois Bulletin,* Vol. 39, No. 11 (Oct. 6, 1931).

G. C. Castle, "Foundry Sands and Their Applications," *Iron and Steel Industry* (London), Vol. 11, No. 9, p. 265 (1929).

D. Chalder, "The Hot Box Process and Some of the Factors Affecting Its Efficiency," *The British Foundryman,* Vol. LVIII, No. 11, p. 419 (Nov. 1965).

J. Corrigan, "Core Tests Show Peculiar Results," *Foundry,* Vol. 57, No. 4, p. 144 (Feb. 15, 1929).

A. S. Coulter, "Humidity and Oil Sand Cores," *Foundry,* Vol. 61, No. 2, p. 13 (Feb. 1933).

V. A. Crosby and R. D. Wysong, "Uniform Methods of Analysis Should Govern Core Oil Specifications," *Foundry,* Vol. 58, No. 3, p. 121 (Feb. 1, 1930).

J. E. Crown, "Bronze Pressure Castings," *Metal Industry* (N. Y.), Vol. 29, No. 8, p. 335 (Aug. 1931).

E. M. Currie, "The Preparation and Testing of Molding and Core Sands," *Foundry Trade Journal,* Vol. 28, No. 382, p. 498 (Dec. 13, 1923).

V. Delport, "Core Room Layout Features English Automobile Foundry," *Foundry,* Vol. 63, No. 12, p. 26 (Dec. 1935).

Diamond Alkali Co., "Self Setting Binder," *Foundry Trade Journal,* p. 737 (June 17, 1965).

A. H. Dierker, "Some Fundamental Considerations in Core Drying," *Industrial Heating,* Vol. 2, No. 11, p. 665 (Nov. 1935).

H. W. Dietert, "Core Behavior at Elevated Temperatures," *Foundry,* Vol. 68, No. 10, p. 52 (Oct. 1940).

H. W. Dietert and E. Woodliff, "A Study of Core Hardness," *Metal Industry* (London), Vol. 51, No. 7, p. 154 (Aug. 13, 1937).

H. W. Dietert, "Control of Sand Is as Important as Control of Metal in the Foundry," *Iron Age,* Vol. 127, No. 18, p. 1432 (April 30, 1931).

J. Duchaillut, "Drying of Foundry Cores," *Fonderie Modern* (Paris), Vol. 24, p. 215 (June 25, 1930).

E. I. DuPont de Nemours and Co., "Sodium Silicate Product Information," Grasselli Chemical Dept.

P. Dwyer, "Set Core Mixture Standards," *Foundry,* Vol. 50, p. 695 (Sept. 1, 1922).

P. Dwyer, "Set Core Mixture Standards," *Foundry,* Vol. 59, No. 5, p. 77 (Mar. 1, 1931).

P. Dwyer, "Hold Cores to Close Tolerances," *Foundry,* Vol. 63, No. 1, p. 28 (Jan. 1935).

P. Dwyer, "Produce Cores by the Thousands with Watchmaking Accuracy," *Foundry,* Vol. 54, No. 16, p. 638 (Aug. 15, 1926).

P. Dwyer, "Stepping Up Production Mechanically," *Foundry,* Vol. 55, No. 14, p. 550 (July 15, 1927).

P. Dwyer, "How Ford Cylinder Blocks Are Cast," *Foundry,* Vol. 49, p. 751 (Oct. 1, 1921).

P. Dwyer, "Molds Faced with Core Sand," *Foundry,* Vol. 65, p. 22 (Jan. 1937).

P. Dwyer, "Valve Castings Made in Steel," *Foundry,* Vol. 52, p. 579 (Aug. 1, 1924).

T. C. Earnhill, "Suggestions for Controlling of Core Sand Mixtures," *Canadian Foundryman,* Vol. 20, No. 5, p. 17 (May 1929).

J. H. Eastham, "Dry Sand Cover Core Cuts Molding Costs," *Foundry,* Vol. 65, No. 4, p. 49 (April 1936).

G. Edgington, "Oil-Sand Cores," *Foundry Trade Journal,* Vol. 31, No. 451, p. 315 (April 9, 1925).

F. C. Edwards, "Extending the Uses of the Oil-Sand Core," *Foundry Trade Journal,* Vol. 31, No. 457, p. 429 (May 21, 1925).

F. C. Edwards, "The Oil-Sand Core," *Metal Industry* (London), Vol. 26, No. 16, p. 391 (April 17, 1925).

F. C. Edwards, "Design and Shrinkage," *Foundry Trade Journal* (London), Vol. 39, No. 624, p. 75 (Aug. 2, 1928).

F. C. Edwards, "Accurate Core Location," *Metal Industry* (London), Vol. 27, No. 12, p. 267 (Sept. 18, 1925).

O. P. Einerl, "Developments of Sodium Silicate Moulding Materials," *Foundry Trade Journal,* p. 539 (May 6, 1965).

G. O. Ekstadt, "Changed Design of Corebox to Speed Production of Tank Cores," *Foundry,* Vol. 64, No. 1, p. 34 (Jan. 1936).

J. Ellis, "Molding and Casting," *Foundry Trade Journal* (London), Vol. 42, No. 716 and 719, p. 348 and p. 397 (May 8 and May 29, 1930).

W. C. Ewalt, "Making Globe Valve Corebox," *Foundry,* Vol. 52, p. 483 (June 15, 1924).

E. G. Fieghen, "Oven-Drying of Cores and Molds," *Foundry Trade Journal,* Vol. 51, No. 934, p. 21 (July 12, 1934).

R. A. Fiske, "Vertical and Overhead Core Ovens," *Iron Age,* Vol. 121, No. 22, p. 1523 (May 31, 1928).

W. M. Flint, "Large Work Simplified with CO_2 Cores," *Foundry,* Vol. 89, No. 7, p. 117 (July 1961).

F. Freytag, "Standardization of Wooden Core Boxes," *Giesserei,* Vol. 18, No. 36, p. 698 (Sept. 4, 1931).

D. W. Frye, "Uniformity in Foundry Cores with Gas Heat," *Industrial Gas,* Vol. 12, No. 11, p. 7 (May 1934).

F. E. Gardiner, "Gas-Fired Owens as Foundry Baking Units," *Canadian Foundryman,* Vol. 21, No. 12, p. 17 (Dec. 1930).

L. E. Gilmore, "Metal for Malleable Iron Fittings Melted in the Cupola," *Foundry,* Vol. 55, No. 31, p. 840 (Nov. 1, 1927).

F. Giolitti, "Cement-Sand Cores and Molds," *Metal Progress,* Vol. 25, No. 1, p. 44 (Jan. 1934).

P. L. Goodale, "Shows Penetration of Steel Cast Against Sand," *Foundry,* Vol. 58, No. 15, p. 93 (Aug. 1, 1930).

L. W. Greene, "Investigate Binding Properties," *Foundry,* Vol. 59, No. 1, p. 71 (Jan. 1, 1931).

R. Gregg, "Coremaking," *Western Machinery World,* Vol. 16, No. 8, p. 336 (Aug. 1925).

M. J. Gregory, "Caterpiller Reclaims Core Sand By Washing Method," *Foundry,* Vol. 59, No. 19, p. 46 (Oct. 1, 1931).

F. Groves-Palmer, "The Use of Rubber as a Core Binder," *Foundry Trade Journal* (British), p. 392 (Nov. 29, 1928).

A. A. Grubb and F. L. Wolf, "Core-Oven Tests," *Amer. Inst. Min. & Met. Eng., Trans.* (April 1922).

A. A. Grubb and U. S. Jamison, "Air Required in Baking Cores Made with Linseed Oil," *Chemical and Metallurgical Engineering,* Vol. 25, p. 792 (Oct. 1921).

J. L. Handley, "Practical Applications of the CO_2 Process," *British Foundryman,* Vol. LIV, p. 270 (1961).

C. A. Hardy, "Speeding Up Handling in the Foundry," *Materials Handling and Distribution,* Vol. 1, No. 11, p. 24 (Aug. 1929).

E. E. Harkess, "Hot Core Box Design and Engineering," *British Foundryman,* Vol. LV, p. 402 (1962).

T. R. Harris, "Core Prints," *Foundry Trade Journal,* Vol. 51, No. 938, p. 93 (Aug. 9, 1934).

T. R. Harris, "Molding a Marine Propeller with Hollow Blades," *Metal Industry* (London), Vol. 51, No. 10, p. 225 (Sept. 3, 1937).

H. J. Heine, "Hardening Molds and Cores Without Heat," AFS Chapter lecture (August 1955).

C. C. Hermann, "The Baking of Cores," *Brass World,* Vol. 21, No. 3, p. 87 (March 1925).

R. H. Herrmann, "New Line Integrates Molding and Coremaking," *Foundry,* Vol. 90, No. 12, p. 48 (Oct. 1962).

R. I. Herrmann, "CO_2 Cores and Shell Molds," *Foundry,* Vol. 85, No. 3, p. 128 (March 1957).

D. B. Hill, "Conveyors for Core Ovens," *Iron Age,* Vol. 125, No. 23, p. 1673 (June 5, 1930).

T. Hill, "Characteristics, Selection and Use of Molding Sand," *Western Machinery World,* Vol. 19, No. 9, p. 405 (Sept. 1928).

F. Hudson, "Reclamation of Foundry Sand," *Foundry Trade Journal* (London), Vol. 43, No. 732, p. 141 (Aug. 28, 1930).

F. Hudson, "Hidden Facts in Oil-Sand Practice," *Foundry Trade Journal* (London), Vol. 41, No. 696 and 697, pp. 443 and 459 (Dec. 19 and 26, 1929).

F. Hudson, "Composition and Its Effect Upon the Properties of Mold and Core Sand Mixtures at Elevated Temperatures," Vol. 54, No. 1034 and 1036, p. 458 and 502 (June 11 and 25, 1936).

F. Hudson, "Some Properties of Mold and Core Materials at Elevated Temperatures," *Foundry Trade Journal,* Vol. 53, No. 1007, p. 411 (Dec. 5, 1935).

K. Huettenes, "Study of Core Binders," *Giesserei,* Vol. 18, No. 4, p. 124 (Feb. 6, 1931).

H. Illies, "Core Ovens with Continuous Operation," *Giesserei* (Dusseldorf), Vol. 17, No. 34, p. 825 (Aug. 22, 1930).

R. I. Iavkin et al, "A Coreshooter for Producing Cores by the CO_2 Process," *Russian Castings Production,* p. 414 (Sept. 1963).

P. Jasson, "Core Production in Hot Boxes at the Renault Works," *British Foundryman,* Vol. LIV, p. 309 (1961).

J. L. Jones, "Core Baking in Electrically Heated Ovens," *Metal Industry* (N.Y.), Vol. 18, No. 10, p. 450 (Oct. 1920).

J. S. Keenan, "Core Baking with Electric Heat," *Canadian Foundryman,* Vol. 19, No. 5, p. 36 (May 1928).

A. D. Kirby, "Intricate Steel Castings for Automobiles," *Foundry Trade Journal,* Vol. 48, No. 873, p. 337 (May 11, 1933).

T. W. Kleinsorge, "Chemical Analysis of Core Oils," *Giesserei* (Dusseldorf), Vol. 17, No. 21, p. 515 (May 23, 1930).

L. B. Kogan, "Problem of Interaction Between a Casting and a Metal Core," *Russian Castings Production,"* p. 83 (Feb. 1962).

E. F. Koglin, "The Evolution of a Modern Sand Binder," *Modern Castings,* Vol. 49, p. 126 (June, 1966).

O. Y. Kotsyubinskii and A. M. Gerchikov, "Stresses Due to the Strength of Cores in Box-Section Iron Castings," *Russian Castings Production,* p. 27 (Jan. 1961).

V. S. Krivitskii and B. B. Gulyaev, "Silicate Bonded Core Sands for Coreshooters and Sandslingers," *Russian Castings Production,* p. 165 (April 1965).

I. Lamoureux, "Fundamentals of Foundry Practice," *Foundry,* Vol. 58, No. 19 and 20, p. 94 and 66 (Oct. 1 and 15, 1930).

I. Lamoureux, "Fundamentals of Foundry Practice," *Foundry,* Vol. 58, No. 10 and 11, p. 165 and 163 (May 15 and June 1, 1930).

I. Lamoureux, "Foundry Practice," *Foundry,* Vol. 58, No. 13, p. 109 (July 1930).

H. M. Lane, "Modern Core Baking Ovens," *Iron Age,* Vol. 146, No. 16, p. 42 (Oct. 17, 1940).

H. M. Lane, "Cores Baked in Continuous Gas-Fired Ovens," *Iron Age,* Vol. 126, No. 26, p. 1916 (Dec. 25, 1930).

H. M. Lane, "Fuels and Their Handicaps as Related to Drying Ovens," *Fuels and Furnaces,* Vol. 1, No. 1, p. 4 (May 1923).

J. F. Langner, "Converting Core Ovens to Gas Heating," *Iron Age,* Vol. 122, No. 23, p. 1424 (Dec. 6, 1928).

R. B. Leckie, "Building the Industrial Load," *Gas World* (London), Vol. 91, No. 2350, p. 117 (Aug. 17, 1929).

P. Lemon, "Development of Resins for the Hot Box Process," *British Foundryman,* Vol. LIV, p. 542 (1961).

A. M. Levin and O. N. Bryukhanov, "Drying Cores Using Infra-Red Radiant Burners," *Russian Castings Production,* p. 98 (Mar. 1961).

R. F. Lincoln, "Fundamentals of Core Blowing," *Foundry,* Vol. 68, No. 3, p. 34 (March 1940).

C. B. Lockhart, "Cores Removed by Hydraulic Method," *Foundry,* Vol. 52, p. 568 (July 15, 1924).

U. Lohse, "Manufacture of Cores with Compressed Air," *V. D. I. Zeit.* (Berlin), Vol. 74, No. 43, p. 1479 (Oct. 25, 1930).

E. Longden, "An Analysis of Defective Castings," *Foundry Trade Journal,* Vol. 31, No. 446 and 447, p. 208, p. 229 (March 5 and 12, 1925).

D. L. Longeuville, "CO_2 Molding Sand Additive Aids Production," *Foundry,* Vol. 88, No. 3, p. 189 (March 1960).

J. MacLachlan and C. A. Otto, "Core and Mold Drying," *Iron and Steel Industry* (London), Vol. 3, No. 2, p. 57 (Nov. 1929).

L. Magee, "Developments in the CO_2 Process for Steel Foundries," *British Foundryman,* Vol. LV, p. 471 (1962).

R. F. Mann, "Core Baking by Gas," *Gas Age Record,* Vol. 60, No. 22, p. 819 (Nov. 26, 1927).

W. Mann, "The Design of Operation of Foundry Driers," *Giesserei* (Dusseldorf) Vol. 15, No. 25, p. 591 (June 22, 1928).

J. Masters, "Oil Sand Cores," *Foundry Trade Journal,* Vol. 25, p. 157 (Mar. 2, 1922).

C. A. Mauch, "Modern Vertical Core Ovens," *Iron Age,* Vol. 140, No. 1, p. 26 (July 1, 1937).

W. J. May, "Casting Cored Work in Iron," *Mechanical World,* Vol. 80, No. 2065, p. 90 (July 30, 1926).

H. L. McKinnon, "Preparation and Distribution of Molding Sands," *American Society of Mechanical Engineers,* advance paper (April 20, 1931).

J. McLachlan, "Protecting Patterns and Core Boxes," *Found-*

ry Trade Journal (London), Vol. 40, No. 648, p. 43 (Jan. 17, 1929).

R. Micks, "The Coreroom and Its Product," *Canadian Foundryman,* Vol. 17, No. 5, p. 12 (May 1926).

R. Micks, "Obtaining Maximum Out-Proper Distribution," *Canadian Foundryman,* Vol. 16, No. 7, p. 9 (July 1925).

F. M. Middleton and F. F. Bownes, "The Knockout Properties of CO_2 Process Core Mixtures," *British Foundryman,* Vol. LVII, p. 153 (1964).

J. M. Middleton, "The Effect of CO_2 Process Sands on Hot Tearing," *British Foundryman,* Vol. LIII, p. 67 (1960).

J. M. Middleton, "The Effect on a Green Sand of Contamination by Used CO_2 Process Sand," *British Foundryman,* Vol. LIII, p. 53 (1960).

M. Miklau, "Oil-Core Quartz Sand and Oil-Sand Cores," *Giesserei* (Dusseldorf), Vol. 17, No. 21, p. 509 (May 23, 1930).

R. E. Morey and E. A. Lange, "Factors Affecting Sodium Silicate Bonded Sands," *Foundry,* p. 188 (April 1955).

S. De Nagourski, "Contribution to Study of Oil Sand Cores of High Strength," *Fonderie Moderne* (Paris), Vol. 23, p. 367 (Aug. 25, 1929).

J. B. Nealey, "Conveyors and Ovens for Large Cores," *Iron Age,* Vol. 124, No. 23, p. 1516 (Dec. 5, 1929).

J. B. Nealey, "Continuous Oven Reduces Core Losses," *Foundry,* Vol. 58, No. 16, p. 58 (Aug. 15, 1930).

J. B. Nealey, "Baking Cores in Gas-Fired Ovens," *Heat Treating and Forging,* Vol. 15, No. 2, p. 223 (Feb. 1929).

J. B. Nealey, "Automatizing Core Baking with Gas," *Fuels and Furnaces,* Vol. 5, No. 11, p. 1507 (Nov. 1927).

H. Nipper, "Oil Cores and Their Testing," *Foundry Trade Journal,* Vol. 56, No. 1081, p. 368 (May 6, 1937).

J. R. Pagan and S. G. Athanikar, "A Method of Producing Repetition Steel Castings by the CO_2 Sand Process in Conjunction with Core-Shooters," *The British Foundryman,* Vol. LVIII, No. 9, p. 325 (Sept. 1965).

E. Parkes, W. Andrews and F. Walker, "Some Factors Affecting the Choice of Cold Setting Methods of Coremaking," *British Foundryman,* Vol. LVII, p. 235 (1964).

N. K. B. Patch, "Eliminate Defects by Avoiding Common Pitfalls," *Foundry,* Vol. 64, No. 9, p. 25 (Sept. 1936).

N. K. B. Patch, "Avoiding Defects in the Non-Ferrous Foundry," *Foundry,* Vol. 68, No. 2, p. 29 (Feb. 1940).

N. K. B. Patch, "Coremaking in the Brass Foundry," *Foundry,* Vol. 66, No. 10, pp. 29, 84, 86 (Oct. 1938) p. 31 (Nov. 1938).

W. A. Phair, "Core Sand Reclamation by the Thermal Method," *The Iron Age,* p. 43 (Dec. 17, 1942).

Philadelphia Quartz Co., "P. Q. Soluble Silicates in Cement," *Bulletin 24-1,* p. 11.

Philadelphia Quartz Co., Private Communication.

Philadelphia Quartz Co., "Soluble Silicates," *Bulletin No. 17-1.*

F. B. Pletcher, "Produces Cores with Speed and Accuracy," *Foundry,* Vol. 58, No. 13, p. 88 (July 1, 1930).

G. Pouplin, "Core and Sand in the Foundry," *Brass World,* Vol. 17, No. 12, p. 345 (Dec. 1921).

T. Prinz and A. Riebold, "Testing of Cores," *Giesserei* (Dusseldorf), Vol. 16, No. 36 and 37, p. 820 and 862 (Sept. 6 and 13, 1929).

P. R. Ramp, "Using Ram-Up Cores for Castings," *Iron Age,* Vol. 124, No. 6, p. 346 (Aug. 8, 1929).

I. Rees, "Further Notes on the CO_2 Process and Core Assembly," *The British Foundryman,* Vol. LVIII, No. 3, p. 92 (Mar. 1965).

F. M. Reiter, "Fuel Economies of Baking Foundry Cores," *Industrial Gas,* Vol. 13, Nos. 10, 11 and 12, pp. 17, 21, 21 (April, May and June 1935).

F. M. Reiter, "Fuel Economics of Baking Foundry Cores," *Industrial Gas,* Vol. 14, No. 3, p. 17 (Sept. 1935).

P. H. Riley and J. J. Marais, "Contamination of Sand Systems by CO_2 and the Effect on Surface Finish," *British Foundryman,* Vol. LV, p. 198 (1962).

W. L. Rose, "Rosin in Mixture Prevents Cracks in Sieve," *Foundry,* Vol. 63, No. 2, p. 50 (Feb. 1935).

A. D. Sarkar, "Effect of Additives on the Retained Strength of a 4% Sodium Silicate CO_2 Bonded Sand," *British Foundryman,* Vol. LIV, p. 436 (1961).

A. D. Sarkar, "Some Properties of a Few Sodium Silicate CO_2 Bonded Non-Siliceous Materials," *British Foundryman,* Vol. LVI, p. 367 (1963).

K. D. Scheffer, "Using Preformed Ceramic Cores, *Foundry,* Vol. 89, No. 8, p. 134 (Aug. 1961).

C. E. Schubert, "Reduces Costs by Controlling Oil Sand Mixtures," *Foundry,* Vol. 58, No. 7, p. 125 (April 1, 1930).

C. E. Schubert, "Absorbed Moisture Lowers Core Strength," *Foundry,* Vol. 57, No. 17, p. 733 (Sept. 1, 1929).

C. E. Schubert and H. S. Austin, "Eliminating Variables in Core Testing," *Foundry,* Vol. 68, No. 6, p. 42 (June 1940).

A. A. Schuetz, "How Gas Can be Used in Core Ovens," *Foundry,* Vol. 49, No. 16, p. 657 (Aug. 1921).

W. Schumacher, "Developments in the Use of the CO_2 Process," *Foundry,* Vol. 87, p. 69 (March 1959).

W. Schumacher, "Recent Developments in the CO_2 Process," *Foundry,* Vol. 84, p. 88 (Jan. 1956).

J. J. Schwalm, T. Ondrejko, T. Fujimoto, and H. Kline, "Matching the Core Process to the Job," *Foundry,* Vol. 93, No. 8, p. 64 (August 1965).

R. Schwanert, "Foundry Driers with Modern Heating Methods," *Giesserei Zeitung* (Berlin), Vol. 27, No. 6, p. 157 (March 15, 1930).

W. S. Scott, "Electric Heating in the Iron Industry," *Iron Age,* Vol. 107, No. 6, p. 384 (Feb. 10, 1921).

A. Skinner, "Cores and Coremaking Practice, Good and Bad," *Canadian Foundryman,* Vol. 13, p. 34 (May 1922).

W. G. Smith, "Use of Rosin in Core Oil," *American Society for Testing Materials, Proc.,* Vol. 30. Pt. 2, p. 839 (June 23-27, 1930).

W. H. Smith, "Foundry Drying and Modern Coreshop Layout," *Foundry Trade Journal,* Vol. 59, No. 1164, p. 423 (Dec. 8, 1938).

A. F. Spasskii and A. A. Rhyzikov, "Gas Formation in Dry Moulds and Cores," *Russian Castings Production,* p. 110 (Mar. 1961).

F. G. Steinbach, "Accuracy Governs Coremaking Process in Automobile Foundry," *Foundry,* Vol. 56, No. 23, p. 956 (Dec. 1, 1928).

F. G. Steinbach, "Speeds Core Baking with Continuous Type Ovens," *Foundry,* Vol. 56, No. 24, p. 1008 (Dec. 15, 1928).

R. Stotz, "Adaptability of Sand for Oil Cores," *Giesserei* (Dusseldorf), Vol. 15, No. 38, p. 948 (Sept. 21, 1928).

Technical Council, First Report of subcommittee TS 62, "A Statement of Existing Knowledge on the New Core-Making Processes," *British Foundryman,* Vol. LVI, p. 100 (1963).

Technical Council, First Report of subcommittee TS 53, "Surface Finish of Grey Iron Castings Using the CO_2/ Sodium Silicate Process," *British Foundryman,* Vol. LVI, p. 159 (1963).

Technical Council, First report of subcommittee TS 55,

"The Testing Under Compression of Gassed CO_2/Sodium Silicate Bonded Sand Test Pieces," *British Foundryman,* Vol. LV, p. 28 (1962).

R. N. Thompson, "Practical Guide to the CO_2 Process," *Foundry Trade Journal,* p. 649 (Nov. 19, 1965).

E. J. Tournier, "Cutting a Major Cost in the Foundry," *Industrial Management* (N.Y.), Vol. 72, No. 4, p. 236 (Oct. 1926).

L. Treuheit, "Molds, Cores, and Molding Sands," *Giesserei-Zeitung,* Vol. 20, No. 25, p. 483 (Dec. 1, 1923).

H. N. Tuttle, "Setting Overhanging Core Simplified Through Practical Method, *Foundry,* Vol. 54, No. 17, p. 691 (Sept. 1, 1926).

T. Tyrie, "Defects in Iron Castings — Their Cause and Cure," *Foundry Trade Journal,* Vol. 52, No. 961 and 962, p. 59 and p. 77 (Jan. 17 and 24, 1935).

U.S. Patent Office, "Patent No. 2861893," issued Nov. 25, 1958.

J. O. Vadeboncoeur, "Tellurium Core Washes," *ASM Transactions,* Vol. 37, p. 303 (1946).

R. G. Van Grundy, "Bakes Cores in Gas Furnace," *Foundry,* Vol. 55, No. 21, p. 851 (Nov. 1, 1927).

J. Varlet, "Studies Use of Chaplets," *Foundry,* Vol. 55, No. 21, p. 858 (Nov. 1, 1927).

C. H. Watts, "Self-Forming Core Process Is Developed," *Foundry,* Vol. 91, No. 5, p. 164 (May 1963).

W. West, "Oil-Sand Cores and Production," Vol. 33, No. 493, p. 69 (Jan. 28, 1926).

W. West, "Pointers for the Successful Production of Oil Sand Cores," *Foundry Trade Journal* (London), Vol. 40, No. 661, p. 287 (April 18, 1929).

I. S. Wishoski, "Core Oven Installation Produces Exceptional Results," *Fuels and Furnaces,* Vol. 7, No. 10, p. 1605 (Oct. 1929).

I. S. Wishoski, "Electric Ovens Used in Baking of Cores," *Fuels and Furnaces,* Vol. 5, No. 3, p. 331 (Mar., 1927).

C. Wood, "Practical Coremaking Up-to-Date," *Iron and Steel Industry* (London), Vol. 3, No. 8, p. 231 (May, 1930).

T. E. Wright, "Carries Cores on Trolley Conveyor," *Foundry,* Vol. 60, No. 14, p. 24 (Dec. 1932).

INDEX

INDEX

A

Acids and Acid Salts
  Foundry control of, 231
Alcohol, Ethyl
  Toxicity of, 230
Alcohol, Methyl
  Toxicity of, 230
Alcohols
  Foundry control of, 231
Aluminum Castings
  Core mixtures for, *Table 4.8,* 52
  Core sand characteristics, *Table 4.9,* 53
  Selection and control of core sand, 52
Arbors
  See Rods and Arbors
Assembling of Cores
  Department for, view of, *Fig. 10.4,* 127
  Fig. 10.5, 127
  Fixture for, *Fig. 10.6,* 128
  Fixtures in, 129
  Operations in, 127
  Of V-12 engine block, *Fig. 10.7,* 128
Atmospheric Humidity
  In drying oil sand cores, 99
Automotive Cores
  Made by hot box process, *Figs. 26.4, 26.5, 26.6,* 261
Auto Oxidation
  Oil oxygen process based upon, 241

B

Baking of Cores
  Arrangement of cores on plate, 101
  Control, automatic, 120
  Effect of position on drying rate, *Fig. 8.12,* 101
  Effect of size on characteristics, *Table 8.1,* 97; *Table 8.2,* 98
  Effect of time and temperature on baking strength, *Figs. 8.4, 8.5,* 97
  Effect of varying time on cores, *Fig. 14.4,* 165
  Fuel control, 120
  Oils used in, 95
  Primary reasons for, 94
  Rate of heating, *Fig. 8.14,* 101
  Strength results of, *Figs. 8.10, 8.11,* 100
  Temperature characteristics of larger during, *Figs. 8.6, 8.7,* 98
  Temperature readings during, *Fig. 8.9,* 99
  Temperature within during, 101
  Time for maximum strength determined, *Fig. 8.13,* 101
  Time required related to fineness of sand, 101
  Utilization of waste heat for, 120
Baking Cycle
  In conventional ovens, 117
Belt Conveyor
  To deliver core sand, 55
Bentonites
  Storage of, 59
  Used in cores, 42
Binders, Cereal
  British gum, 40
  Chemical analysis of, 162
  Dextrin, 40
  Effect of additions to core mix on green and hot strengths, *Table 14.4,* 171
  Effect of on hot strength, 171
  Specifications for, 41
  Storage of, 59
Binders, Core
  Adhere on heating, 39
  Adherence to plates and driers, 45
  Advantages of slow drying, 44
  Blended, 43
  Booking and patching, 45
  Chemical analysis of, 161
  Classes of, 31
  Clay, 41
  Clay-cereal combinations, 42
  Clay-pitch combinations, 42
  Cleanliness of handling, 44
  Collapsibility, 45
  Data on, *Table 3.7,* 41
  Desirable attributes and characteristics, 43
  Determining apparent density of, 64
  Dry on heating, 32
  Ease of handling, 44
  Ease of mixing, 44
  Effect of combination on baking time, *Fig. 14.5,* 166
  Effect of draining, 44
  Effect on mixing equipment, 44
  Fire clays, 41
  Function of under variable conditions, 44
  Gas generation, 45
  Green strength control, 44
  Harden on cooling, 37
  Influence on flowability, 44
  Knockout, 45
  Measuring of dry, 64
  Methods for determining weight per gallon, 64
  Moisture absorption, 45
  No bake, 247
  Physical properties, 45
  Protein, 39
  Requirements for, 31
  Resins used as, 117
  Selection of, 94, 197
  Sensitivity to oven atmosphere, 45
  Settling properties, 44
  Single package, 44
  Sticking, 44
  Storage of, 59
  Types of, 94
  Value of concentrated form, 44
Binders, Resinous
  Hazards from use of, 228
Bins
  For core sand, 55
Blowing of Cores
  Arrangement of blowing holes, 86
  History, 80
  In hot box process, 257
  Precautions, 88
  Theory of, 82
Blowing of Cores, Machines for
  Air supply for, 83; diagram of installation, *Fig. 7.44,* 83
  Built in mechanical draw feature, 90
  Description, 82
  Factors governing installation, 81
  Function of, 81; *Figs. 7.41, 7.42, 7.43,* 81
  Handling of, 89
  Operation, 82
  Pneumatic, 81, 82
  Reservoir capacity, 82
  Sand mixture for, 83; *Table 7.2,* 84
  Scope and operation of, 80
  Selection of machine, 83
  Served with gravity conveyor loop, *Fig. 7.52,* 89
  Sizes, 82
  With special turntable for handling core boxes, *Fig. 7.53,* 89
Bolting of Cores, 128
Brass and Bronze Castings
  Core mixtures for, *Table 4.5,* 50; *Table 4.6,* 51
  Moisture in core mixture, 51
  Oil sand ratios of core mixes for, 50

C

Campbell, H. L.
  Baking Practice for Oil Sand Cores, 36
Carbon Dioxide Gas
  Used in making silicate bonded cores, 233
Carbon Monoxide
  Foundry control of, 231
  Toxicity of, 230
Case Core
  Hand method of making, *Fig. 7.38,* 79
Casting Defects Due to Cores
  Agitation or scars, 205
  Caused by loose core sand, 205
  Caused by metal agitation, *Fig. 20.7,* 205
  Core blow, *Fig. 20.4,* 204
  Core buckle, *Fig. 20.8,* 205
  Core down, 205
  Core peeling, 206
  Core raise, *Fig. 20.6,* 205
  Core-sand mix effect on, 193
  Core scab, 206
  Core shift, 205
  Core wash, 206
  Fin, *Fig. 20.3,* 204
  Fissures, 204
  Hot tear, *Fig. 20.9,* 206

Casting Defects Due to Cores *(contd.)*
Inclusion, *Fig. 20.5,* 205
Metal penetration, *Fig. 20.1,* 203; *Fig. 20.2,* 204
Cast Iron Shell
Cross-sectional view of core for, *Fig. 7.13,* 71
Chaplets
Angle stem, *Fig. 15.9,* 180
Bridge, *Fig. 15.10,* 180
Cast, *Fig. 15.6,* 179
Casting for which requirements are given, *Fig. 15.15,* 184
Centrifugal pump base casting, *Fig. 15.16,* 185, for which chaplet requirements are given, 185
Cleanliness, 178
Coatings, 178
Determining number needed, 184
Double head, *Fig. 15.5,* 178
Effect of material, 178
Effect of molding conditions, 178
Effect of shape, 177
Effect of surface preparation, 178
Effect of volume on fusion, 177
Factors affecting reactions, 177
Forces they must resist, 180
Gaging height of, *Fig. 15.4,* 176
Load safely sustained by, *Table 15.2,* 181
Mechanism of fusion, 184
Perforated, *Fig. 15.12,* 180
Radiator, *Fig. 15.8,* 179
Requirements for performance, 176
Shell, *Fig. 15.11,* 180
Sheet metal, 180
Spur and two story, *Fig. 15.14,* 180
Spurred, 180
For steel castings, 182
Stem, *Fig. 15.7,* 179
Type to use, 181
Ventilated, *Fig. 15.13,* 180
Chemical Cements
Core binders, 32
Chill Nails
Used in oil oxygen process, 244
Chills, Core
Coatings for, 75
Reasons for avoiding, 74
Size and shape of, 74
Use of metal, *Fig. 7.22,* 74
Clays
Storage of, 59
Coal
Fuel for core oven, 116
Coatings, Core
For aluminum, 135
Basic refractory materials, 131
Bonds for, 130
For brass and bronze, 135
Composition of, 130
Conditions governing behavior of, 131
Dipping in large foundry, *Fig. 11.1,* 132
Drying of, 134
Forms of, 131
Functions of, 130
Green vs. dry, 133
Large, 133
Maintenance of solution, 132
Methods of application, 133
Nature of film, 134
Physical characteristics and ingredients, 130
Preparation of solutions, 132
Small to medium, 133
Solution control, 132
Specific gravity of solutions, 133
Spray unit for, *Fig. 11.2,* 132
For steel castings, 134
Types of, 130
Used on furan no bake cores, 249
Used in hot box process, 258
Coatings, Core *(contd.)*
Used in oil oxygen process, 244
CO_2 Cores
See Silicate Bonded Cores
Coke
Fuel for core oven, 116
Used in core washes, 131
Collapsibility of Cores
Control of, 170
Permeability and clay content vs., 170
Tensile strength vs., 170
Test data, *Table 14.2,* 170
Continuous Core Machines
Core mixtures for, *Table 7.1,* 77
For shaping stock cores, *Figs. 7.26, 7.27, 7.28,* 76
Conveyor Loops and Turntables
To facilitate core box handling, 89
Conveyors, Belt
Two ovens equipped with, *Fig. 12.5,* 138
Conveyors, Gravity, 139
For core handling, 108
Coolers
Core sand, 56
Copper Castings
Core mixtures for, 51; *Table 4.7,* 52
Core Arbors
See Rods and Arbors
Core Assembling
See Assembling of Cores
Core Baking
See Baking of Cores
Core Baking, Dielectric
See Dielectric Core Baking
Core Blowing
See Blowing of Cores
Core Blowing Machines
See Blowing of Cores, Machines for
Core Box Drawing Machines
To facilitate flow of core boxes, 89
Core Boxes
For blowing automotive barrel and crankcase cores, *Fig. 7.49,* 86
Box and drier, *Figs. 7.5, 7.6, 7.7,* 68
For core blowing machines, 84
Gang core box and pattern, *Fig. 7.1,* 67
Hinged box and pattern equipment, *Fig. 7.3,* 68
Large wooden, *Fig. 7.8,* 69
Materials for construction of, 85
And pattern equipment for angle fitting, *Fig. 7.2,* 67
For production of automotive manifold cores, *Fig. 7.48,* 86
Rigging for, *Fig. 7.47,* 85
With rod vents in place, *Fig. 7.10,* 70
Skeleton, *Fig. 7.9,* 69
Used in furan no bake process, 248
For use with hot box process, 259
Core Driers
See Driers, Core
Core Finishing
See Finishing of Cores
Core Grinding
See Grinding of Cores
Core Handling
See Handling of Cores
Core Hardness
See Hardness of Cores
Core Ingredients
Data on, *Table 3.8,* 42
Core Knockout
See Knockout of Cores
Coremaking
Factors involved in, 1
Furan no bake process, 247
See also entries under Furan No Bake Process
Hot box process, 257
See also entries under Hot Box Process
Coremaking *(contd.)*
By oil no bake process, 252
See also entries under Oil No Bake Process
Oil oxygen process, 241
See also entries under Oil Oxygen Process
Shell Core process, 207
See also entries under Shell Cores
Silicate bonded core process, 233
See also entries under Silicate Bonded Cores
Unit in machine tool foundry, *Figs. 12.8, 12.9,* 139
View of core room in automotive foundry, *Fig. 12.10,* 139
See under individual names of processes
Core Mixtures
For aluminum castings, 52
Approximate sand measures, *Table 4.15,* 54
For brass and bronze castings, 50
Control testing, 66
Conversion table for bond ratios, *Table 4.14,* 54
For copper castings, 51
Data for calculation of, 54
Effect on core smoothness, 194
For gray iron castings, 49
Importance of selecting sand for a particular core oil, *Table 19.1,* 197
For magnesium castings, 53
For malleable castings, 48
Procedure for adding ingredients, 64
Requirements of, 46
For steel castings, 46
Weight of binder for different ratios, *Table 4.13,* 54
Core Plates
Marinite, 118
Materials for, 69
Placing on core box, *Fig. 7.32,* 78
Plywood, 118
Steel or iron, 70
Transite, 118
Core Prints, 176
Fitting of, 67
Load sustained by, 181
For manifold casting, *Fig. 7.4,* 68
Core Properties
See Properties of Cores
Core Ramming
See Ramming, Core
Core Rods
See Rods and Arbors
Core Rod Straighteners
Machines, *Figs. 7.23, 7.24,* 75
Core Room
Distribution of cores to and from, 196
Factors to consider in layout, 195
Floor types for, 195
Illumination of, 195
Location of, 196
Selection of equipment for, 196
Ventilation of, 195
Cores
Dispensing of raw materials for, 198
Facilities for treating, 196
Function of, 1
Most common method of forming, 67
Selection of raw materials for, 197
Types of, 31
Core Sand
See Sand, Core
Core Setting
See Setting of Cores
Core Shooting
In hot box process, 258
Core Sizing
See Sizing of Cores

Core Strength
Effect of various factors on, 98
Core Vents
See Vents, Core
Core Washes
See Coatings, Core
Cost of Cores
Distribution of indirect, 201
Factors in, 201
Importance of personnel selection, 201
Measurement for, 198
Table 19.2, 200
Crane, Overhead
Stripping core from core box with, *Fig. 7.33,* 78
Croning, Dr. Johannes
Originator of shell process, 207
Croning Process
Original name of shell process, 207
Cut Off and Tapering Machine
Fig. 7.29, 77

D

Dermatitis
Prevention and precautions, 231
Dielectric Core Baking, 116
Driers for, 118
Energy consumption in, 119
Equipment, space needed for, 119
Fuel consumption in, 119
Mixes for, 117
Uniformity of, 118
Driers, Core
For blown cores, *Fig. 7.45,* 84; *Fig. 7.46,* 85
Cast aluminum and magnesium, 69
Combination parallel and counter flow, *Fig. 5.7,* 58
Counter flow, *Fig. 5.4,* 56; 57, 58; *Fig. 5.8,* 59
Figs. 7.5, 7.6, 68
Metal, 85
Parallel flow, *Fig. 5.3,* 56
Through flow, *Figs. 5.5, 5.6,* 57
Vertical, 58
Drying Rate of Cores
Effect of size and temperature on, *Fig. 8.8,* 98

E

Electricity
Fuel for core oven, 116
Exobond
Sodium silicate based binder, 238
Explosion Hazards
Foundry control of, 231

F

Fans
Used in core ovens, 104
Faults of Cores
Cracked, 203
Green centers, 203
Loose sand on surface, 203
Loose surface, 203
Off gage, 202
Rough surface, 202
Shifted, 202
Soft rammed, 202
Sticking to box, 202
Surface peeling, 203
Too flexible, 203
Weak, 203
Finishing of Cores
Brushing, 124
Coating, 125
Divisions of, 124
Line at side of oven, *Fig. 10.1,* 124
Mudding, 125
Trimming, 124
Fly Ash
Effect on core smoothness, 194
Formaldehyde
Toxicity of, 229
Fuels
For core ovens, 115
Cost considerations, 119
Economies vs. oven types, 119
Relative heating value of, *Table 9.2,* 119
Furan, 247
Furan No Bake Process
Advantages of, 249
Base sand for, 248
Casting from mold made by, *Fig. 24.1,* 249
Chemistry of, 247
Control of, 250
Definition of terms, 247
Description, 247
Disadvantages of, 250
Operating and production practices, 248
Slinger filling mold, *Fig. 24.1,* 249
Tensile development, *Fig. 25.2,* 254
Testing procedures for, 250
Furfural, 247
Furfuryl Alcohol
Prime material in formulation of furan resins, 247
Toxicity of, 230

G

Gas
Fuel for core oven, 116
Gas, Core
Content as related to baking temperature, *Table 14.5,* 172
Diagram of gas generating capacities and rates of generation, *Fig. 14.19,* 173
Effect of baking temperature on, 172
Effect of quantity of binder on, 171
Effect of sand fineness on, 171
Effect of sand grain size on, *Fig. 14.16,* 171
Effect of sand to oil ratio on, *Fig. 14.17,* 172
Importance of liberation rate, 172
Methods of reducing, 171
Graphites
Used in core washes, 131
Gray Iron Castings
Core mixtures for, 49; *Table 4.3,* 48-49; 118
Green Sand Cores
Desirable from economic standpoint, 94
Grinding of Cores
Core inserted in fixture for, *Fig. 10.3,* 126
Machine setup for, *Fig. 10.2,* 126
Precision, 126
Groove or Slot Vents
For core blowing, 88

H

Half Hood
Typical, *Fig. 7.57,* 91
Handling of Cores
Coremakers loading rack, *Fig. 12.1,* 136
Electric lift for transporting, *Fig. 12.11,* 140
Equipment limitations, *Fig. 12.14,* 141
Filled racks ready for oven, *Fig. 12.2,* 136
Floor racks for, 136
Overhead tramrail system, *Fig. 12.12,* 140
Racks pushed into ovens, *Fig. 12.13,* 141
View of second floor core room, *Fig. 12.7,* 138
Hardness of Cores
Conditions that affect, 164
Range of hardness readings, *Table 14.1,* 164
Relationship between and baking time and temperature, *Fig. 14.2,* 165
Relation between sand to oil ratio, 167
Hexamethylenetetramine
Accelerator in mixtures for shell cores, 208, 209
Toxicity of, 230
High Frequency (Dielectric) Heat
See Dielectric Core Baking
Hinge Tubes
For casting holes for hinge pins, 91
Typical, *Fig. 7.56,* 91
Hopper
Installed on monorail, *Fig. 23.3,* 243
Hot Box Process
Advantages of, 260
Comparison of tensiles, *Table 26.1,* 259
Curing of cores, 258
Cylinder block machine, *Fig. 26.3,* 260
Description, 257
Disadvantages, 261
Equipment used in, 259
Field of application, 260
Finishing of cores, 258
Indexing machine, *Fig. 26.1,* 259
Preparation of sand for, 257
Single machine, *Fig. 26.2,* 259
Test program for, 261

I

Ilmenite
For core chills, 74
Infrared Heat
For core baking, 116
Iron Grit
For core chills, 74
Iron Oxide
Effect of addition to core mixture, *Table 14.3,* 170
Effect on collapsibility of cores, 170
Effect on core smoothness, 194
Effect on expansion of cores, 170
Effect on refractoriness of cores, 171
Effect on tensile strength of cores, 170

K

Kneading Machine
For core sand mixing, *Figs. 6.8, 6.9,* 62
Knockout of Cores
Effect of baking, 186
Effect of binder, 186
Effect of design, 186
Effect of time in mold, 186
Equipment for, 186
Flow diagram of wet method, *Fig. 16.3,* 187
Hand method, 186
Installation, *Fig. 16.4,* 187
Installation of wet method, *Fig. 16.2,* 187
Mechanical vibrator unit for, *Fig. 16.1,* 186
Methods of, 186
Reducing difficulties in, 188
Selection of sand, 186
Tumbling barrels for, 187
Vibrator mechanical knockouts, 187
Wet methods of, 187

L

Leading of Cores, 128
Lift Truck
For corehandling, 136
Cores being conveyed by, *Fig. 12.3,* 137
Hand, 137
For handling core racks, 106
Power, *Fig. 12.4,* 137

M

Machinery and Equipment
- *See* under individual types of equipment

Magnesium Castings
- Binders for core mixtures, 53
- Core mixtures for, *Tables 4.10, 4.11, 4.12,* 53

Malleable Iron Castings
- Core binders for, 48
- Core mixtures for, *Table 4.2,* 47
- Moisture in core mixtures for, 49
- Sand fineness in core mixtures for, 48

Marine Animal Oils
- Core oils, 37

Measuring Equipment
- For core sand, 62
- Measuring hopper, 63
- Sliding drawer measuring gate, 63

Measuring Liquids
- Sprinkler can for, 64
- Tin measuring cup for, 64

Melamine
- Core binder, 117

Metallic soap
- Lubricant in shell core mix, 207

Mica
- Used in core washes, 131

Mineral Oils
- Core oils, 37

Mixers, Continuous
- *Fig. 23.4,* 244
- For oil no bake process, 253

Moisture
- Elimination of in cores, 98
- Heat required to eliminate in cores, 99

Molasses
- Core binder, 40
- Storage of, 59

Muller Mixer
- For core sands, *Fig. 6.2,* 60; *Figs. 6.3, 6.4, 6.5,* 61; *Figs. 6.6, 6.7,* 62
- Effective for, 61
- Used in furan no bake process, 248
- For use in hot box process, 259
- For use with oil oxygen process, 242

N

Nishiyama Process
- Variation of silicate bonded core process, 237

O

Oil
- Fuel for core oven, 116

Oil No Bake Process
- Advantages, 252
- Conversion time when baked, 255
- Description, 252
- Effect of baking at various temperatures, *Fig. 25.4,* 255
- Effect of set time with various percentages of drier, *Fig. 25.5,* 255
- Making cores and molds by, 253
- Operating and production practices, 252
- Recommended formulas, 256
- Tensile development, *Fig. 25.3,* 254
- Tensile development and scratch hardness, *Fig. 25.6,* 255
- Washing cores and molds, 253

Oil Oxygen Process of Coremaking
- Activators in, 241
- Advantages of, 244
- Daily control chart, 242
- Disadvantages of, 245
- Equipment required for, 242
- Operating and production practice, 243

Oil Oxygen Process *(contd.)*
- Principles of process, 241
- Sand mix for, 241
- Test procedures for, 245
- Types of metal cast with, 245

Oils, Core
- Adjusting to baking time-temperature relation, 34
- Chemical analysis of, 161
- Components of, *Fig. 8.1,* 96
- Isomeric form of, *Fig. 8.2,* 96
- Manufacture of, 32
- Oxidation of, 95
- Physical properties of, *Table 3.1,* 33
- Polymerizable form of, *Fig. 8.3,* 96
- Polymerization of, 95
- Requirements for, 32
- Specifications for, *Tables 3.2, 3.3,* 33; *Tables 3.4, 3.5,* 34
- Storage of, 59
- Tensile strength of, *Figs. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6,* 35; *Figs. 3.7, 3.8, 3.9,* 36
- Tensile strength, graphs, *Fig. 3.10,* 37
- Types used for, 37
- Used in core baking, 95

Ovens, Core
- Arrangements for converting firing of, *Fig. 9.5,* 105
- Battery of rack, *Fig. 9.15,* 109
- Battery of rolling drawer, *Fig. 9.14,* 109
- Car, 109
- Car for equipped with tiering skids, *Fig. 9.17,* 110
- Combination vertical and horizontal, 113
- Continuous, 107
  - Early, *Fig. 9.10,* 107
  - Vertical, *Fig. 9.28,* 113
- Conveyor, 109
- Design of early reel, *Fig. 9.6,* 106
- Diagram of, *Fig. 9.3,* 104
- Drawer, 105, 108
- Efficiency of modern, 115
- Fuels for, 115
- Gas-fired, 105
- Gravity seal continuous vertical, *Fig. 9.30,* 114
- Heat distribution in, diagram of, *Fig. 9.33,* 115
- Heater unit for, diagram of, *Fig. 9.31,* 115
- High frequency dielectric, *Fig. 9.34,* 117
- History of, 103
- Horizontal, 110; *Fig. 9.21,* 111
- Horizontal continuous, *Fig. 9.11,* 107
- Horizontal conveyor
  - Battery of, *Fig. 9.19,* 110
  - Layouts for, 138
  - Unloading station of, *Fig. 9.20,* 110
- Improved reel, *Fig. 9.7,* 106
- Large car, *Fig. 9.16,* 109
- Layout
  - For combination, *Fig. 9.29,* 114
  - Large horizontal, *Fig. 9.12,* 108
  - Modern continuous, *Fig. 9.18,* 110
  - Oven equipped with fans, *Fig. 9.2,* 104
- Mezzanine-floored, 107; *Fig. 9.9,* 107
- Modern, classes of, 108
- Passageway at loading and unloading stations, *Fig. 9.26,* 113
- Rack, 106, 108
- Rack installation, *Fig. 9.8,* 106
- Reel, 106
- Rolling drawer, *Fig. 9.13,* 108
- Shelf, 108
- Steam-heated, 114
- Stoker-fired, 105
- Temperature control
  - Air operated system, *Fig. 9.36,* 121

Ovens, Core
- Temperature control *(contd.)*
  - Air operated valves for, *Fig. 9.35,* 121
  - Air thermocouple system, *Fig. 9.38,* 122
  - Electrical, 123
  - Recording, 121; *Fig. 9.37,* 122
- Temperatures generated by steam, *Table 9.1,* 114
- Test of temperature conditions in, *Fig. 9.1,* 103
- Unit heaters, 114
- Vents, location of, 114
- Venturi exhaust pipe for, *Fig. 9.4,* 105
- Vertical, 111
  - Conveyor layouts for, 138
  - Design of, *Fig. 12.6,* 138
  - Diagram of, *Fig. 9.22,* 111
  - Method of grouping coremakers around, *Fig. 9.25,* 112
  - Time-temperature curve showing conditions in, *Fig. 9.23,* 112
- Vertical conveyor
  - Battery of, *Fig. 9.24,* 112
  - Unloading station from, *Fig. 9.27,* 113

Oxygen
- Required for drying core oils, 99

P

Paddle Mixer
- For core sands, *Fig. 6.1,* 60

Parting Agents
- Used in furan no bake process, 248

Pasting of Cores, 127

Patching
- Furan no bake cores, 249

Permeability, Sand
- Base of sand grains, *Fig. 2.1,* 3; *Figs. 2.2, 2.3,* 4
- Effect on of adding fine to coarse grains, *Table 2.2,* 3

Phenol
- Toxicity of, 229

Phenol-Formaldehyde
- Thermosetting resin, 38, 117, 208

Phosphoric Acid
- Activator used in furan no bake process, 248

Pipe and Pipe Fittings
- Cores for, 73
- Loam core for, *Fig. 7.21,* 74
- Methods for making cast iron, 73

Pitch
- Core binder, 38

Polymerization
- Oil oxygen process utilizes, 241

Portland Cement
- Core binder, 32

Potentiometer Controller
- For control of burners in core oven, 112

Production of Cores
- Economics of, 195
- Scheduling of work, 198

Properties of Cores
- Baked permeability vs. fineness, 168
- Baking time for maximum strength as affected by sand grain size, *Fig. 14.14,* 169
- Baking time vs. fineness, 168
- Controlling elevated temperature properties, 169
- Controlling expansion, 169
- Development of strength and hardness while cooling, *Fig. 14.9,* 167
- Effect of baking temperature on tensile strength and gas generating capacity, *Fig. 14.18,* 172
- Effect of cooling time on, 166

Properties of Cores *(contd.)*
- Effect of cores standing in air before baking, *Fig. 14.7,* 166
- Effect of iron oxide additions on, 170
- Effect of sand grain size on, 167
- Effect of variation in sand fineness on, 168
- Effect of various ingredients in core mix, *Table 14.7,* 174
- Effect of varying moisture content on, *Fig. 14.6,* 166
- Grain shape of sand vs. strength, 168
- Hardness vs. expansion, 169
- Necessary to produce smooth cores, 194
- Permeability affected by sand grain size, *Fig. 14.13,* 169
- Relation between various factors, *Fig. 14.15,* 170
- Relation of strength and hardness to cooling, *Fig. 14.8,* 167
- Relation of surface area of sand grains to tensile strength, *Fig. 14.12,* 168
- Surface area vs. strength, 168
- Tensile strength vs. expansion, 169
- Variation in with variation in sand grain size, *Fig. 14.11,* 167
- Variation when sand to oil ratio is varied, *Fig. 14.10,* 167

R

Racks, Core, 137

Rammer, Air
- Ramming a core box with, *Fig. 7.30,* 78

Ramming, Core
- Air, 79
- By hand, 79
- Methods used, 77

Resins
- As binders in dielectric core baking, 117
- Chemistry of phenolic, 209
- Classes of, 208
- Core binders, 37
- Dry blend shell process, 229
- Flake, 208
- Hot box, 229
- Phenolic used in shell cores and molds, 209
- Powdered, 208
- Self-curing resin binder systems, 229
- Shell process cold coating, 229
- Shell process hot coating, 228
- Specifications for as core binders, *Table 3.6,* 38
- Types of phenolic, 210
- Water-borne, 208

Resin Solutions, 208

Resorcinol
- Core binder, 117

Rods and Arbors
- For large cores, 71
- In large sand cores, 72
- For pipe elbow cores, *Figs. 7.18, 7.19, 7.20,* 73
- To reinforce blown cores, 88
- Views of, *Figs. 7.14, 7.15, 7.16, 7.17,* 72
- Wire, *Fig. 7.12,* 71

Rollover Coremaking Machines, 79
- Hand, *Figs. 7.34, 7.35,* 78; *Figs. 7.36, 7.37,* 79
- Hand jolt, 79; battery of, *Fig. 7.40,* 80

Rosin Oils
- Core binders, 38

Rubber Cement
- Core binder, 32
- Storage of, 59

S

Sand
- Alabama, 23
- Arkansas, 25
- Bank, effect on core smoothness, 194
- Base permeability of, 3
- California
  - Beach sands, 29
  - Corona, 28
  - Corona, sieve tests of, *Table 2.38,* 29
  - Del Monte, chemical analysis of, *Table 2.35,* 28
  - Del Monte, screen analysis of, *Table 2.34,* 28
  - Del Monte, view of core sand deposit, *Fig. 2.36,* 28
  - Los Angeles, 29
  - Pittsburg, 28
  - Pittsburg, chemical analysis of, *Table 2.37,* 29
  - Sieve tests of, *Table 2.36,* 29
- Chemical analyses of, 2; *Table 2.8,* 14
- Control based on test findings, 5
- Distribution to coremakers, 65
- Drying and cooling, 56
- Effect of adding additional sieves on grain distribution curve, *Fig. 2.4,* 5
- Fineness tests of Eastern, *Table 2.3,* 7
- Georgia
  - Albany, 23
  - Fineness tests of, *Table 2.25,* 24
  - Howard, 23
  - Junction City, 23
  - Ochlochnee, 24
  - Sewanee silica, 24
- Grain distribution curve of, *Fig. 14.1,* 164
- Grain shape, 3
- Grain size, 3
- Handling, 55; *Figs. 6.15, 6.16,* 65
- Illinois
  - Ottawa, being released from storage bins, *Fig. 2.23,* 17
  - Ottawa, chemical analyses of, *Table 2.13,* 16
  - Ottawa, pit of, *Fig. 2.21,* 16
  - Ottawa, round-grained, *Fig. 2.20,* 15
  - Ottawa sand being pumped into bins, *Fig. 2.22,* 16
  - Ottawa, sieve tests of, *Table 2.11,* 16
  - Ottawa, sieve tests of washed and dried, *Table 2.12,* 16
- Importance of drying, 56
- Indiana
  - Fineness tests of, *Table 2.6,* 13
- Iowa, 17
- Michigan
  - Bank sand mining, *Fig. 2.16,* 13
  - Chemical analysis of, *Table 2.9,* 15
  - Fineness tests of, *Table 2.6,* 13; *Table 2.7,* 14; *Table 2.10,* 15
  - Rockwood silica pit, *Fig. 2.18,* 14
  - Storage piles, *Fig. 2.17,* 14
- Minnesota
  - Screen analysis of, *Table 2.14,* 17
  - Shape of grains, *Fig. 2.24,* 17
- Missouri, 18
- Mixture for core blowing machines, 83
- Nevada, 25
  - Amber, 26
  - Arden, 27
  - Chemical analysis of Fire Valley, *Table 2.28,* 26
  - Fineness tests, *Table 2.28,* 26
  - Jean, chemical analysis of, *Table 2.33,* 27

Sand, Nevada *(contd.)*
- Overton, chemical analysis, *Table 2.30,* 26
- Overton, quarry, *Fig. 2.34,* 26
- Overton silica, chemical analysis of, *Table 2.32,* 27
- Overton, washing plant at, *Fig. 2.35,* 26
- Sieve tests of, *Table 2.31,* 27

New England, 6
- Providence, 8; *Fig. 2.7,* 7
- Provincetown, 8
- Wareham, *Fig. 2.8,* 8

New Jersey
- Deposit, *Fig. 2.11,* 10
- Fineness tests of, *Table 2.4,* 10
- Round-grained, *Fig. 2.9,* 9
- Sand preparation plant, *Fig. 2.12,* 11
- Subangular grains, *Fig. 2.10,* 9

New York
- McConnellsville, *Fig. 2.6,* 6
- Mexico Bay, 9

Ohio
- Columbus, mining operation for, *Fig. 2.31,* 21
- Conneaut, 21
- Fineness data, *Tables 2.20, 2.21, 2.22, 2.23,* 21
- Geauga Lake, chemical analysis of, *Table 2.19,* 20
- Geauga Lake, fineness tests of, *Table 2.18,* 20
- Glassrock, 21
- Glassrock, grains of sand produced at, *Fig. 2.30,* 20
- Phalanx, shooting a blast at, *Fig. 2.32,* 22
- Relation to one another geologically, 22
- Sandusky, 21
- View of washing plant, *Fig. 2.33,* 23

Oregon, 29
- Sieve test of, *Table 2.39,* 30

Pennsylvania
- Deposit, *Fig. 2.14,* 12
- Fineness tests of, *Table 2.5,* 12
- Oriskany sandstone formation, *Fig. 2.15,* 13
- Subangular grains of, *Fig. 2.13,* 12

Preparation of in hot box process, 257

Principal areas of production in Eastern states, *Fig. 2.5,* 6

Progressive subdivision of, *Table 2.1,* 3

Properties of, 2

Records of purchases, 5

Resin Coated
- Advantages of, 208
- Automatic hot coating installation, *Fig. 21.10,* 215
- Cold and warm coating, 212
- Complete hot coating unit, *Fig. 21.9,* 215
- High speed muller for hot or cold coating, *Fig. 21.8,* 214
- Hot coating process, 214
- Use of lubricant in, 215
- Wax content affects cold tensile strength, *Fig. 21.11,* 216

St. Peter sandstone, 2, 15
- Thickness in feet, *Fig. 2.19,* 15

Screen analysis of, 3

Selection of for cores, 4, 197

For shell cores, 211

Siliceous, 2

Southern, sieve analysis of, *Table 2.24,* 24

Special, 30

Sand *(contd.)*
- Specifications of AFS standard testing, 142
- System for delivering, *Fig. 23.1,* 241
- Tennessee, 23
- Terms and control methods for, 5
- Tests to determine behavior under heat, 11
- Texas, analysis of, *Table 2.26,* 25
- Transported by small hopper, *Fig. 23.2,* 243
- Types and locations, 2
- Utah, fineness data of, *Table 2.27,* 25
- Washington, 30
- Wisconsin
  - Berlin, view of pit, *Fig. 2.25,* 18
  - Core sand drier, *Fig. 2.29,* 19
  - Doylestown, view of deposit, *Fig. 2.26,* 18
  - Fineness data of, *Tables 2.15, 2.16, 2.17,* 19
  - Portage, views of deposit, *Fig. 2.27, 2.28,* 18

Sand Mixing Equipment
- Sketch of unit for handling, *Fig. 6.10,* 63
- Types of, 60

Sand Reclamation
- Casting shakeout and dry sand reclaiming system, *Fig. 17.2,* 190
- Cleanliness of reclaimed sand, 191
- Dry, 189
- Fineness analyses of new and wet method, *table,* 190
- Photomicrographs of used, reclaimed and new, *Fig. 17.3,* 191
- Thermal, 189
- Thermal reclaiming unit, *Fig. 17.1,* 189
- Wet, 190
- Wet sand unit, *Fig. 17.4,* 192

Sand Storage
- Gates for storage hoppers, 66
- Interior view of storage unit, *Fig. 5.2,* 55
- Sketch of arrangement, *Fig. 5.1,* 55
- Storage hoppers for, *Figs. 6.17, 6.18, 6.19, 6.20,* 66

Sand Throwing Machines
- In automotive foundry, *Fig. 7.54,* 90
- For mechanically ramming cores, 90
- Stationary, *Fig. 7.55,* 91

Sawdust
- Core ingredient, 43

Schmidt-Philipp Process
- Original name for silicate bonding process, 234

Setting of Cores
- Assembling cores for engine block, *Fig. 15.2,* 176
- Chaplets, 176
- Core prints for, 176
- Design vs. chaplets, 185
- Fixtures for, 175
- Gages for, 175
- With an overhead crane, *Fig. 15.1,* 175
- Ratio of lifting force to weight of core, *Table 15.1,* 181
- Reducing manual effort, 175
- Setting engine block core, *Fig. 15.3,* 176
- Use of ram-up cores, 175

Sheet Metal Forms
- Used in coremaking, 91

Shell Core Boxes
- Cast iron for, 218
- Fill position of, *Fig. 21.12,* 217
- Preparation of, 216

Shell Cores
- Curing temperature and time, 219
- Making of, 216; *Figs. 21.13, 21.14,* 217
- Preparation of mix for, 218

Shell Cores *(contd.)*
- Problems and remedies, 219
- Quality control of, 218
- Rollover machines for, *Figs. 21.15, 21.16,* 217
- Rollover shell and hot box blower, *Fig. 21.18,* 218
- Sands used for, 211, 219; *Table 21.1,* 212
- Sand preparation for, *Figs. 21.2, 21.3,* 212; *Figs. 21.4, 21.5, 21.6, 21.7,* 213
- Special additives to mix for, 216
- Two station shell or hot box blower, *Fig. 21.17,* 218
- Typical core and casting, *Fig. 21.1,* 207

Shell Molding
- Application of technique in core room, 207

Shell Process
- Patents for, 232
- Testing procedures, 224
- Toxicity of materials used in, 229

Shovel and Riddle
- For mixing core sand, 60

Silica
- Used in core washes, 131

Silica Dust
- Foundry control of, 231
- Toxicity of, 230

Silica Flour
- As core ingredient, 43
- Effect on core smoothness, 194
- Effect on hot strength of core mixture, *Table 3.9,* 43; 172
- Influence on oil-bonded cores, *Table 14.6,* 173

Silica Sand
- Base material for cores, 2
- Hot and retained strength of, *Fig. 22.13,* 240

Silicate Bonded Cores
- Binder for, 235
- Bronze propellor core in silicate sand, *Fig. 22.2,* 233
- Casting and core for outboard motor, *Fig. 22.1,* 233
- CO_2 core blower, *Fig. 22.8,* 236
- CO_2 cores being assembled, *Fig. 22.4,* 234
- Coremaking and equipment, 236
- Core shooter for silicate sands, *Fig. 22.9,* 236
- Core storage and strengths, 239
- Curing, 237
- Dry ice converter, *Fig. 22.10,* 237
- Effect of gassing time and aging on strength, *Fig. 22.12,* 239
- Fine sands require more binder, *Fig. 22.7,* 235
- General principles and application, 233
- History of process, 234
- Mixing and handling, 235
- Sand requirements, 235
- Scale housing and its CO_2 core being set, *Fig. 22.3,* 234
- Small CO_2 cores blown and gassed, *Fig. 22.5,* 234
- Surface treatment, 238
- Various gassing arrangements, *Fig. 22.11,* 238
- Viscosity-temperature relation for silicate binder, *Fig. 22.6,* 235

Silicones
- Toxicity of, 230

Sillimanite
- Special core sand, 30

Sizing of Cores
- Performed when, 125
- Templates for, 126

Smoke
- Toxicity of, 230

Smoothness of Cores
- Effect of core strength on, 193
- Effect of grain distribution on, 193
- Effect of hot strength on, 194
- Effect of pressure on, 193
- Effect of stickiness of mixtures on, 193

Sodium Silicate
- As core binder, 32, 234

Spray Gun, Syphon
- Used on molds, *Fig. 11.3,* 133

Squeezing Machine, 79
- For coremaking, *Fig. 7.39,* 80

Steel Castings
- Core mixtures for, *Table 4.1,* 47; 118
- Core mixtures vs. section size, 46

Stock Cores
- Continuous machine for shaping, 76
- Cut off and tapering machine for, 76
- Shapes of, 75
- Storage of, 77
- Uses of, 76

Storage
- Of materials for cores, 198

Sulfite Liquor
- Core binder, 39

T

Temperature
- Control in core baking, 121
- Effects of varying baking, 164
- Effect of varying baking on tensile strength of cores, *Fig. 14.3,* 165

Temperature Control
- Installation in core ovens, *Fig. 9.39,* 123

Temperature Gradients
- Measure of inside cores, 97

Tensile Development
- Of various processes, 253; *Fig. 25.1,* 254

Testing Apparatus
- Blowability test core box, *Fig. 13.25,* 151
- For blowing AFS tensile briquette cores, *Fig. 13.28,* 152
- For blowing core specimen, *Fig. 13.26,* 151
- Compression tester, *Fig. 13.1,* 143
- Compressive test machine, *Fig. 13.22,* 150
- Core box and jolter, *Fig. 24.6,* 251
- Core permeability specimen container, *Fig. 13.14,* 148
- Electric permmeter, *Fig. 23.7,* 245
- Fan-cooled desiccator, *Fig. 13.17,* 148
- For gas generated by cores, *Figs. 13.29, 13.30, 13.31,* 153; *Fig. 13.33,* 154
- Gas volume determinator, *Fig. 26.12,* 263
- Green core hardness tester, *Fig. 13.12,* 147
- Gyratory sieve shaker, *Fig. 13.42,* 160
- Hardness tester, *Fig. 13.24,* 151
- Heated shell tensile curing accessory, *Fig. 21.21,* 224
- Heated shell transverse curing accessory, *Fig. 21.23,* 225
- Hot box stripping strength tester, *Fig. 26.11,* 263
- Hot box tensile curing machine, *Fig. 26.7,* 262
- Hot distortion tester, *Fig. 21.26,* 226
- Inferior cores from furan no bake process, *Fig. 24.5,* 251
- For measuring gas pressure, *Fig. 13.34,* 155
- Melting point, *Fig. 21.19,* 221
- Mercury cup attachment to permeability air flow apparatus, *Fig. 13.5,* 144
- Moisture indicator attached to rammer, *Fig. 13.11,* 146

Testing Apparatus *(contd.)*
- Moisture teller, 144; *Fig. 13.9,* 145
- Moldability index test equipment, *Fig. 24.3,* 250
- Mold strength tester, *Fig. 23.5,* 245
- Oven built to AFS specifications, *Fig. 13.13,* 147
- Permeability air flow apparatus, *Fig. 13.6,* 144
- Rammer for high temperature testing, *Fig. 13.36,* 156
- For ramming bar test specimen, *Fig. 13.19,* 149
- Sand rammer, *Fig. 13.20,* 149
- Sand rammer with core box, *Fig. 13.16,* 148
- Sand scrubber, *Fig. 13.40,* 159
- Sand strength machine, *Fig. 13.18,* 149; *Figs. 13.21, 13.23,* 150
- Sieve shaker, *Fig. 13.41,* 159
- For silicate sands, *Fig. 22.14,* 240
- Sintering for determining refractoriness, *Fig. 13.37,* 157
- Sinter-meter, 158
- Specimen containers, *Fig. 13.4,* 144; *Figs. 13.7, 13.8,* 145
- Speedy moisture tester, *Fig. 13.10,* 146
- Standard ramming, *Fig. 13.2,* 143
- Stick point, *Fig. 21.28,* 227
- Tensile specimen curing and stripping accessory for hot box cores, *Fig. 26.8,* 262
- Tensile strength tester, *Fig. 26.10,* 263
- Test core oven, *Fig. 23.6,* 245
- Thermolab, *Fig. 26.13,* 264
- Thermolab dilatometer, *Fig. 13.35,* 156
- Universal sand strength machine, *Fig. 26.9,* 263

Test Procedures
- Ash determination, 221
- Baked core strength
  - Compressive test, 150
  - Tensile test for, 148
  - Transverse strength test, 149
  - Baking test specimens, 146
- Binders
  - Cereal, 142
  - Oil, 142
- Of blown cores, 151
  - Permeability and green strength of, 152
  - Tensile strength and core hardness of, 152
- Chemical analyses of core binders, 161
- Core hardness, 151
- For core moisture, 144
- Core permeability, 147
- Of core properties at elevated temperatures
  - Core collapsibility, 156
  - Expansion-contraction, 157
  - Hot strength, 156
- Cumulative method of analysis of core sands, 160
- Deflection test, 150
- Determining oil in core sand mix, 155
- Dimensions of testing briquet, *Fig. 13.5,* 148
- Fineness test of sand, 159
- For furan no bake process, 250

Test Procedures *(contd.)*
- For gas generation, 152
- For gas pressure created by core, 155
- Green core hardness, 146
- Green strength testing, *Fig. 13.3,* 143
- For hot box process cores, 261
- Laboratory tests for resins, 220
- Measuring core hardness in blowability test, *Fig. 13.27,* 152
- Melting point determination, 220
- Moisture absorption test, 155
- Moldability index for hot box cores, *Table 26.2,* 262
- For oxygen setting oils, 245
- Permeability of oil oxygen cores, 246
- Rate and gas volume curves, *Fig. 13.32,* 154
- Results from moldability index test, *Fig. 24.4,* 250
- Retained strength, 157
- Selection of standard testing sand, 142
- Shell sand and core
  - Breaking cold tensiles on universal sand strength machine, *Fig. 21.22,* 225
  - Breaking shell transverse specimen, *Fig. 21.24,* 225
  - Casting finish, 228
  - Cold tensile strength test, 224
  - Density, 227
  - Drawing of hot distortion test, *Fig. 21.25,* 226
  - Expansion of sands by hot distortion, *Table 21.4,* 227
  - Hot distortion data, *Fig. 21.27,* 226
  - Hot shell distortion, 225
  - Hot shell tensile test, 223; *Fig. 21.20,* 224
  - Shell permeability, *Fig. 21.29,* 228
  - Shell transverse strength test, 225
  - Stick point, 227
- Sieve analysis of core sands, 160
- Sintering point of core sand mixtures, 157
- For size and distribution of core sands, 160
- Standard mixing procedure, 142
- For strength of core paste, 158, *Fig. 13.39,* 158
- Strength and deflection of cores, *table,* 151
- Strength tests on silicate binders, 240
- Temperature corrections for emissivity of platinum, *Fig. 13.38,* 158
- Tensile development and scratch hardness in oil no bake cores, 255
- Viscosity in centipoises, 221
- Warm strength test, 151
- Work time for oil oxygen process, 246

Time Study
- To provide data on coremaking costs, 198

Tin Forms
- Common applications for, *Fig. 7.61,* 92
- For forming holes, *Figs. 7.66, 7.67,* 93
- Lifter bar tins, *Fig. 7.60,* 92
- For making bearing anchor holes, *Fig. 7.65,* 93

Tin Forms *(contd.)*
- For producing threaded holes, *Fig. 7.63,* 93
- For producing transverse holes, *Fig. 7.58,* 92
- Special shapes, *Fig. 7.62,* 92
- Typical square slot, *Fig. 7.59,* 92

Tramrail System
- For core handling, 140
- For handling core sand, 55
- Transfer bridge for, *Fig. 12.15,* 141

Transfer cars
- For core handling, 106

Traveling Overhead Crane
- For sand handling, 55

Trucks, Core, 137

U

Urea
- Toxicity of, 230

Urea-Formaldehyde
- Synthetic thermosetting resin binder, 38, 117, 208

V

Vegetable Drying Oils
- Core oils, 37

Venting
- Of cores, 70, 125
- By pressing vent plate on parting, *Fig. 7.31,* 78

Vent Plugs
- For venting core boxes for blowing, 87

Vents, Core
- Cross, 71
- Groove, 125
- Plate, *Fig. 7.11,* 70; 71
- Prick, 125
- Ram-up, 125
- Rope, 71
- Wax, 70, 125

Vents, Core Box
- For core blowing, 87
- Diagram of types and arrangement, *Fig. 7.51,* 88

Vibrating Stripping Machine
- For cores, *Fig. 7.25,* 75

W

Water
- As core binder, 31

Weighing Equipment
- Automatic for core sand mixing, *Figs. 6.11, 6.12,* 63; *Fig. 6.13,* 64
- For core sand, 62
- Installation of automatic for core mixtures, *Fig. 6.14,* 65

Wooden Plug
- Tapered, *Fig. 7.64,* 93

Wood Flour
- Core ingredient, 43

Z

Zirconium Oxide
- For core chills, 74

Zirconium Silicate
- Special core sand, 30