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Guide for Welding Iron Castings



American Welding Society

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Guide for **Welding Iron Castings**

Prepared by
AWS Committee on Welding
Iron Castings

Under the Direction of
AWS Technical Activities Committee

Approved by
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Abstract

This standard presents briefly the history and metallurgy of cast iron and the welding processes applicable to it. A newly developed weldability test is described in detail and instructions given for its application in specific cases. Provision is made for qualification of welding procedures and welders when necessary; quality control practice is also included.



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Foreword

(This Foreword is not a part of ANSI/AWS D11.2-89, *Guide for Welding Iron Castings*, but is included for informational purposes only.)

This guide was prepared by the American Welding Society Committee on the Welding of Iron Castings as a service to the industry. Sufficient data have been gathered and organized to yield an authoritative source of sound technical practices for joining iron castings. The description of iron castings, together with factors to be considered in joining them, is presented here as clearly and concisely as possible. It is the Committee's hope that this guide will lead to better quality and performance.

These recommendations represent the best of current practice in the opinion of the Committee. At the present state of the art, all recommendations may not be applicable to all products and situations. Selection of pertinent requirements should be the result of rational decisions and not lack of knowledge on the part of those who are welding iron castings.

Comments on this publication are welcome. They should be addressed to Secretary, AWS Committee on Welding Iron Castings, American Welding Society, 550 N.W. LeJeune Road; P.O. Box 351040, Miami, FL 33135.

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Guide for Welding Iron Castings

1. Scope and History

1.1 Scope. The term *cast iron* encompasses a family of ferrous alloys with a variety of metallurgical, mechanical, and physical properties. The chemical composition and welding requirements of the metals vary within the family. This document discusses the relative weldability of various types of cast irons and the filler metals and processes used to weld them. It recommends the steps for qualification of welding procedures, welding operators and welders, and requirements for the quality of welds. The terms *welding procedure*, *welding operator*, and *welder*, are used as defined in the latest edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

1.2 History

1.2.1 Types of Iron. Although iron has been used in various forms for over two thousand years, iron castings in the form used today evolved in Europe in the 15th and 16th centuries. The microstructure of medieval castings basically was gray iron with areas of white iron and nonmetallic inclusions. Refinements in foundry practices and melt control resulted in a more uniform structure.

Malleabilizing, a method of increasing the ductility of white cast iron by heat treatment, was first developed in the early 1700's. About a century later, black heart malleable iron was developed.

In the 1940's, ductile (spheroidal graphite) iron was developed. The ductility is improved by spheroidizing the graphite by the addition of magnesium, rare earth elements, or both.

The most recently developed form of cast iron is compacted graphite, a hybrid material with properties between gray and ductile irons.

1.2.2 Welding. Oxyfuel gas and arc welding of cast iron did not gain wide acceptance until early in the 20th century. The first filler metals were cast along with the iron castings so that the compositions were similar. Later, both ferrous and nonferrous (copper or nickel)

base electrodes and rods were developed and are still in use today.

New, more refined welding processes and procedures were developed to extend greatly the number of applications where welding is used. Shielded metal arc (SMAW), gas metal arc (GMAW), flux cored arc (FCAW) and submerged arc (SAW) welding currently are popular arc welding processes.

Gas tungsten arc (GTAW) and proprietary processes are used in a variety of applications.

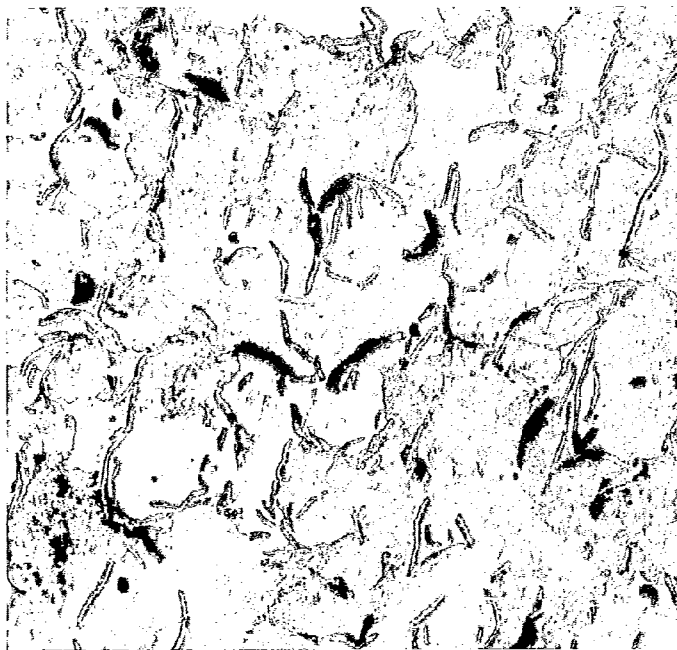
2. Cast Iron — Its Metallurgy and Weldability

2.1 Metallurgy

2.1.1 General. Cast iron may be described as an alloy of iron, carbon and silicon. All commercially produced irons also contain manganese. They may be alloyed with nickel, chromium, copper, molybdenum, tin, antimony, vanadium, and other elements. The alloying elements may be present individually or in combination.

The carbon content is in excess of the quantity that can be retained in solid solution by austenite. Thus, during solidification, a portion of the carbon separates from the melt as either iron carbide (Fe_3C) or graphite. If the cooling rate is rapid, the carbon rich phase will be iron carbide. Elemental carbon (graphite) precipitates if the cooling rate is slow enough. The type of carbon constituent and its shape (if graphite), in part, determines the type and properties of cast iron. The phases present in the matrix also affect the properties; therefore, the entire microstructure of the casting must be considered when planning a suitable welding procedure.

2.1.2 Gray Iron. The most commonly used form of cast iron is gray iron. In this material, the excess carbon precipitates as flakes of graphite in a matrix of ferrite, pearlite, or a mixture of the two microconstituents (see Figure 1). The resultant product has moderate strength,



**Figure 1 — Gray Iron Microstructure Showing Random Flake Graphite Distribution in a Matrix of Ferrite and Pearlite
Magnification 100x. Nital etch**

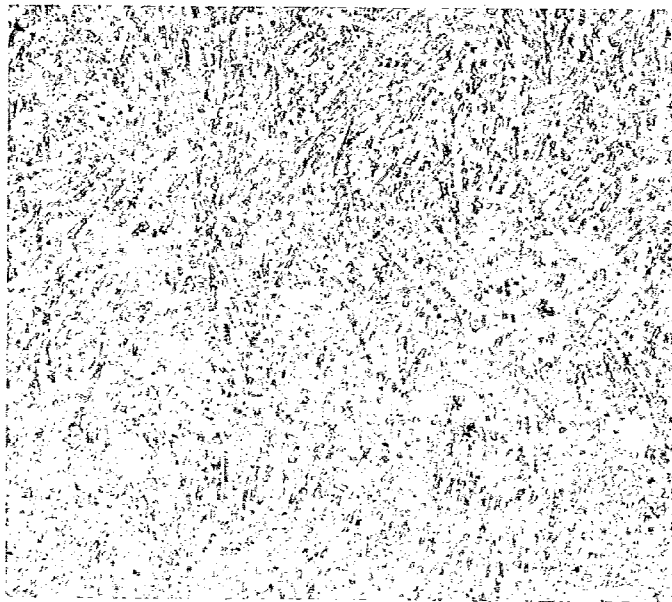
excellent machinability and damping properties, but low ductility. The material is low in cost and easily cast, and thus, is used extensively. Gray iron typically contains 2 to 4 percent carbon, 1 to 3 percent silicon and up to 1 percent manganese, and has tensile strength up to 40 000 psi (276 MPa).

The microstructure and resulting properties of gray iron may be altered by the addition of any of the following elements: silicon (up to 6 percent), nickel (up to 36 percent), copper (1.5 to 7.5 percent), chromium (1 to 6 percent), molybdenum (up to 1 percent). Tensile strength of these alloyed grades may be as high as 80 000 psi (380 MPa). Microstructures may contain various intermetallic compounds such as chromium or molybdenum carbides, and the matrix may be austenitic in nature. Because of the complexity of these alloy systems, special welding procedures are often required. Not all grades of higher alloyed gray iron are weldable.

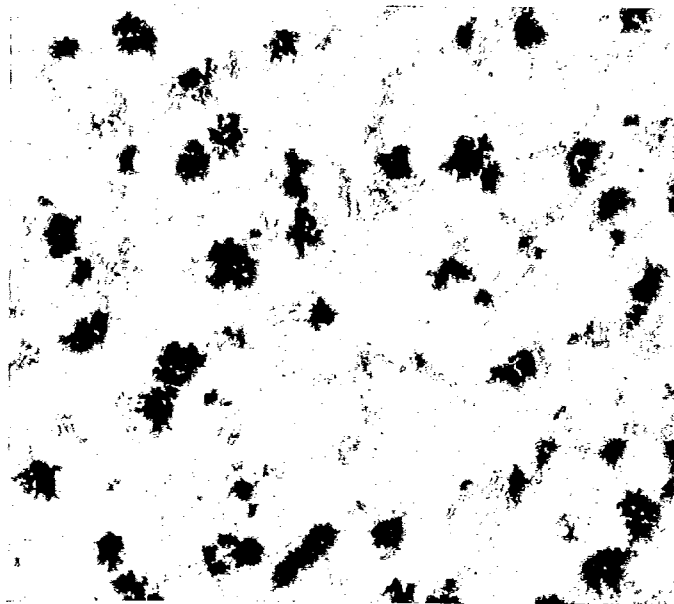
2.1.3 White Iron. If cooling is rapid (such as in a water or oil quench or at times in the heat affected zone of a weld), there is insufficient time for formation of graphite particles. The carbon remains in the metastable form of iron carbide (Fe_3C , also called cementite) (see Figure 2). This intermetallic compound is very brittle. Its abundance in the microstructure greatly reduces ductil-

ity and weldability, but increases hardness and abrasion resistance. As a result, the presence of cementite in applications subject to severe wear is often desirable. However, microstructures containing large amounts of cementite are quite prone to cracking and are essentially non-weldable. These irons contain typically 2.5 to 3.8 percent carbon, 0.2 to 2.8 percent silicon and, if designed for wear resistance, may contain up to 5.5 percent nickel, as much as 30 percent chromium, up to 6.5 percent molybdenum, and as much as 30 percent manganese. Tensile strengths range from 23 000 to 90 000 psi (160–620 MPa).

2.1.4 Malleable Iron. With heat treatment, white iron may be transformed to a ductile form of cast iron known as malleable iron. During long-time heat treatment, up to 60 hours, at high temperatures, up to 1600° F (871° C), the iron carbide dissociates, leaving a dispersion of graphite particles of approximately spherical shape. If the furnace atmosphere is oxidizing in nature, some of the carbon will be oxidized. This microstructure is called white heart malleable iron and is considered quite weldable (see Figure 3). When the atmosphere is reducing, the full amount of carbon is retained. This material, black heart malleable iron, is considered unweldable. Malleable iron typically contains 2.0 to 2.8 percent carbon and 1.0 to 1.7 percent silicon. Tensile



**Figure 2 — White Iron Microstructure Showing Nearly Complete Carbon Solution
in a Matrix of Cementite (Iron Carbide)
Magnification 100x. Nital etch**



**Figure 3 — Malleable Iron Microstructure Showing Temper Carbon Nodule Distribution
in Ferrite and Pearlite
Magnification 100x. Nital etch**

strengths range from 45 000 to 90 000 psi (310–620 MPa), with tensile elongations ranging from 2 to 20 percent.

2.1.5 Ductile Iron. By controlled addition of nodularizers, such as magnesium or rare earths, the excess carbon in the cast iron melt will form spherical particles (see Figure 4). These materials possess the highest strength and ductility of the cast iron family. Thus, close control of welding practices is necessary to minimize reduction of these optimum properties. Ductile iron (also called spheroidal or nodular iron) typically contains 3 to 4 percent carbon, 1.8 to 2.8 percent silicon, and 0.7 percent manganese, maximum. Some manufacturers of ductile iron restrict manganese content to a maximum of 0.4 percent when impact properties are important. An increase of manganese in the heat affected zone during welding can result in segregation at base metal grain boundaries with a consequent reduction in impact resistance of the weld.

Tensile strength range is 60 000–120 000 psi (410–830 MPa).

As with gray irons, alloying additions are made to these types of iron to improve heat and corrosion resistance. These grades may contain 2 to 3 percent carbon, 1 to 6 percent silicon, 0.7 to 2.4 percent manganese, 18 to 36 percent nickel, and up to 5.5 percent chromium.

The matrix of the ductile iron may be varied by heat treatment, alloying, and casting practices. The common “as cast” product is 65-45-12 [65 000 psi (450 MPa) tensile strength, 45 000 psi (310 MPa) yield strength, and 12 percent elongation]. The matrix is ferrite with 10 to 20 percent pearlite. By annealing, the matrix becomes ferritic, producing 60-40-18 iron.

Several other higher strength grades are produced by alloying or heat treatment: 80-55-06, 100-70-03, and 120-90-02. In general, as the strength of the iron increases, the potential for welding problems also increases. Thus, the lower strength grades should be easily welded, while satisfactory welding of higher strength grades will be more difficult.

2.1.6 Compacted Graphite. The newest addition to the cast iron family is compacted graphite iron. The microstructure of this material may be described as intermediate between gray and ductile iron, giving it many of the features of both types (see Figure 5). Compacted graphite iron has better machinability and dampening characteristics than ductile iron and has improved ductility over gray iron. Since the material is new to the market at the time of this writing, little information is available regarding welding procedures.

2.1.7 Identification. Determination of the type of cast iron being welded is essential to producing sound

weldments with acceptable properties. A few suggestions are listed below:

- (1) Check the files for specifications, purchase orders and other paperwork which might list the type.
- (2) Contact the manufacturer of the iron.
- (3) Study a small piece under the microscope.
- (4) Run mechanical tests such as hardness, and determine chemical composition.

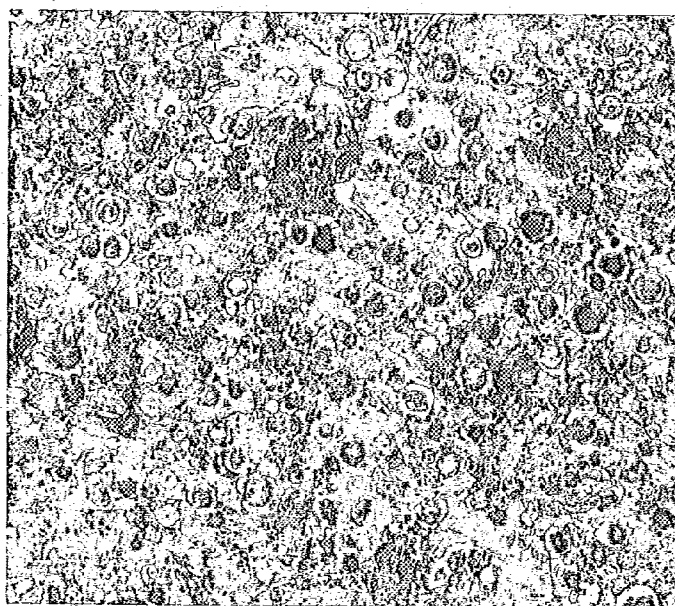
2.2 Difficulties in Welding Iron Castings. Because of the high carbon content and the various forms it can have in cast irons, as well as the wide range of microstructures and chemical composition, cast irons are among the most difficult metals to weld. The following paragraphs describe some of the sources of problems in welding cast irons and some recommended steps to alleviate them.

2.2.1 The Weld Metal. The weld metal consists of the base metal which is melted during welding, plus any filler metal. When molten cast iron is cooled rapidly (as is the case in an autogenous weld), the carbon is not rejected from the melt as graphite, but forms a hard, brittle iron carbide which is susceptible to cracking and is difficult to machine. The quantity of iron carbide formed can be reduced by the addition of alloying elements, by use of appropriate filler metal, or the use of a low-dilution welding technique. Post weld heat treatment may reduce or eliminate carbide in the weld metal.

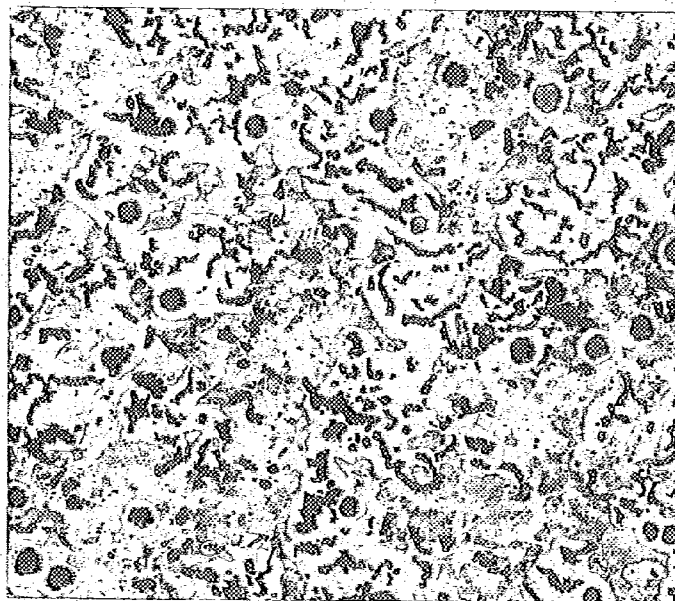
2.2.2 Fusion Zone. There are three distinct regions in the fusion zone. The first is the weld metal, which is a mixture of melted base metal and filler metal. The second is base metal which melts but does not mix with the filler metal. The third is base metal which only partially melts. Carbide formation can be a problem in those regions where mixing with the filler metal does not take place.

2.2.3 Heat Affected Zone. The heat affected zone is that part of the base metal that reaches a temperature high enough to effect metallurgical changes, but not high enough to cause any melting. In this zone, the graphite is not altered sufficiently to cause carbide problems. The matrix however, is transformed to a hard, martensitic structure upon rapid cooling. Brittleness associated with the martensite can be reduced by slow cooling or a postweld heat treatment (PWHT).

2.2.4 Welding Stresses. Expansion and contraction associated with the welding process may cause distortion and residual stresses in any material. These stresses may cause cracking in iron castings with low ductility and in areas of reduced ductility such as the fusion zone. Residual stresses can be reduced by proper control of preheat, welding procedures, peening, and by PWHT.



**Figure 4 — Ductile Iron Microstructure Showing Nodular Graphite Distribution
in a Matrix of Ferrite and Pearlite
Magnification 100x. Nital etch**



**Figure 5 — Compacted Graphite Microstructure Showing Mixture of Flake and
Nodular Graphite Distribution in a Matrix of Ferrite and Pearlite
Magnification 100x. Nital etch**

2.2.5 Porosity. Gases emitted during welding may cause porosity in the weld deposit. Such gases may result from volatile materials in the casting or from reactions between filler metals and atmospheres. The graphite in cast irons absorbs and retains lubricants and other liquids which permeate the entire section. When the material is welded, these liquids escape in a gaseous form and are trapped in the weld metal as porosity. Most porosity problems attributable to contaminants in the base metal can be avoided by proper preparation of the casting before welding (see 3.1).

2.3 AWS Weldability Test Program. Available literature on welding cast irons did not yield specific information on the weldability of cast iron base materials, especially on the relative weldability of the various types of cast irons. For this reason, the Committee on Welding Iron Castings undertook an investigation into the relative weldability of the various types of cast irons.

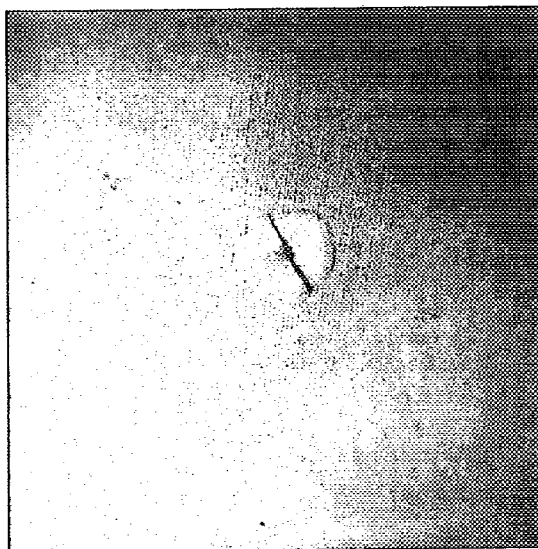
The committee considered the existing standard weldability tests such as V-restraint, Cruciform, Lehigh, and Houldcroft. It was found that these either required more base metal ductility than is found in some cast irons, used a filler metal, or were expensive and time consuming to prepare. It was decided, therefore, to develop a new test which would be practical, simple, repeatable, and did not require a filler metal.

2.3.1 Development of Weldability Test. Initial tests consisted of making an autogenous arc spot weld on the cast base metal with the gas tungsten arc welding process and attempting to evaluate the extent of cracking in the weld (see Figure 6). The tests were then refined to include travel of the torch and addition of preheating.

The test method finally developed consists of autogenous bead-on-casting welds made by a standard weld technique at various test temperatures to determine the minimum temperature (called *no-crack temperature*) at which there was no cracking in the test weld (see Figure 7). The test method is described in detail in Appendix A.

2.3.2 Weldability Test Results. When all the specimens had been welded and the no-crack temperature established for each, efforts were made to relate these results to some other variable that could be used to establish the no-crack temperature independent of this test. Variables evaluated were base metal type and strength as grouped by M number, weld and HAZ hardness, and chemical composition.

Table 1 compares the no-crack temperatures to the base metal type, actual strength, and M number from ANSI/AWS B2.1-84, *Standard for Welding Procedure and Performance Qualification*. Since there is no apparent correlation of any of these items to the no-crack temperature, strength and "M" number are not suitable for establishing the weldability of iron castings.



PREHEAT — 70°F



PREHEAT — 600°F

**Figure 6 — Grade 80-60-03 Ductile Iron GTAW Spot Weld Specimen (No Filler Metal).
Test Temperature as Indicated**

Table 2 compares the no-crack temperatures to the hardness of weld and HAZ of the test specimens welded at the no-crack test temperatures. The hardnesses were measured with Rockwell hardness testers on the A and B scales, and the values were converted to Brinell for comparison purposes. For all the base metals tested, there was considerable overlap of hardness data for the welds and heat affected zones, and no clear cut pattern or trend can be seen when the hardness values are compared. Based on this information, it was determined that hardness is not a suitable criterion for determining the weldability of iron castings.

Table 3 gives the chemical composition of the cast irons tested in this program, and Figure 8 is a plot of the calculated carbon equivalent versus the measured no-crack temperature. From this graph it can be seen that the chemical composition is directly related to the no-crack temperature and that the type of material (gray, malleable or ductile iron) has no apparent influence. The tolerance band has a temperature width of $\pm 60^\circ\text{F}$ (33°C), and a carbon equivalent width of ± 0.20 . A complete listing of all test results (hardness, mechanical properties, and weld tests) are given in Appendix A.

2.3.3 Carbon Equivalent Formula. In attempting to plot the no-crack temperature values against the carbon equivalent (CE), it was found that the conventional CE formula for steels was not applicable. A CE formula

especially for cast irons was found, and the results showed a definite correlation when plotted against the CE values calculated from this formula:

$$\text{CE \#1} = \text{C} + 0.31\text{Si} + 0.33\text{P} + 0.45\text{S} - 0.028\text{Mn}^*$$

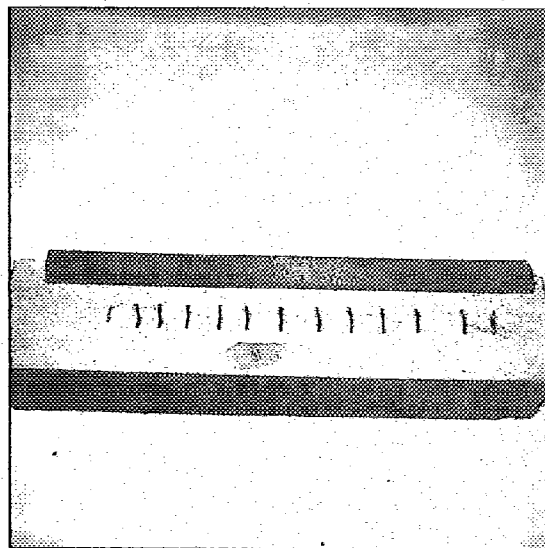
There was still considerable scatter, so the committee evaluated the chemical composition of the specimens further and found significant amounts of copper, nickel, chromium, and molybdenum were present. The formula was then modified to take these elements into account as follows:

$$\text{CE \#2} = \text{C} + 0.31\text{Si} + 0.33\text{P} + 0.45\text{S} - 0.028\text{Mn} + \text{Mo} + \text{Cr} - 0.02\text{Ni} - 0.01\text{Cu}$$

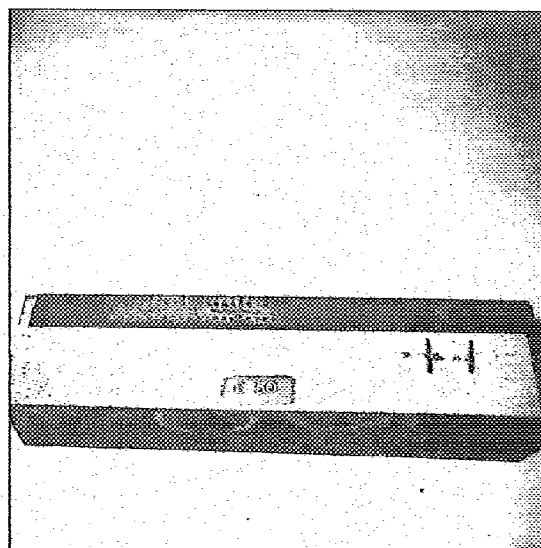
The results plotted in Figure 8 are based on CE #2, and are valid for castings with a total copper, nickel, chromium, and molybdenum content of 1.5 percent maximum. Weldability of higher alloy cast irons should be determined by testing by the user.

2.3.4 Discussion of Results. These tests were not conducted to determine a preheat temperature for specific base metals and should not be used for that purpose.

**Ductile Iron, The State of the Art.* Chicago, IL: S.I., Karsay, Miller & Co. (1980) p 47.



PREHEAT — 70°F



PREHEAT — 600°F

**Figure 7— Grade 80-60-03 Ductile Iron GTAW Weld Bead Specimen (No Filler Metal).
Test Temperature as Indicated**

Table 1
Comparison of No-Crack Temperature to Material
Type, Strength, and "M" Number

No-Crack Temperature	Material Type	Strength		Yield (psi)	(MPa)	"M" Number
		Tensile (psi)	(MPa)			
<70°F (20°C)	Malleable	48 000	(228)	31 000	(147)	2C
<70°F (20°C)	Malleable	78 000	(370)	50 000	(238)	2D
<70°F (20°C)	Malleable	95 000	(451)	59 000	(280)	2E
<70°F (20°C)	Malleable	106 000	(504)	66 000	(314)	2E
110°F (43°C)	Gray	45 000	(214)	—	—	2B
290°F (145°C)	Gray	52 000	(247)	—	—	2B
450°F (230°C)	Ductile	64 000	(304)	48 500	(230)	*
450°F (230°C)	Ductile	109 000	(518)	55 000	(261)	*
460°F (240°C)	Gray	46 000	(219)	—	—	2A
520°F (270°C)	Ductile	132 000	(627)	111 000	(527)	*
520°F (270°C)	Gray	36 000	(171)	—	—	2A
630°F (330°C)	Ductile	97 000	(461)	69 000	(328)	*

*Not classified in AWS B2.1-84.

Table 2
Comparison of No-Crack Temperature to
Weld and HAZ Hardness

No-Crack Temperature	Hardness (BHN)		Material (REF)		
	Weld	HAZ	Type	Strength ksi	(MPa)
<70°F (20°C)	534-561	152-212	Malleable	50	(238)
<70°F (20°C)	546-561	331-444	Malleable	70	(333)
110°F (43°C)	561-575	421-485	Gray	45	(214)
290°F (145°C)	564-587	432-519	Gray	50	(238)
450°F (230°C)	534-591	223-255	Ductile	65	(309)
450°F (230°C)	566-611	241-444	Ductile	80	(380)
460°F (240°C)	519-587	271-353	Gray	40	(190)
520°F (270°C)	591-611	321-444	Ductile	120	(570)
520°F (270°C)	546-587	286-326	Gray	34	(162)
630°F (330°C)	465-611	269-285	Ductile	100	(475)

Filler metal selection, weld heat input, and peening are some variables which can compensate for lack of pre-heat. The tests were run to determine if some measure of the relative weldability of iron castings could be found apart from conducting an elaborate test. It is suggested that the carbon equivalent is a good ranking process and is more realistic than the present "M" number classification system in ANSI/AWS B2.1-84, which recognizes only differences in casting types and mechanical properties.

It is therefore recommended that classification of iron castings for welding qualifications be based on a carbon equivalent value rather than the existing material-strength rating system of "M" numbers, especially when applying existing qualified procedures to cast iron base metals other than those used in the specific qualification tests.

This information can be used in two ways:

(1) When an existing qualified welding procedure is to be used on a new application, it should be successful if

Table 3
Chemical Composition

Specimen	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Mg	CE#1	CE#2
<u>Gray Iron</u>												
G1	3.25	0.58	0.017	0.062	1.75	0.22	0.08	0.34	0.09	—	3.811	4.226
G2	2.53	0.99	0.019	0.064	1.61	0.03	0.11	0.35	0.74	—	3.036	3.488
G3	2.62	1.00	0.022	0.066	1.66	0.03	0.11	0.02	0.04	—	3.144	3.273
G4	3.48	1.00	0.043	0.093	1.78	0.49	0.17	0.03	0.17	—	4.060	4.248
<u>Ductile Iron</u>												
D1	3.60	0.29	0.029	0.016	2.31	0.05	0.04	0.01	0.88	0.026	4.325	4.365
D2	3.67	0.29	0.028	0.006	2.20	0.06	0.04	0.20	1.32	0.022	4.356	4.582
D3	3.63	0.28	0.027	0.005	2.23	0.05	0.04	0.01	0.96	0.023	4.324	4.363
D4	3.51	0.43	0.030	0.014	2.37	0.88	0.10	0.03	0.10	0.025	4.248	4.359
<u>Malleable Iron</u>												
M1	2.42	0.73	0.015	0.030	1.54	0.04	0.05	0.01	0.10	—	2.896	2.954
M2	2.38	0.59	0.015	0.031	1.54	0.04	0.05	0.01	0.08	—	2.859	2.917
M3	2.21	0.94	0.027	0.050	1.51	0.05	0.03	0.01	—	—	2.684	2.723
M4	2.30	0.87	0.025	0.049	1.52	0.05	0.03	0.01	—	—	2.777	2.816

the carbon equivalent of the metal to be welded is lower than the carbon equivalent of the base metal used in the qualification test. The committee is recommending that welding procedures be limited to 1.1 times the CE of the base metal without requalification.

(2) When a new procedure needs to be qualified on a cast iron with a higher CE, a comparison of the CE's of the qualified base metal to the new base metal in conjunction with Figure 8 can assist in establishing a new preheat temperature for the new procedure.

2.3.5 Metallographic Examination. Figures 9 through 13 are representative photomicrographs of the weld, HAZ, and base metal of Grade 35 gray iron, Grade 50005 malleable iron, Grade 100-70-03 ductile iron, and Grade 120-90-02 ductile iron, tested in this program. The compacted graphite iron, Figure 13, is included for reference only, as it was received too late to be tested with the other iron castings.

The photographs show the nearly complete dissolution of the graphite flakes or nodules in the weld metal, the effect of heat (HAZ) on the matrix but not the graphite in the base materials.

Shallow cracks, shaped like a racetrack, occurred at the toe in the HAZ of all weld beads on gray iron specimens (see Figure 14). This is common even when filler metal is added. During liquid penetrant examination, the crack is first visible as a series of minute indications in very close proximity to each other, then the

liquid penetrant quickly spreads to give the appearance of a continuous crack. Figure 15 shows a cross section through one of these indications in the HAZ. It appears to be a microcrack connecting several graphite flakes, caused by the high residual stress imposed during cooling of the weld. Test temperatures in excess of 1100°F (593°C) did not eliminate these cracks. The cracks occur in the HAZ because this is the hardest area of the weldment, and it has the least ductility and the most notch sensitivity.

2.3.6 Weldability. Since the test developed for weldability of cast iron is unique to these base metals, the weldability of a specific iron casting is relative only to other iron castings. It may be determined by either of two methods:

(1) Establish the test temperature at which cracking will not occur when welded according to the established test method, and locate this temperature on the CE #2 versus Temperature graph. The lower this no-crack temperature, the more weldable the specific iron casting.

(2) Determine the carbon equivalent from the CE #2 formula (modified Karsay) and locate this value on the CE #2 versus Temperature graph. The lower this CE, the more weldable the specific iron casting.

2.3.7 Future Research. While the Committee has developed some basic data, subsequent evaluation of that data revealed that additional work needs to be performed in several areas.

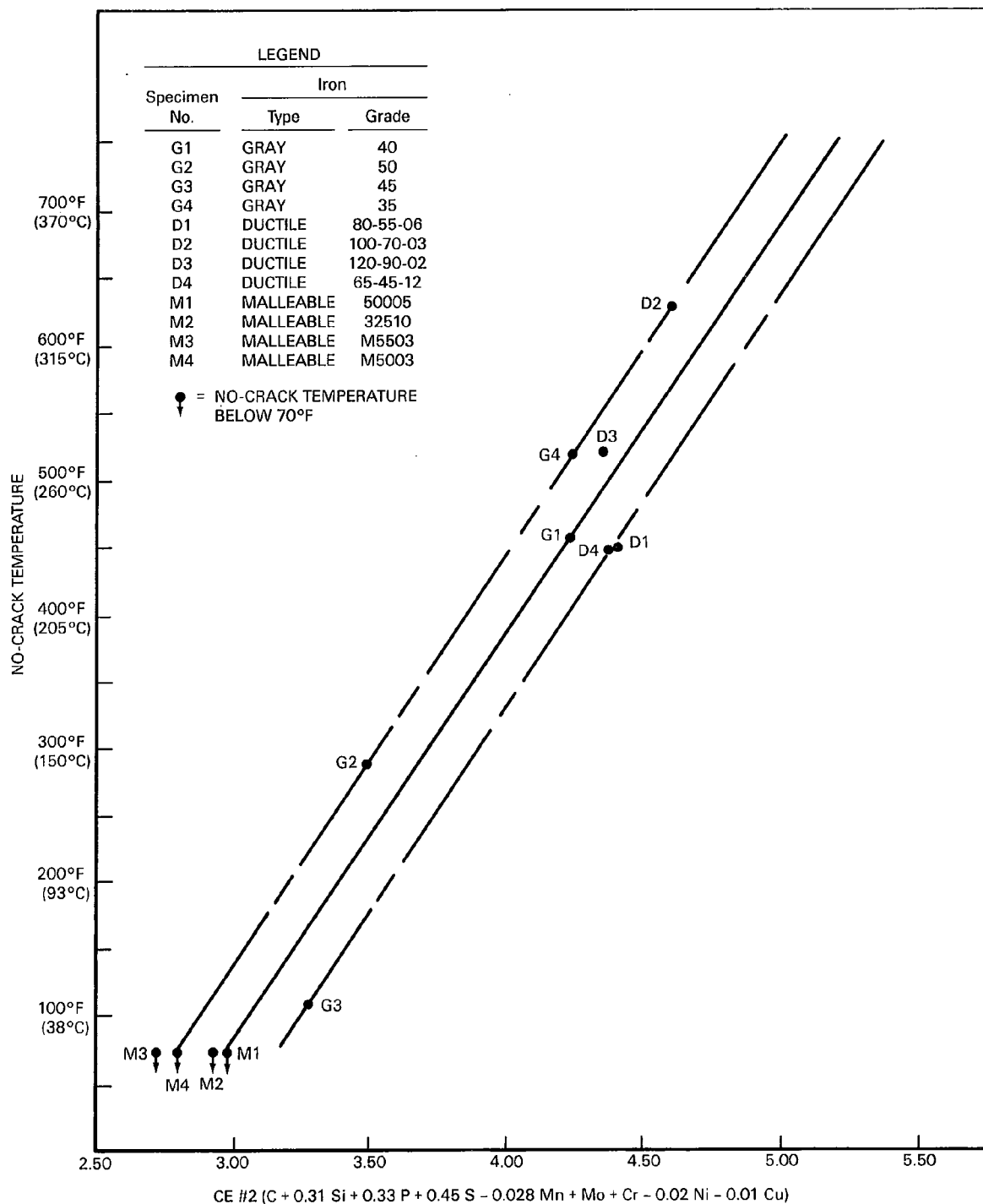


Figure 8 — Relation of No-Crack Temperature to C.E. #2 for Several Grades of Iron Castings

First, the test data should be duplicated by others to verify the repeatability of the test, and thereby its reliability. Second, the validity of the Carbon Equivalent #2 Formula when applied to highly alloyed cast iron, needs to be established. Third, the maximum HAZ hardness of welds made according to the weldability test conditions with the base metal at room temperature should be compared to the no-crack temperatures of the cast irons, to see if there is any correlation.

2.4 Preweld Testing for Weldability. The AWS weldability test program established a correlation between the chemical composition of a cast iron and its tendency to crack when welded according to the standard test method described in 2.3 and Appendix A. These data should not be used to establish a preheat temperature for a particular casting to be welded. There are many other factors which also affect the ability to make a good weld on iron castings, such as filler metal, peening, and heat input. In addition, local contaminants such as phosphorous and sulfur in the skin of the casting, trapped sand, absorbed lubricants or other materials can be sources of poor weldability.

2.4.1 Effects of Contaminants. When heat is transmitted into the casting from a welding arc, the contaminants volatilize and become gaseous. The pressure from the escaping gases repel or force the molten weld metal away from the base metal, causing incomplete fusion and porosity at the base of the weld bead. These discontinuities greatly reduce the strength of the weld, frequently causing failures.

The surface of most iron castings often contain excessive concentrations of sulfur and phosphorus which should be removed by grinding prior to welding. Sand inclusions are also frequently present near the surface and into the casting itself. Due to the porous nature of cast iron, castings which have been in service for a period of time and have been exposed to grease, oil, chemicals, etc. will absorb these contaminants into the pores of the iron casting. It is important to preweld test for the presence of any of these contaminants prior to welding.

2.4.2 Preweld Testing for Contaminants. In the area where the welding will be done, with the electrode selected for the cast iron repair, weld a short stringer bead approximately two to three inches long, remove the

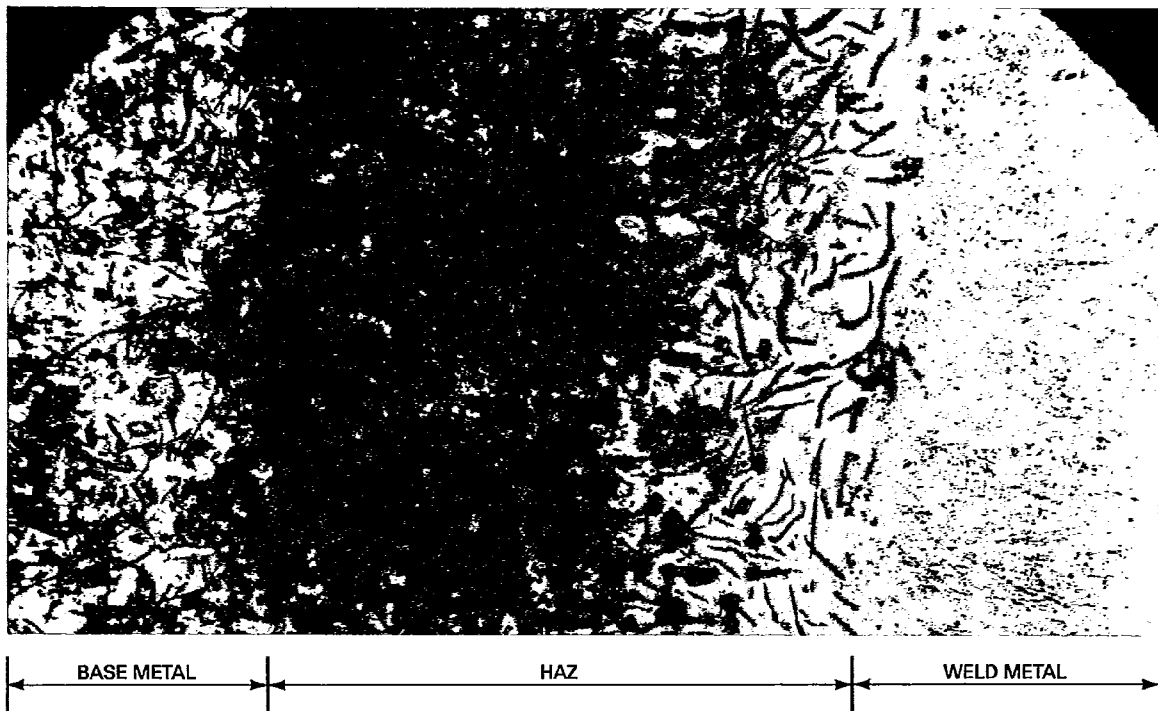
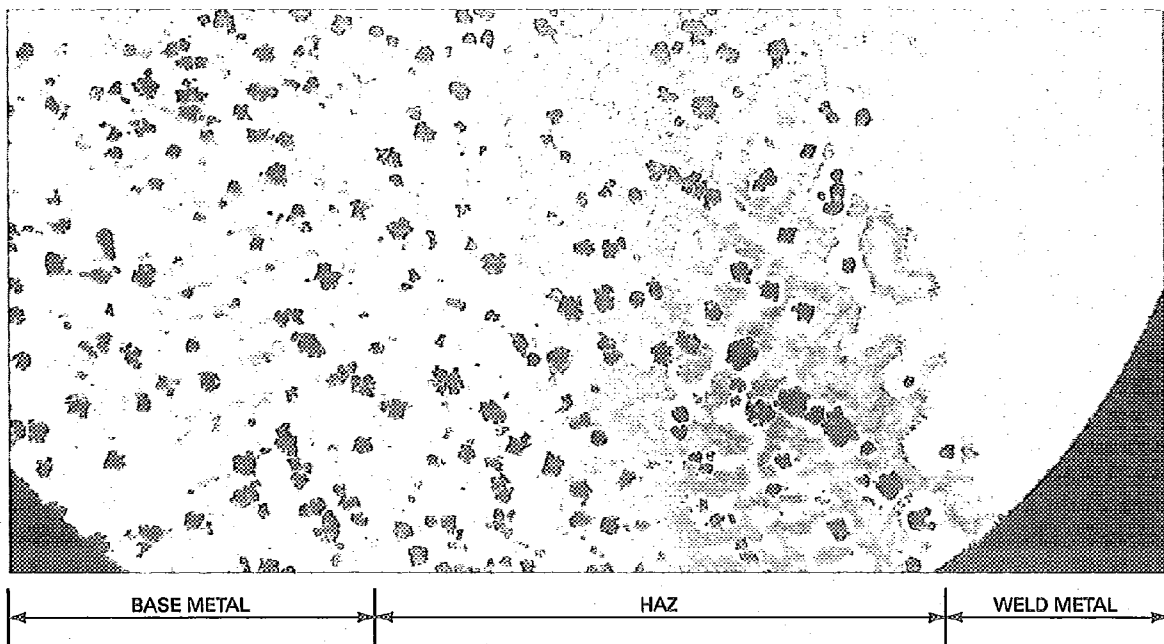
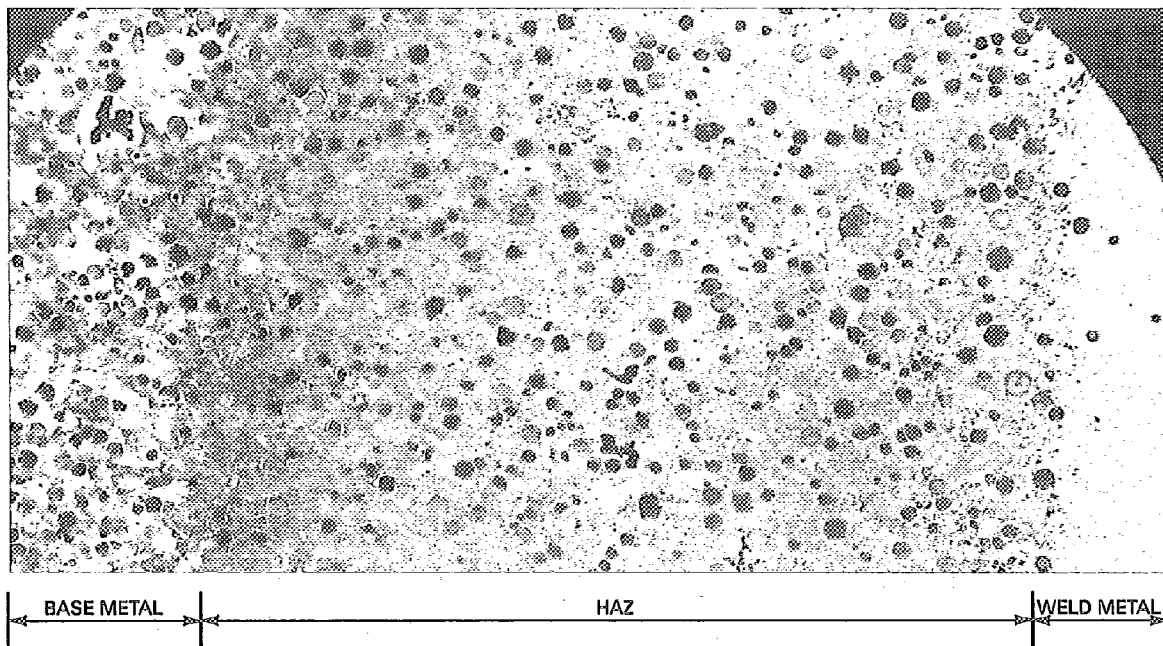


Figure 9 — Gray Iron ASTM A48, Grade 35, Typical Microstructure Showing As-quenched Weld Metal, Partially Hardened Heat Affected Zone, and Unaffected Base Metal (Note the Unaffected Graphite in HAZ and Base Metal) (50x Magnification)



**Figure 10 — Malleable Iron ASTM A220, Grade 50005, Typical Microstructure of Temper Carbon Nodules, in Coarse Dendritic Matrix
(Note Isolated Graphite in Islands of Martensitic Matrix in HAZ) (50x Magnification)**



**Figure 11 — Ductile Iron ASTM A536, Grade 100-70-03, Showing Nearly Uniform Nodular Graphite Distribution, Including Isolated Nodules in Weld Metal
(50x Magnification)**

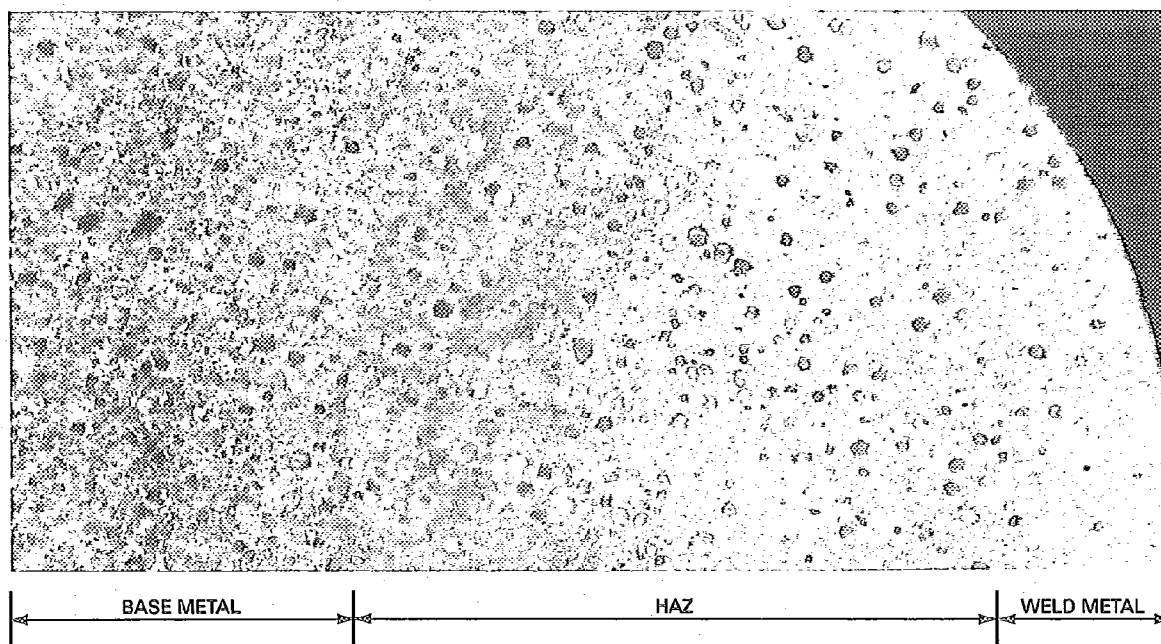


Figure 12 — Ductile Iron ASTM A536, Grade 120-90-02, Showing Uniform Nodular Graphite Distribution (50x Magnification)

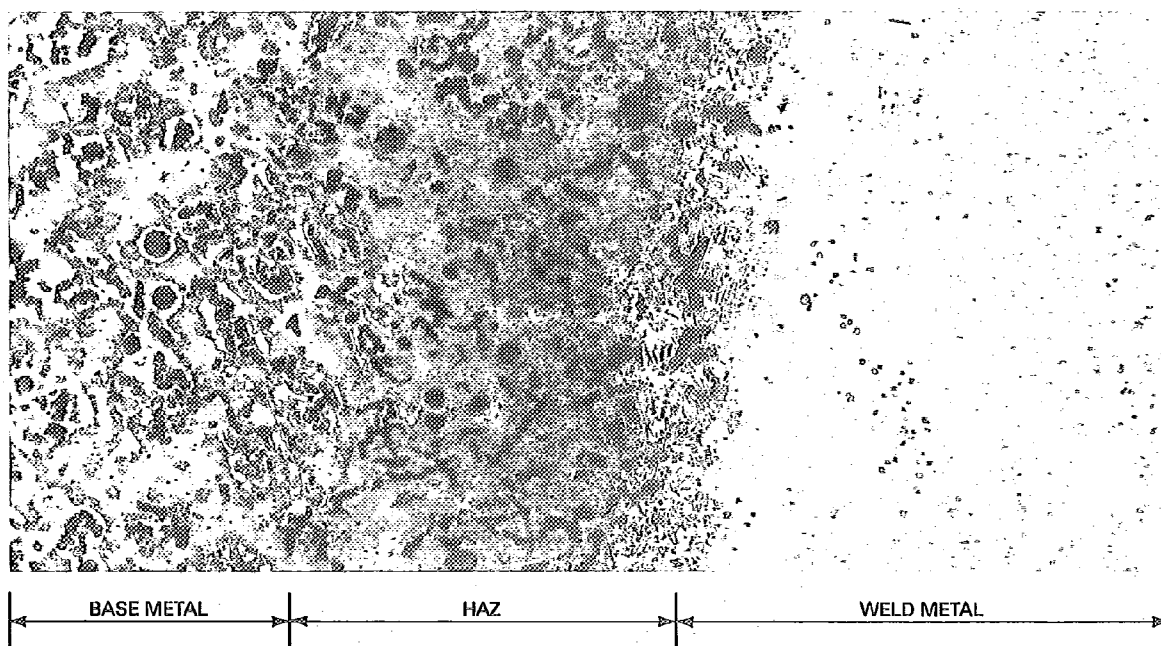


Figure 13 — Compacted Graphite Showing a Typical Microstructure of the Weld and HAZ (50x Magnification)

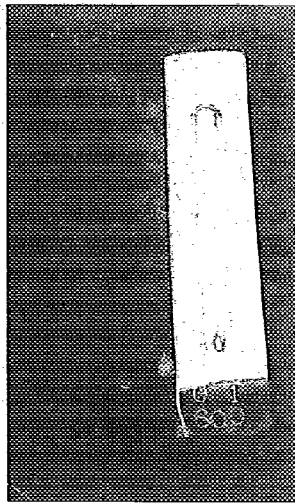


Figure 14—Weld Toe Crack in Specimen of Gray Iron Welded Without Filler Metal Using GTAW

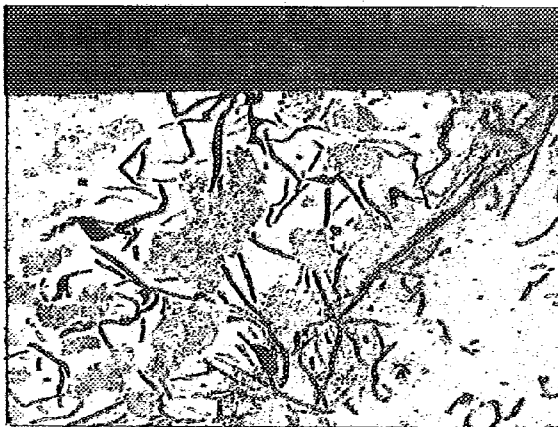


Figure 15—Photomicrograph of HAZ Weld Toe Crack Shown in Figure 14 (Unetched, 15x Magnification)

slag, and grind the weld bead back to the original surface of the cast iron. A dense, porosity free surface where the weld bead was applied should remain after grinding. However, if porosity is in evidence, some form of contamination is present and must be removed before welding (see 3.1). Cast irons containing a great deal of contamination usually exhibit excessive porosity throughout the weld bead, and it is evident without grinding. However, where lesser amounts are present, the molten weld metal

will solidify before the gas formed can travel to the top of the weld bead. The resultant weld bead may appear sound, but excessive amounts of gas may be trapped, forming porosity and islands of incomplete fusion at the base of the weld bead. This can be detected only by grinding.

Caution: If the preweld test bead is applied without preheat, it should be in an area that does not require subsequent machining.

2.4.3 In situations where high phosphorous content, sand inclusions, severe oxidation, or extensive carburization exist, this test may also indicate to the experienced user the suitability of the filler metal selected or whether a fusion welding process is a viable choice. Danger signals are a collapsing base metal appearance resulting in excessive undercut, and lack of wetting during the test.

2.4.4 The test can also be used to select filler metal. For example, it is known that welds made with high nickel filler metals are severely embrittled by phosphorous or sulphur. Thus, a cracked weld bead may indicate the presence of too much of these elements.

3. General Considerations When Welding Iron Castings

The following items should be evaluated when welding cast iron, regardless of the type of iron being welded, or the process, equipment, electrode, or filler metal being used.

3.1 Base Metal Preparation. If a sound weld is to be produced, it must be made on a sound, clean, base metal. Thus, when a crack or linear defect is to be repaired, it should be completely removed before welding is begun. The same is true when repairing casting tears, porosity, shrinkage defects, inclusions, and other defects. The defect must be completely removed.

Casting skins, coatings, sand, rust, paint, oil, grease, moisture, dirt, and other materials may cause weld discontinuities unless removed prior to welding. Castings which have been exposed to high temperatures during service may be oxidized or carburized. Before repair, all affected metal in the weld area should be removed.

Baking at a temperature in the range 700–900° F (370–480° C) will remove most absorbed oil and grease. Casting components, such as submersible pump parts, may be impregnated with silt or sand which makes cleaning and subsequent welding difficult. Baking and preheat do not alleviate this situation.

One method of repair is to apply a weld bead and grind, repeating until the casting surface is sealed and free of defects.

Many excavation methods may lead to defect propagation unless precautions are taken. Often it is wise to "pin" the defect before beginning excavation. This is accomplished by first locating the ends of the defect by visual, magnetic particle, or liquid penetrant inspection. Holes are then drilled through the ends of the defect. The crack then terminates in a hole and cannot propagate. An alternate method to drilling is to weld a ductile bead across the end of the crack transverse to its direction, using a nickel or nickel-iron electrode. The excavation can then be completed and welded as required.

3.1.1 Thermal Cutting and Gouging

3.1.1.1 Air-Carbon Arc Process (AAC). The air carbon arc process may be used for cutting and gouging to prepare gray, ductile, or malleable irons for joining and repairs. It requires a power source, a source of compressed air, a torch, and an electrode. The power source should have 60 volts minimum open circuit voltage. Air carbon arc electrodes require higher voltages and currents than equivalent size shielded metal arc electrodes. The compressor should be capable of delivering air at 80 to 100 psi (560 to 700 kPa) at the torch to provide adequate pressure to remove the molten metal.

Either direct or alternating current may be used with cast irons. If the current is DCEP, it should be set near the maximum that the electrode is designed for. The arc length (distance between electrode and workpiece) should be minimal. However, the electrode should not be allowed to touch the workpiece. These steps are necessary to prevent formation of a refractory slag on the surface of the cast iron which interferes with the cutting action. Copper coated electrodes that are specifically designed for alternating current may also be used on DCEN. Recommended current ranges follow.

Electrode Size		DCEP	DCEN	AC
in.	mm	A	A	A
3/16	4.8	150-200	150-180	150-200
1/4	6.4	200-400	200-250	200-300
3/8	9.5	350-600	300-400	300-500
1/2	12.7	600-1000	400-500	400-600
5/8	15.9	800-1200	—	—
3/4	19.1	1200-1600	—	—

The push angle and travel speed control the depth of the cut. A steep push angle (approaching perpendicular to the workpiece) and a slow travel speed will produce a deeper groove than a flat push angle (approaching parallel to the workpiece) and a fast travel speed. Weaving will increase the width of the groove. As is the case with any process which results in temperature high enough to cause transformation in adjacent areas of the base metal, the AAC process will create a heat affected zone (HAZ)

with undesirable properties. To prevent wide heat affected zones, procedures should be chosen which minimize heat input. The HAZ may be removed by grinding or other mechanical methods before welding.

3.1.1.2 Shielded Metal Arc Cutting (SMAC). SMAC electrodes that do not require supplemental compressed air or a special torch can also be used to prepare gray, ductile or malleable irons for joining and repairs, and provide a clean, efficient method for the removal of unwanted or defective metal. Special exothermic flux coverings develop an instantaneous concentration of heat into a very small crater at the tip of the electrode. When placed in contact with the base metal, the high concentration of heat in the arc causes the base metal to melt very rapidly in an area the width of the electrode diameter. The combination of elements in the flux covering dissolve with the molten metal core, resulting in a tremendous forward thrust, forcing the melted base metal from the crater formed.

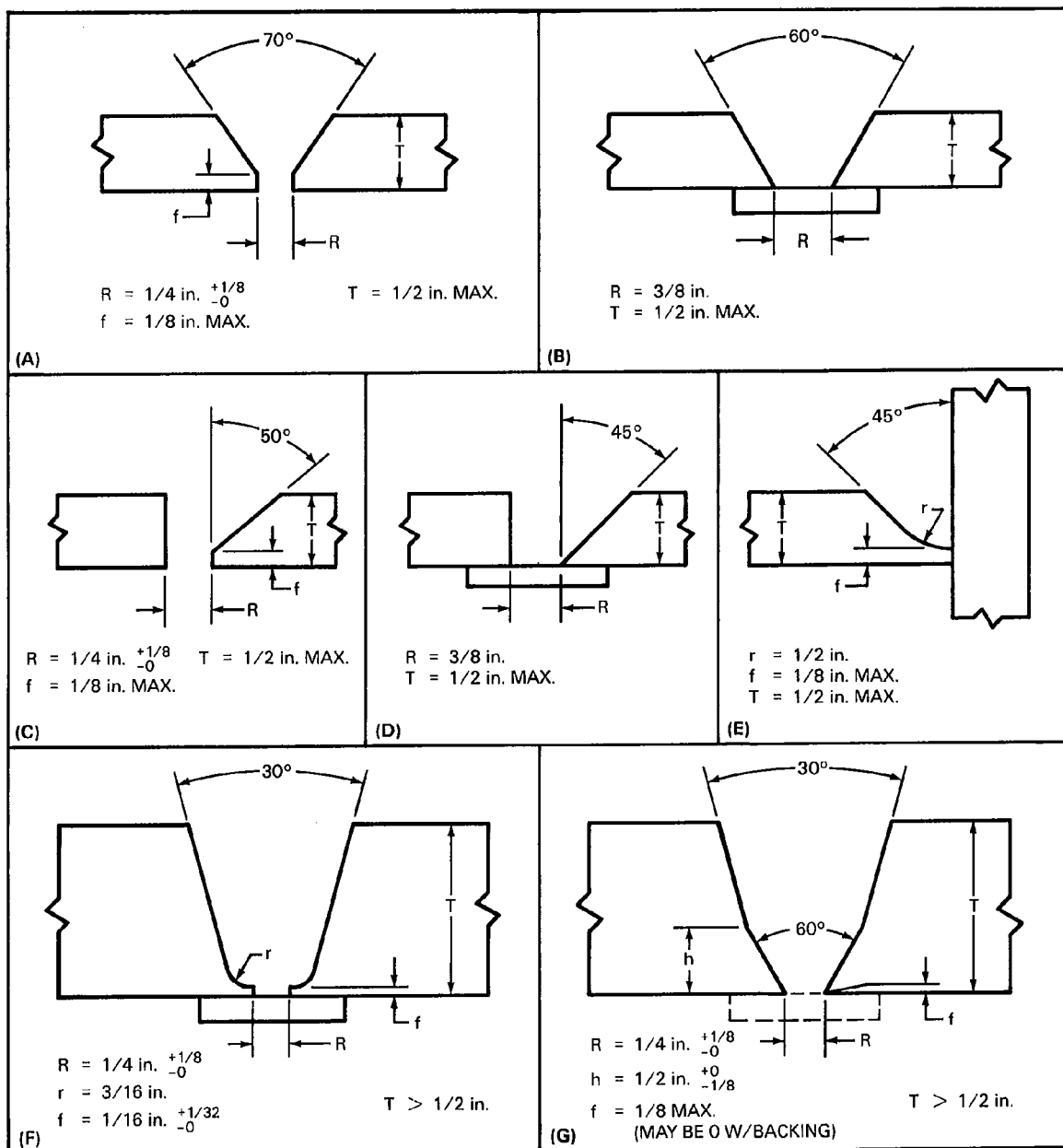
A standard electrode holder is used with ac or dc electrode negative and current settings near the maximum for the size being used. During cutting, the electrode covering will remain in contact with the base metal at the bottom of the groove. Otherwise, the same procedures previously outlined for the AAC process may be employed.

3.2 Joint Design. The design of the weld groove to be filled in an iron casting can greatly influence the properties of the weld and ultimately its performance in service. Base metal thickness and type, filler metal, and accessibility will influence the design of the groove.

3.2.1 Thin Base Metal. Welds in thin cast iron may be made with single-V or single-U grooves. For superficial repairs using steel filler metals, standard steel weld grooves are acceptable. With nickel base filler metals, groove angles should be increased to allow for manipulation of the sluggish weld pool. The root face must be reduced because the nickel base electrodes achieve less root penetration than steel electrodes [see Figure 16(A), (B), (C), (D), and (E)].

3.2.2 Thick Base Metal. For thicknesses greater than approximately 1/2 in. (12.7 mm), grooves that evenly distribute the stresses induced during welding should be used. Double welded joints are effective in such applications when both sides of the joint are accessible. For thicknesses up to 3/4 in. (19 mm), a double-V-groove or a double-bevel-groove should be used. For thicknesses over 3/4 in. a double-U-groove or double-J-groove should be considered.

When only one side of the section is accessible, a modified U-groove may be used. This allows access to the joint root and decreases the width of the weld face,



METRIC VALUES

in.	mm
1/32	0.8
1/16	1.6
1/8	3.2
3/16	4.8
1/4	6.4
3/8	9.5
1/2	12.7

Figure 16 — Suggested Complete Joint Penetration Single Grooves

thus decreasing both weld metal mass and shrinkage stresses induced [see Figures 16(F) and (G), and 17].

When welding thick base metal, buttering of the groove faces is often used. In this manner, the initial welding on the low ductility casting is done at a minimum stress level.

3.2.3 Braze Welding Joints. Joints for braze welding in cast iron are essentially the same as those used for arc welding. To allow for better flow, ease of access, and finishing, the edges of the joint may be rounded. This idea is shown schematically in Figure 18.

3.2.4 Joint Penetration Requirements. The degree of joint penetration required is dependent on the relative strength of the weld metal and base metal, the stresses in service, and the thickness of the workpiece being welded. The savings in welding time and filler metal achieved by making less than complete joint penetration welds must be carefully weighed against the service environment and the fitness for service of such a weld. If the use of a partial joint penetration weld is questionable, complete joint penetration should always be required.

Thick castings of gray iron are sometimes joined with less than complete joint penetration welds. Since most nickel base weld metals are considerably stronger than gray iron castings, partial joint penetration welds are often acceptable. For sections over 1/2 in. (12.7 mm) in thickness, welding only 2/3 of the thickness is usually adequate. For such applications, a double-U-groove is preferred.

Because of their considerably higher strength, ductile (nodular) iron castings require complete joint penetration welds. Even with CJP, 100 percent joint efficiency is not possible for the higher strength grades [greater than 80 ksi (550 MPa) tensile strength].

Welds in iron castings which will be exposed to fatigue loading should always be complete joint penetration welds. The unfused joint root can act as a crack, and propagate under fatigue.

Pipe welds should always have complete joint penetration. A joint with incomplete penetration can act as a crevice and induce accelerated corrosion.

3.2.5 Joint Alteration Techniques. The strength or fitness for service of weldments in iron castings can be improved by the incorporation of various welding techniques into standard procedures. Use of such procedures essentially incorporates some of the design features of mechanical fastening into welding procedures.

3.2.5.1 Groove Face Grooving. Grooving is accomplished by simply grinding or gouging weld bead size grooves on the groove faces of the weld groove (i.e., parallel to the direction of weld progression) as illustrated in Figure 19. The grooves are filled first by welding

with the chosen weld process and filler metal, then the joint is filled. In this manner, the weld interface is interrupted so that the path a crack might follow is not straight. To propagate, a crack must change direction so that the stress required is increased. Thus, the strength of the weld is higher, and fitness of the weld for service is improved.

3.2.5.2 Studding. The mechanical application of studs to the groove faces has been shown to increase the quality of the joint. Studs, depending on their design, are either driven or threaded into the groove faces (see Figure 20). The material of the stud is chosen so that it is compatible with the filler metal.

3.2.6 Joint Design Improvements. Methods for improving the design of joints in iron castings are shown in Figure 21. By applying these designs, the service of the resulting weldment should be improved.

In illustration (A), a complete joint penetration weld is compared with a partial joint penetration weld. The crevice created by incomplete penetration can act as a crack and propagate through the weld in conditions of fatigue.

Illustration (B) shows how improved casting design can locate welds away from changes in metal thickness where bending stresses will be concentrated. Thus, the weld is not in a highly stressed area.

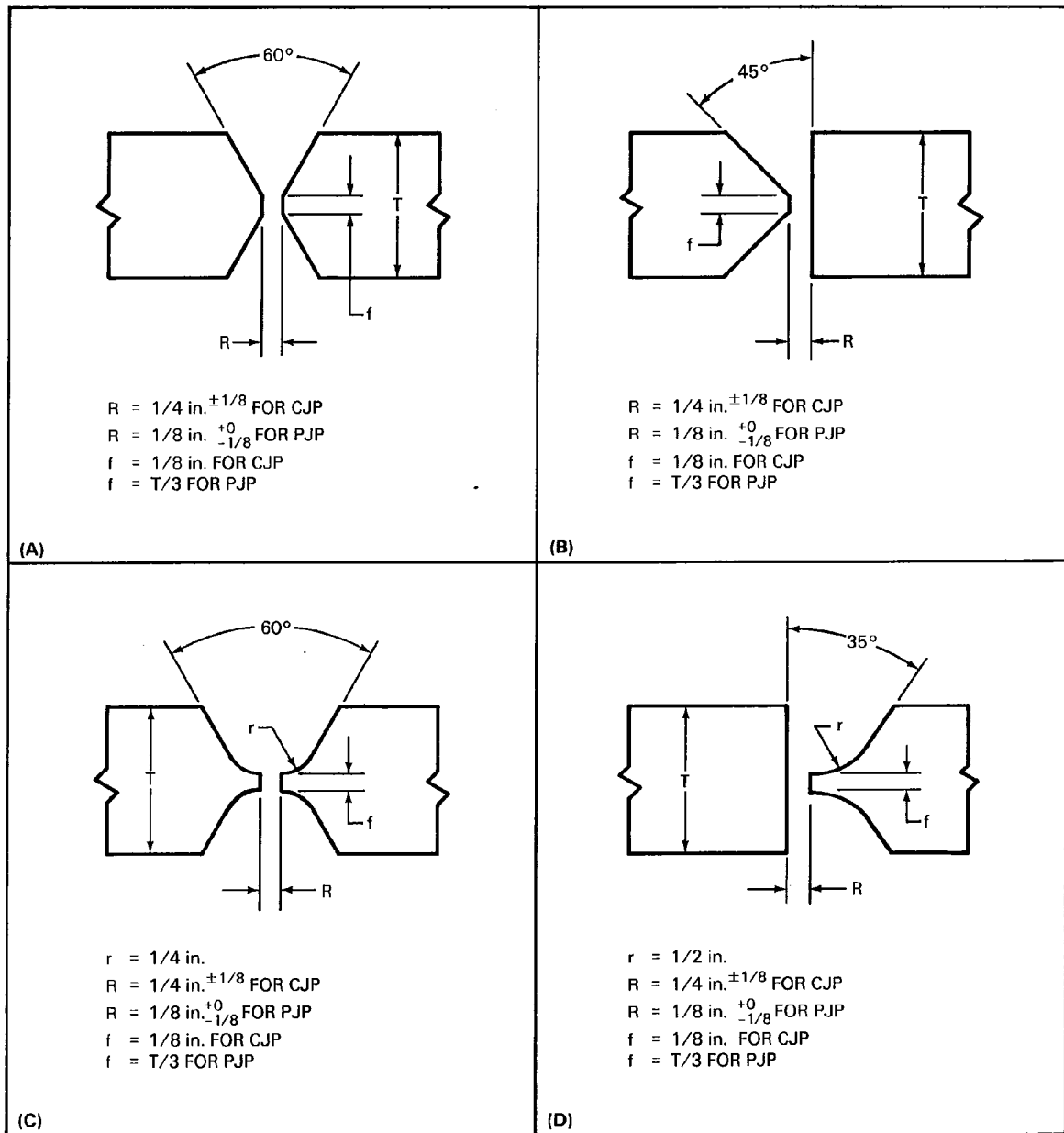
A fillet weld is added to the joint in the third frame, (C), to decrease flexing between the top and bottom joint member. Thus, the life of the joint under fatigue loading should be improved.

3.3 Heat Input. The size of the heat affected zone of a weld is dependent upon the heat input. Thus, the lower heat input processes are most applicable to the welding of iron castings. Welding currents should be maintained at the minimum consistent with complete fusion.

3.4 Preheat. Preheating castings before welding has the following advantages:

- (1) Improves fusion of weld metal to groove face to obtain complete fusion
- (2) Prevents cracking caused by temperature gradients and thermal stresses
- (3) Reduces residual stresses
- (4) Reduces distortion
- (5) Reduces hardness of heat affected zone
- (6) Reduces temperature gradients when welding thin to thick base metals
- (7) Reduces temperature gradients when welding dissimilar base metals

When, and how much to preheat are questions often asked. There are no simple answers, but general rules can assist in making this decision.



METRIC VALUES

in.	mm
1/32	0.8
1/16	1.6
1/8	3.2
3/16	4.8
1/4	6.4
3/8	9.5
1/2	12.7

**Figure 17 — Suggested Complete Joint Penetration (CJP)
and Partial Joint Penetration (PJP) Grooves**

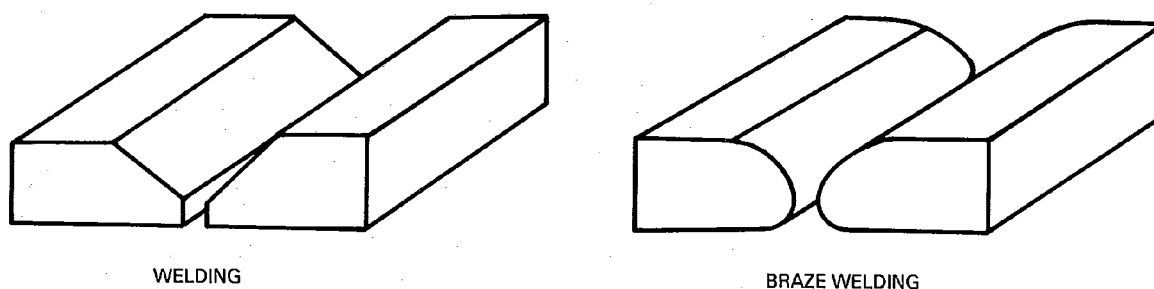


Figure 18 — Groove Designs

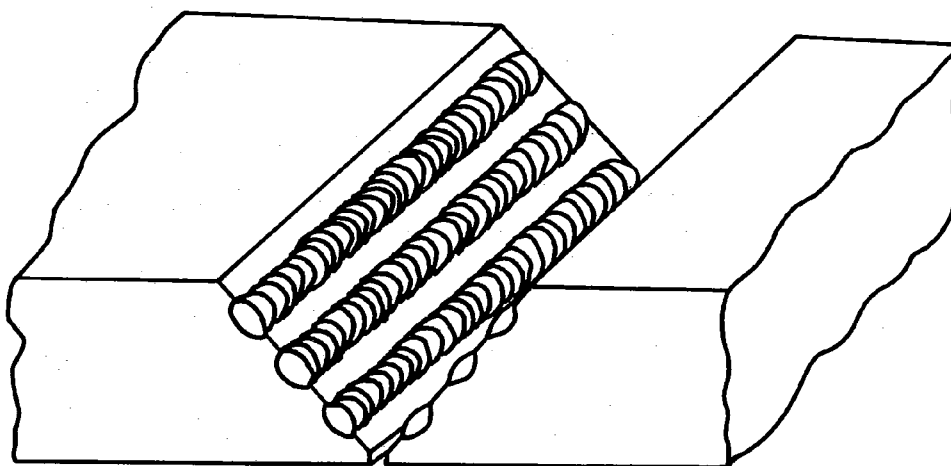


Figure 19 — Groove Face Grooving

If the chemical composition of the cast iron is known, the carbon equivalent can be calculated and used as a guide to estimate preheating requirements. The higher the carbon equivalent, the higher the preheat temperature. If the type or grade of casting is known, but not the specific chemical composition, then the best estimates for preheat temperature are based on the strength and microstructure. Low strength cast irons usually require lower preheat temperature than high strength castings. Malleable or ductile types usually require lower preheat temperature than gray or white cast irons, and ferritic microstructures usually require lower preheat temperature than pearlitic, martensitic or highly alloyed types.

The shape of the casting influences the preheat temperature. A complex casting will usually need a higher preheat temperature to control distortion or residual stresses. When welding thin to thick base metal,

it may be desirable to preheat the thicker member. This decreases its heat sink capacity, which reduces thermal stresses caused by temperature gradients.

Preheat is applied to control the microstructure of the weld area. By preheating to relatively high temperatures, 600–1000° F (320–540°C), the cooling rate can be slowed to the point that formation of martensite is minimized. Slow cooling in this manner also assists in decreasing residual stresses. By decreasing these stresses and the hard phases referred to above, machinability of the welded casting is improved.

If preheating is to accomplish its intended purpose, certain rules must be followed in its application, otherwise, the heat may be ineffective or even detrimental. Preheat should be applied so that the weld is in compression on cooling. While the weld metal is contracting due to cooling, the base metal around it is also contracting. A

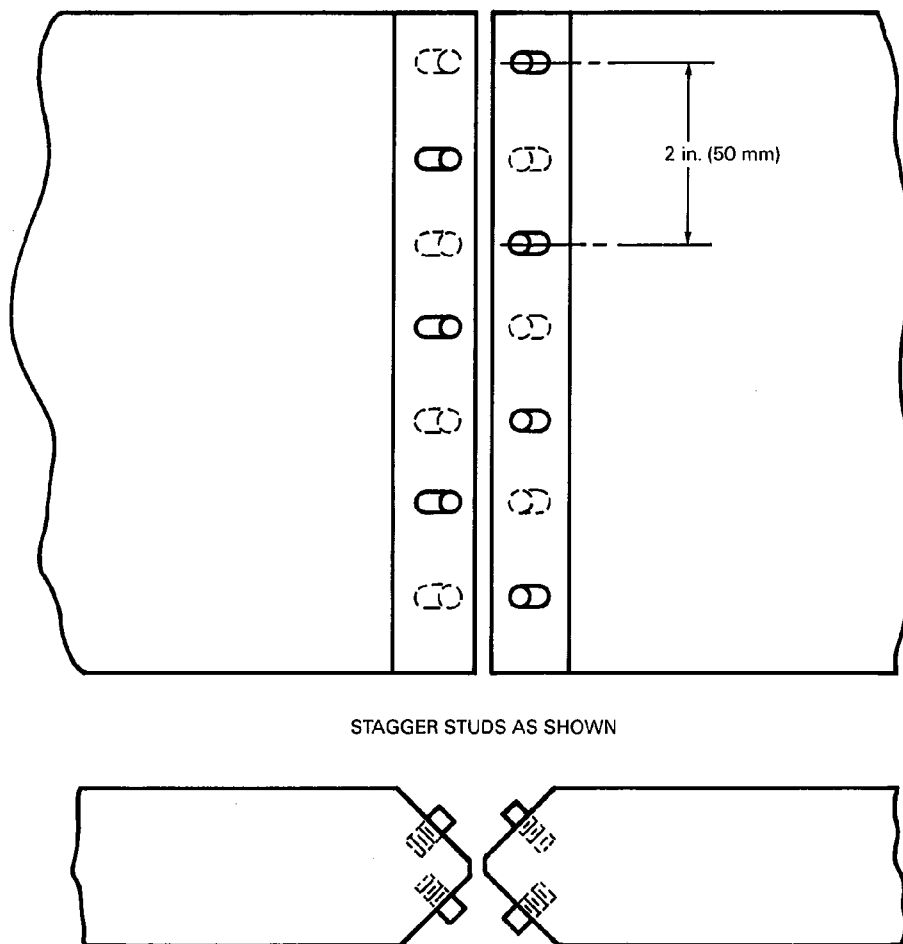


Figure 20 — Studding to Increase Strength at the Weld Interface

good example of this is shown in Figure 22. Preheating in the areas indicated in Figure 22(B) will expand the metal, as shown in Figure 22(C). Thus, the weld groove opens. After welding, Figure 22(D), the weld will be compressed as the ends cool and the metal shrinks.

When preheating castings of a complex shape, it may be necessary to apply heat to the entire casting to avoid inducing high stresses due to thermal gradients. The area to be welded may be brought to an even higher temperature if necessary. A complete structural analysis of the casting will determine how preheat can be applied most effectively.

3.5 Electrode Manipulation. Welds can be made in any position by using either a stringer or weave technique.

Dilution can be minimized by utilizing stringer beads in the flat position and holding the electrode almost vertical with the arc directed into the weld pool. The weave should not be more than three times the diameter of the electrode. When welding in grooves, a weaving technique may be used to improve the fusion to the groove faces. A skip technique may be used to minimize distortion in extensive repair welds, extra long welds, or thick base metal.

Arc length should be as short as practical to assure good bead shape. Flux should be removed from each crater before making a restrike and completely removed from each pass before starting subsequent passes. Removal is done readily by light hammer blows with the corner of a cold chisel or slag hammer followed by wire brushing.

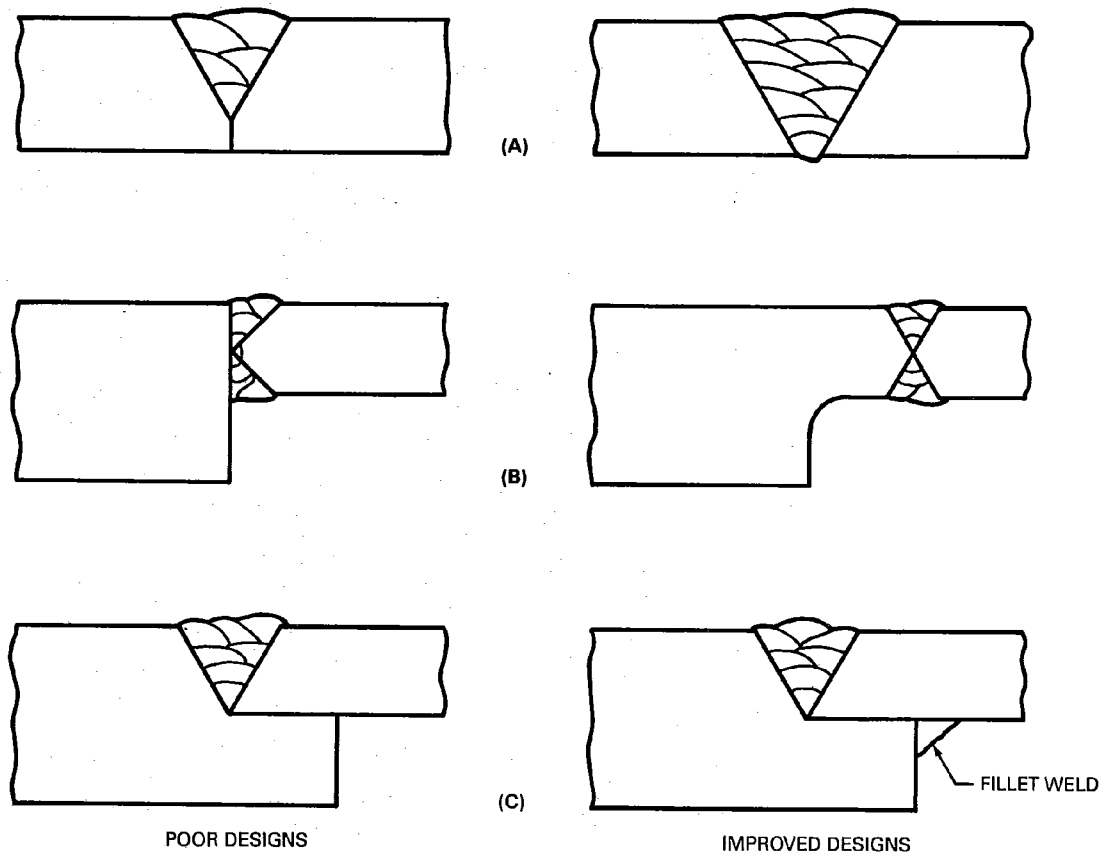


Figure 21 — Joint Design Improvements

3.6 Peening. Peening can be used to control distortion or to reduce cracking by altering the stress distribution in the weldment. If peening is to be done, it should be by many moderate blows perpendicular to the weld surface rather than by a few heavy blows, peening each bead as deposited. A 1/2 to 3/4 in. (13 to 19 mm) diameter rounded peening tool or a ballpeen hammer is suitable. During any peening operation, the weld metal should be maintained at, or near, red heat, but never allowed to cool below 1000°F (538°C).

A typical peening procedure is the use of a reciprocating air hammer operating at 90 psi (600 kPa) (to approximate many moderate blows) on a weld of up to 3 in. (76 mm) in length. The peening tool tip should be no wider than the weld bead and with a tip radius of half the tip width. Recommended peening travel speed is 30–40 in. (750–1000 mm) per minute.

Peening, properly done, can be quite effective in reduction of distortion. For example, a single-V-groove

weld, unpeened and unrestrained, causes considerable distortion. The same weld, properly peened, can be completed with virtually no distortion.

3.7 Cooling. The final stress level of a welded casting is affected by its rate of cooling. If the casting is cooled rapidly, residual stresses remain in the casting. If the residual stress is high enough, cracking may occur. Slowing the cooling rate can alleviate this problem. This can be accomplished by the following:

- (1) Burying the casting in sand or vermiculite
- (2) Postheating the welded casting with a torch
- (3) Transferring the welded units to a furnace
- (4) Covering the casting with an insulating blanket

3.8 Postweld Heat Treatment (PWHT). After welding, heat treatment may be necessary to accomplish the following:

- (1) Improve the ductility of the HAZ of the weld.
- (2) Improve the machineability of the weld and HAZ.

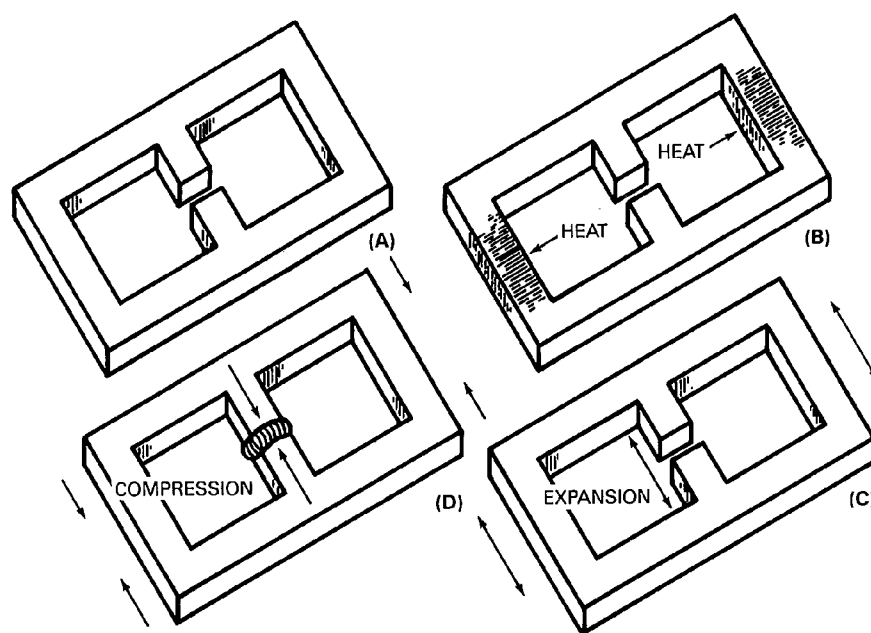


Figure 22 — Fundamentals Involved in Preheating Castings for Welding

- (3) Decompose the cementite formed during welding.
- (4) Transform martensite to a less brittle phase.
- (5) Relieve residual stresses.

The selection of the final PWHT depends in large part on the condition of the casting, the effect on finish machined surfaces, possible distortion, and prior heat treatment. Unfinished castings still at the foundry can generally be heat treated after weld repairs. New, finish machined castings may be given a stress relief PWHT, with actual temperature dependent on the composition and prior heat treatment.

Castings taken out of service may be given a complete or local stress relief, or no PWHT whatever. Thermal cycles, if used, are described in 3.8.1 and 3.8.2. The selection is based on the individual case, taking into consideration economics, weldability, critical nature of the part, and location of the repair.

To avoid thermal stress cracking due to temperature variations in the casting, the postweld heating and cooling rate should not exceed 100° F (55° C) per hour when heat treating large or complex castings. Unusual cases may require even slower rates.

3.8.1 Gray Iron. If a minimal stress relief (30 percent) or only a partial reduction of hardness is necessary, heating the casting to 900° F (480° C) and cooling in still air should produce suitable results. A temperature of

1100° F (590° C) will reduce the residual stress to about one-half and further reduce the hardness. Again, cooling in still air is satisfactory. For maximum softening, heat to 1650° F (900° C) and furnace cool.

3.8.2 Ductile Iron. Because of this material's comparatively high ductility, it is often desirable to heat treat castings after welding to restore the ductility of the weld area. For best results, the casting should be either heat treated immediately after welding or cooled slowly after welding.

If only moderate improvement of ductility is necessary, heating to 900° F (482° C) and slow cooling in still air is sufficient. The treatment will stress-relieve the weldment, as well as reduce the hardness of the heat affected zone.

If greater ductility is required, the following annealing cycle may be used:

- (1) Heat the part to 1650° F (900° C) at a rate not to exceed 100° F (55° C) per hour.
- (2) Hold at 1650° F (900° C) for one hour per inch of maximum thickness.
- (3) Furnace cool to 500° F (260° C) at a rate not to exceed 100° F (55° C) per hour.
- (4) Cool to room temperature in still air.

This high temperature annealing cycle dissolves iron carbides and transforms the martensite and bainite to

austenite. The slow cooling allows the formation of ferrite, pearlite, and the precipitation of the carbon as graphite, while avoiding the reformation of the harder constituents, martensite and bainite.

If maximum ductility is required, the following ferritizing annealing cycle may be used:

- (1) Heat the part to 1500–1700°F (840–900°C) at a rate not to exceed 100°F (55°C) per hour.
- (2) Hold at temperature for one hour per inch (25 mm) of maximum thickness.
- (3) Furnace cool to 1250°F (675°C) at a rate not to exceed 100°F (55°C) per hour.
- (4) Hold at temperature for 5 to 6 hours.
- (5) Furnace cool to 500°F (260°C) at a rate not to exceed 100°F (55°C) per hour.
- (6) Cool to room temperature in still air.

This treatment, in addition to transforming the hard constituents as in the preceding treatment, will allow time for the formation of a ferrite matrix.

4. Gas Processes

4.1 Oxyfuel Welding (OFW)

4.1.1 Process Description. OFW includes any welding process that uses oxygen and a fuel gas as a heating medium. The process involves the melting of the base metal and a filler metal by means of the flame produced at the tip of a welding torch. Fuel gas and oxygen are mixed in the proper proportions in a mixing chamber which may be part of the welding tip assembly. Molten metal from the groove faces and filler metal intermix in the weld pool and, upon cooling, coalesce to form a continuous piece.

An advantage of this welding process is the control a welder can exercise over the rate of heat input, the temperature of the weld zone, and the oxidizing or reducing potential of the welding atmosphere. Weld bead size and shape and viscosity of the weld pool are also controlled in the welding process because the filler metal is added independent of the welding flame. OFW is ideally suited to the welding of thin sections, tubes, and small diameter pipe, and also for repair welding. Except for repair welding, the process is not economical for thick base metal.

The equipment is low in cost, usually portable, and versatile enough to be used for a variety of related operations, such as bending, straightening, preheating, post-heating, surfacing, braze welding, and torch brazing. With relatively simple changes in equipment, manual and mechanized oxygen cutting can be performed.

Commercial fuel gases all require oxygen to support combustion. To be suitable for welding, a fuel gas, when burned with oxygen, must have the following:

- (1) High flame temperature
- (2) High rate of flame propagation (combustion velocity)
- (3) Adequate heat content
- (4) Minimum chemical reaction of the flame with base and filler metals

Among the commercially available fuel gases, acetylene most closely meets all these requirements. Other fuel gases, such as stabilized methylacetylene-propadiene, propylene, propane, natural gas, and proprietary gases based on these have sufficiently high flame temperatures but exhibit low flame propagation rates. These other gas flames are excessively oxidizing at oxygen-to-fuel gas ratios high enough to produce usable heat transfer rates. For this reason, acetylene is preferred for welding cast irons.

Oxyacetylene welding (OAW) with cast iron filler rod has been used widely for the weld repair of minor defects in gray cast iron and less frequently for ductile iron castings. The characteristic slow heating rate of the process causes a wide heat affected zone, but prevents formation of hard martensite. Oxyacetylene welding procedures reported in the literature commonly recommend the following filler metals and procedural guidelines to avoid cracking and produce sound welds. Use of proper welding techniques is an important factor in producing a weld metal that closely matches the strength and machinability of the gray iron base metal.

4.1.2 Filler Metals and Fluxes. Many different compositions of filler metals are used for welding cast iron. Some of those most used and their best application are described below.

4.1.2.1 Gray Iron Welding Rods. Gray iron welding rods normally are cast with higher silicon and carbon content than the casting itself to compensate for losses during welding. The resultant weld metal has a graphitic structure, is machineable, and maintains a good color match. Chemical composition requirements for the two gray iron welding rods covered by ANSI/AWS A5.15-82, *Specification for Welding Rods and Covered Electrodes for Cast Iron* (Class RCI and RCI-A) are given in Table 4. RCI filler metal is used to join Class 20 through 35 gray irons. RCI-A filler metal, with higher levels of nickel and molybdenum, is intended to weld Class 35 through 45 gray irons.

Proprietary filler metals also are available for welding gray irons. Although compositions are not generally stated, these filler metals must be designed to furnish weld metal of adequate strength containing a minimum of iron carbide. To achieve the foregoing, alloying elements which promote solid solution strengthening are combined with a graphitizing agent. Nickel, manganese,

Table 4
Chemical Composition Requirements of Filler Metals, Percent

AWS Classification	C	Mn	Si	P	S	Fe	Ni ^{3a}	Mo	Mg	Ce
Cast Iron Filler Metals ^{3b}										
RCI	3.2-3.5	0.60-0.75	2.7-3.0	0.50-0.75	0.10	remainder	trace	trace	—	—
RCI-A	3.2-3.5	0.50-0.70	2.0-2.5	0.20-0.40	0.10	remainder	1.2-1.6	0.25-0.45	—	—
RCI-B	3.2-4.0	0.10-0.40	3.2-3.8	0.05	0.015	remainder	0.50	—	0.04-0.10	0.20

Notes:

1. Analysis shall be made for the elements for which specific values are shown in this table.
2. Single values shown are maximum percentages.
3. Excerpted from ANSI/AWS A5.15-82.
 - (a) Nickel plus incidental cobalt.
 - (b) Chemical composition requirements for the Cast Iron Filler Metals are based on the as-manufactured composition of the bare welding rod.

molybdenum, and silicon are the most common additions. Silicon plays a dual role as a hardener and a graphitizing agent. Aluminum, in conjunction with calcium, can be substituted for silicon.

Phosphorus improves fluidity of molten iron. There is an upper limit to its usefulness, however, because the end product is a hard, brittle, iron/iron phosphide eutectic which is no more desirable than the iron/iron carbide eutectic which it resembles. Chromium, molybdenum, nickel, and copper are alloying elements frequently added to gray iron melts; therefore, their presence in a filler metal would be expected. If these elements are added to filler metal, the quantities must be carefully regulated. Chromium promotes iron carbide formation which can embrittle the weld metal. Copper will be present as a film along grain boundaries if its solubility in the matrix is exceeded. This film can cause hot cracking.

4.1.2.2 Ductile Iron Welding Rods. Ductile iron welding rods are different from gray iron rods because they contain additions of nodularizing elements such as magnesium (Mg) and cerium (Ce). Such filler metal is classified in ANSI/AWS A5.15-82 as RCI-B, as shown in Table 4. Bare welding rods containing other nodularizers or alloying elements are available, but are not yet classified by AWS. Welding rods, capable of producing nodular graphite weld metal, often are made by individual foundries from small quantities of production iron with Mg or Ce additions. These types are capable of producing weld metal with a nodular graphite structure, provided the Mg or Ce addition from the rod is sufficient to compensate for oxidation losses incurred during welding. Such losses vary depending on the welder's technique, and may be on the order of 50 to 80 percent.

Cerium-containing welding rod may be preferred to minimize porosity problems. Magnesium-containing rods develop a scum during welding unless adequate flux is employed. This scum is hard to remove and results in contaminated, low-strength welds. It is absolutely necessary that the filler metal be thoroughly mixed with the weld pool during welding. Proper welding must be followed closely to consistently produce high quality ductile iron weldments. Strength of the weld will depend greatly on the soundness of the weld metal. According to the program reported in AWS D11.1-65, the tensile strength of some welds made in ferritic ductile iron test blocks with ductile iron welding rods containing cerium, was as high as 73 000 psi (500 MPa).

The overall average tensile strength was about 56 000 psi (390 MPa), mainly due to the variability in the soundness of the welds. Even though the strength of the weld metal may closely match that of the minimum base metal requirements, the ductility of the oxyfuel gas weld repair will be considerably lower when compared to the ductile iron base metal, even after a postweld annealing heat treatment. Test results presented in AWS D11.1-65 had an average tensile elongation of only 3 percent compared to a base metal elongation of 19 to 20 percent.

4.1.2.3 Malleable Iron. The cast iron welding rods listed in Table 4 have been used for welding malleable iron. However, the effect of oxyacetylene gas welding on malleable iron is to create a wide heat affected zone of brittle white iron. Thus, the base metal ductility is lost, and the weld is prone to cracking. Rather than repair weld the finished casting, some foundries make the repair on the rough casting while it is still in the white iron condition, before the malleabilizing heat treatment.

White iron welding rods cast by the foundry are used. Repair procedures suitable for gray iron are followed.

4.1.2.4 Flux. Fluxes are used for oxyacetylene welding of cast iron to protect the molten metal from oxidation, increase the fluidity of the iron silicate slag that forms, and dissolve oxides and other impurities. Proprietary fluxes are available. Fluxes for oxyacetylene welding gray iron typically contain borax (sodium borate) or boric acid, soda ash (sodium carbonate), plus some iron oxide powder. Fluxes used for the oxyacetylene welding of ductile iron are similar to those for gray iron, except they may be formulated to produce a slag with a lower melting point. Some proprietary ductile iron fluxes also may contain inoculant powders to promote the formation of spheroidal graphite.

4.1.3 Welding Procedure Guidelines

4.1.3.1 Preparation for Repair Welding. Preparation and careful cleaning of the repair excavation is necessary to obtain sound welds and to minimize the oxyacetylene welding time.

The defect must be completely removed. Base metal must be free of all foreign material. The casting skin should be removed at least 1 in. (25 mm) from the edges of the weld groove.

The groove excavation must be prepared wider than that used for shielded metal arc welding to allow room for unrestricted manipulation of the welding rod and torch. Groove angles of 90 to 120 degrees commonly are employed, the former for double groove welds and the latter for single groove welds.

4.1.3.2 Preheat and Interpass Temperature. A preheat temperature of 1000–1200°F (540–640°C), a dull red color, is recommended for the oxyacetylene welding of cast irons. This allows repairs to be made rapidly and results in a slow cooling rate, thus preventing formation of martensite in the base metal heat affected zone. Ideally, the entire casting should be preheated uniformly in a furnace to reduce danger of cracking from thermal stresses. Gray iron, which has low strength and nil ductility, is especially susceptible to cracking due to thermal stresses induced by localized preheating of the repair area. Localized preheating carefully done with a torch can be used successfully on small castings.

Once the proper preheat temperature is reached, the repair weld should be made quickly before the adjacent base metal can cool. Ideally, a weld repair should be made in less than five minutes without allowing the casting to cool below 600–800°F (320–470°C). If the welding takes so long that the casting cools below this temperature, the casting should be reheated to the original preheat temperature range. An insulating blanket material placed over the casting, exposing only the repair

area, reduces heat loss, especially when the surrounding air is cold or drafts are present.

The repair area should not be heated above 1250°F (680°C). At higher temperatures, phase transformations take place with accompanying volume changes which may introduce increased stress levels. Excessive preheat temperatures further increase the danger of distortion and a possible reduction in tensile strength due to the high interpass temperatures and extended welding times.

Temperature-indicating crayons are recommended to monitor the temperature of the repair area during preheating and welding when preheating is used. If a permanent furnace is not available, a preheat table or temporary furnace can be used to heat the casting before, during, and after welding. A preheat table is relatively inexpensive compared to the cost of a permanent furnace. It can be made from sheet steel with a fire brick top and gas burners underneath. The castings will be heated more uniformly, kept hot during welding, and can be covered up on the table after welding to slow their cooling rate.

4.1.3.3 Welding Technique. General details of the techniques considered good practice for the oxyacetylene repair welding of cast iron are as follows:

(1) The size of the welding torch and tips employed should be the same as would be used for welding similar thicknesses of mild steel.

(2) A neutral flame or very slightly reducing (carburizing) flame should be employed. An oxidizing flame must be avoided to prevent oxidation loss of the silicon, the resultant formation of brittle white iron (iron carbide), and porosity in the weld metal.

(3) After preheating, flux is sprinkled on the groove faces, and the flame directed to the bottom of the groove to begin welding. The cone of the flame should be kept approximately 1/8 to 1/4 in. (3.2 to 6.4 mm) from the base metal surface. Contact of the cone with the surface may cause oxidation of silicon and carbon and formation of hard spots.

(4) The weld pool is formed in the same manner as for steel welding. When the bottom of the groove has melted, the torch flame is moved from side to side to melt down both groove faces and the welding rod added, gradually forming the weld pool. The fluxed welding rod should be placed into the pool for melting. Melting the rod over the pool drop by drop by direct contact of the flame should be avoided.

(5) Flux is added at intervals during welding by heating the tip of the welding rod in the outer portion of the flame and dipping the heated tip into the flux. The appearance of white spots or gas bubbles in the weld pool is a sign that impurities are present and additional flux is required.

(6) A "puddling" or stirring action with the welding rod is used to help oxide and slag impurities float to the surface of the weld pool, and to obtain good fusion with the groove faces. Excessive stirring must be avoided, however, to minimize oxidation. Impurities on the top of the weld pool can be skimmed from the weld with the welding rod, and removed from the rod by lightly tapping it against the work table.

(7) The filler metal can be deposited using a block sequence (see Figure 23), where separate sections, each about 1 in. (25 mm) long, are welded before intervening lengths are welded. Care must be taken to obtain complete fusion between block sections, as well as to the groove faces. Excess molten metal that runs ahead of the block being welded must be remelted before welding over it. Some welders prefer a cascade sequence where the weld is made in successive thin layers as in arc welding (see Figure 23).

4.1.3.4 Postweld Heat Treatment. The completed weld must be cooled carefully. Sudden chilling of the casting must be avoided as the fast cooling rate may produce hard brittle phases in the weld repair area. As a minimum requirement, the casting should be insulated from the surrounding air or drafts and cooled slowly. As an additional precaution, the entire completed repair can be heated to above 1000°F (540°C) followed by slow cooling.

It is recommended that large castings with complex shapes, or those requiring stability during machining, be given a postweld stress-relief heat treatment immediately after welding without allowing the casting to cool. Stress relief treatment consists of holding the casting at 1000–1200°F (540–650°C) for one hour per inch of thickness, followed by slow cooling. The stress relief will relieve residual stresses imposed by welding and stabilize dimensions for machining.

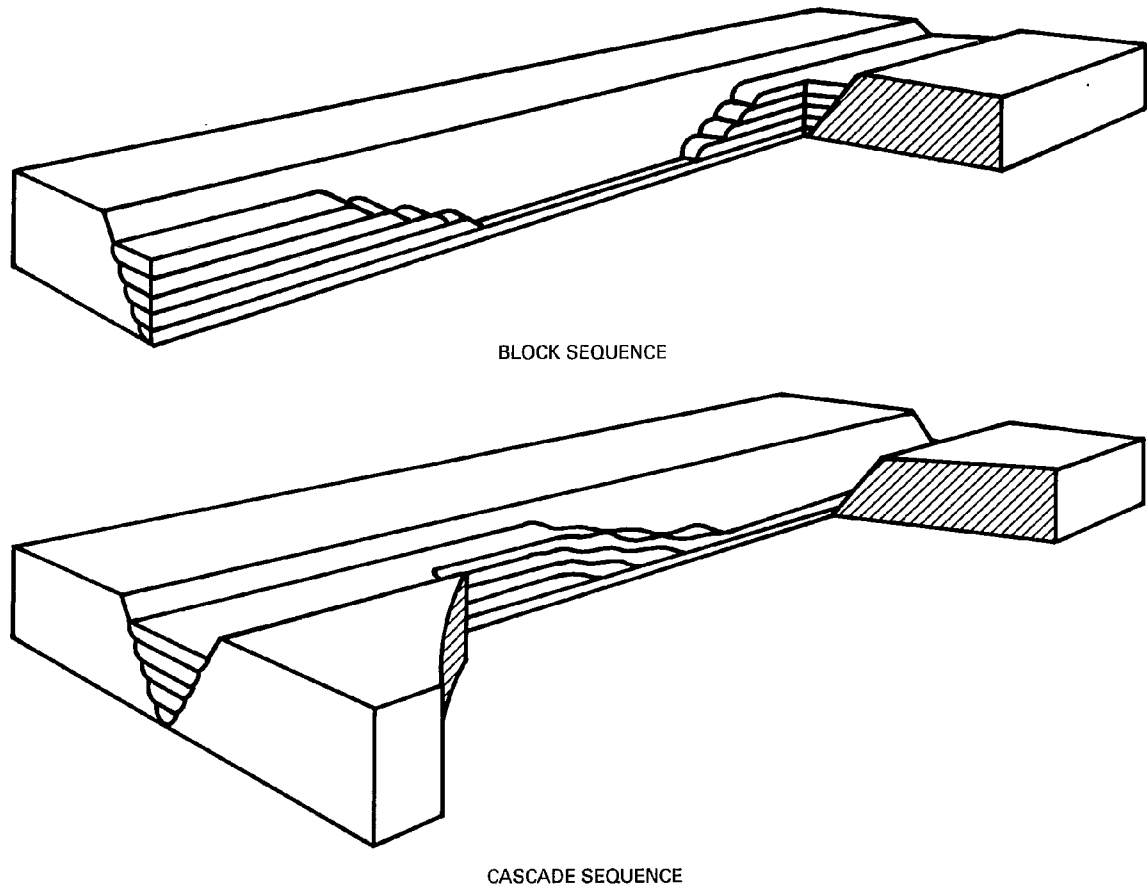


Figure 23 — Block and Cascade Welding Sequences

4.2 Flame Spraying (FLSP) of Gray Iron. The use of flame spraying for the repair of minor defects in gray iron castings originated in the glass industry, specifically for the repair of worn areas, defects, and broken corners on gray iron glass molds. Over the last 25 years, it has proven to be the most successful process available for glass mold repair for the following reasons:

(1) The precision control of the deposited powder surfacing metal requires a minimum of finishing time. Spray deposits as thin as .004-.005 in. (.1016-.1270 mm) can be applied uniformly to a complex contour.

(2) High strength bonds are obtained with varying hardness values.

(3) The deposits are easily hand-filed or machined back to the original finished contours of the casting.

As a result of the many years of proven success on gray iron glass molds, it has now become an accepted practice for the repair of minor defects uncovered in gray iron castings during finish machining operations.

4.2.1 The Process. The flame spraying process employs a special oxyacetylene torch designed to store and inject powder particles into the gas stream ahead of the flame. The powder particles then pass through the flame and become semimolten before striking the workpiece.

4.2.2 Surfacing Metals (Powder Alloys)

4.2.2.1 Atomization. The powder alloys used for cast iron repairs are manufactured by an atomization process. This process incorporates a special nozzle located at the top of a tank into which the molten alloy is poured. As the molten metal is released from the nozzle, high pressure jets of inert gas or water cause the molten metal to explode into fine particles and settle at the bottom of the tank.

4.2.2.3 Blending. After the atomization process, the finished powder then is blended to become an aggregate of various sized particles. Following is a typical distribution of particle size.

Mesh Size	Percentage
+100	0
-100 +140	5-15
-140 +325	Balance
-325	35-50

The importance of maintaining the correct mesh size distribution relates to both efficient flow of the powder through the torch and thermal spraying deposition efficiency. The balance of mesh sizes greater than 325 promotes uniform flow of powder through the torch. The smaller mesh sizes melt quickly and enhance bonding to the base metal. An improper blend of powder mesh sizes will cause torch clogging, poor bonds, and decrease deposition efficiency.

4.2.2.4 Grades. A family of powder alloys providing machineable spray deposits for gray iron repairs has been developed around the standard AMS 4779 nickel-base brazing alloy with the following chemical composition:

Aerospace Materials Specification 4779*

C	B	Si	Fe	Ni
0.6 max	1.0-2.2	4.0-5.0	1.5 max	Remainder

Variations in performance and hardness are produced by selectively altering the percentage of each element, by the addition of chromium, or both. Hardness values range from 85 HRb through 40 HRC. Performance can vary from a very liquid, thin flowing alloy for surfacing to a sluggish alloy for buildup work.

4.2.3 Preparation. The area to be flame sprayed must be completely clean and free of all foreign materials. All oxides on the casting surface must be removed by grinding, machining, or filing. Sandblasting is not recommended. Minute particles of silica can become imbedded in the casting surface and inhibit bonding of the surfacing metal.

4.2.4 Fusing Technique. The area to be flame sprayed is first preheated with the oxyacetylene flame to a temperature of 500-600°F (260-320°C). The preheated area is then sprayed completely with a thin layer 0.004-0.007 in. (0.10-0.18 mm) thick. The powders are self-fluxing and this initial spraying eliminates the formation of oxides during the fusion cycle.

Using the oxyacetylene flame only, starting at one end, edge, or corner of the spray deposit, the deposit and base metal are heated simultaneously to a temperature of 1850-2100°F (1010-1150°C). This procedure is continued until all of the spray deposit has been completely fused to the substrate.

After the original deposit has been applied, additional surfacing metal can be deposited to the desired depth using this spray-and-fuse technique.

4.3 Braze Welding

4.3.1 Process Definition. Braze welding is a welding process variation in which a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base metal is used. Unlike brazing, in braze welding the filler metal is not distributed in the joint by capillary action.

4.3.2 Process Essentials. Braze welding was originally developed for the repair of cracked or broken cast iron parts. Unlike arc welding, braze welding requires heating, but not melting of the base metal. The lower

*Specification may be obtained from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

temperature reduces the tendency to form brittle cementite, and also the tendency to form cracks.

To obtain a strong, metallic bond between the filler metal and the unmelted base metal, the molten filler metal must wet the hot base metal.

The base metal is heated to the required temperature with an oxyfuel gas torch.

With torch braze welding, flux is generally required to clean and protect both the base metal and weld metal. Filler metal is fed to the progressively heated groove faces in one or more passes until the groove is completely filled. Stringent control of joint fit up is not critical because the filler metal is deposited in grooves and spaces. Joint design is similar to that required for oxyfuel gas or arc welding. Typical groove and joint designs are presented in Figures 16 through 21.

4.3.3 Advantages. Braze welding exhibits the following advantages when compared to the fusion welding processes:

(1) Less heat is required permitting higher travel rates and lower fuel consumption. Distortion and susceptibility to cracking are decreased.

(2) The weld metal is relatively soft and ductile, providing excellent machinability and low residual stresses.

(3) Joints can be produced with adequate strength for many applications.

(4) Equipment is simple and easy to use.

(5) Cast iron grades which are brittle and sensitive to thermal shock, can be braze welded without extensive preheating.

4.3.4 Disadvantages. Conversely, there are specific disadvantages to be recognized in braze welded joints:

(1) Joint strength is limited to that of the braze weld metal or the braze weld interface.

(2) Permissible service performance temperatures are lower than those of fusion welds because of the lower melting temperature of the filler metal. With copper alloy filler metal, the service temperature is limited to 500°F (260°C) or lower.

(3) Braze welded joints may be susceptible to differential chemical attack caused by galvanic corrosion.

(4) Braze welding metals will not match the color of the base metal.

(5) Nonwetted areas are harder to detect than fusion weld defects.

4.3.5 Equipment. Braze welding uses an oxyfuel gas welding torch and associated equipment. In some applications, an oxyfuel gas preheating torch may be required. Clamping and fixturing equipment may also be needed to hold and align the part. The manufacturer and distributor of this equipment should be consulted.

4.3.6 Base Metals. Braze welding can be used to join cast iron to itself or dissimilar metals such as steel and stainless steels, if suitable filler metals are selected.

Retention of ductility in the braze weld joint can be improved, in many cases, by buttering one or both groove faces. The surfacing can be the same as the filler metal, or it can be another surfacing metal chosen to act as a buffer between two incompatible base metals.

4.3.7 Filler Metals. The most commonly used filler metal is a brass containing 60 percent copper and 40 percent zinc. Small additions of tin, iron, manganese, silicon and nickel may be added to improve flow characteristics, lower the melting temperature, decrease volatilization of zinc, scavenge oxygen, and increase strength and hardness. The chemical composition and properties of several filler metal rods are listed in Tables 5A and B. The minimum tensile strengths of these alloys vary between 40 000 and 70 000 psi (276 and 483 MPa). However, the strengths of these alloys will decrease rapidly at service temperatures above 500°F (260°C).

4.3.8 Fluxes for braze welding are proprietary compounds developed for use with specific combinations of base metals and filler metals. These compounds are designed for use at higher temperatures and must remain active for longer periods than fluxes used for brazing. The following types are in general use for braze welding cast iron:

(1) A basic flux of alkali fluoride and borax mixtures which cleans the base metal and weld metal, assists in wetting of the base metal, and is active over the full melting range of the filler metal used for malleable iron.

(2) A modified flux which performs the same functions as the basic flux and also suppresses the formation of zinc oxide fumes may be used.

(3) A flux that is formulated specifically for braze welding of cast iron contains iron oxide or manganese dioxide that combines with the free carbon on the cast iron surface to promote wetting.

Fluxes may be applied by one or a combination of the following four methods:

(a) The heated filler metal rod may be dipped into the flux and transferred to the joint during braze welding.

(b) The flux may be brushed into the joint.

(c) The filler metal rod may be precoated with flux.

(d) The flux may be introduced through the oxy-fuel gas flame.

4.3.9 Metallurgical Considerations. The metallic bond between the filler metal and the base metal is the same as with brazing. The clean base metal is heated to a temperature that is sufficient to permit the wetting of its surface by the molten filler metal and the development of

Table 5A
Chemical Composition
Rods and Electrodes for Braze Welding Iron Castings

AWS Specifi- cation	AWS Specifi- cation	Cu	Zn	Sn	Fe	Ni	Mn	Al	Si	Pb	P	Total Other
A5.27	RBCuZn-A	57.0– 61.0	Bal.	0.25– 1.00	—	—	—	0.01	0.04– 0.15	0.05	—	0.50
A5.27	RBCuZn-B	56.0– 60.0	Bal.	0.80– 1.10	0.25– 1.2	0.20– 0.80	0.01– 0.50	0.01	0.04– 0.15	0.05	—	0.50
A5.27	RBCuZn-C	56.0– 60.0	Bal.	0.80– 1.10	0.25– 1.2	—	0.01– 0.50	0.01	0.04– 0.15	0.05	—	0.50
A5.27	RBCuZn-D	46.0– 50.0	Bal.	—	—	9.0– 11.0	—	0.01	0.04– 0.25	0.05	0.25	0.50

Table 5B
Properties and Applications of Braze Welding Filler Metal

AWS Classification	Room Temperature Tensile Properties Minimum		Liquidus Temperatures		Applications
	Ksi	MPa	°F	°C	
RBCuZn-A	40	275	1650	900	A low fuming bronze used on copper sheet, mild tube steel, deep drawing steel and cast iron (OFW).
RBCuZn-B	50	344	1630	890	Higher strength, used to surface, or braze weld copper, steel, cast iron or wrought iron (OFW).
RBCuZn-C	50	344	1630	890	Better color match with mild steel, cast iron, and wrought iron (OFW).
RBCuZn-D	60	413	1715	935	Nickel silver bronze filler metal providing best strength and color match with cast iron and wrought iron (OFW).

a metallic bond. Since the presence of dirt, oil, grease, oxide film, carbon, and other contaminants will inhibit wetting, cleanliness is important to obtain the wetting necessary for braze welding.

Wetting accomplishes metallic bonding between the braze weld filler metal and the base metal in a narrow zone at the braze weld interface. For some filler metal/base metal combinations, the filler metal may slightly penetrate the grain boundaries of the base metal, affecting strength, corrosion properties, and cracking behavior.

4.3.10 Braze Welding Techniques

4.3.10.1 Fixturing. Fixturing is generally required to hold parts in their proper location and alignment for braze welding. In repairing cracks and other defects in cast iron parts, fixturing may not be necessary, unless the part has separated.

4.3.10.2 Joint Designs and Preparation. Joint designs are similar to those used for fusion welding. Fit is

not as critical as the tolerances required for brazing. The braze welding filler metal is deposited in the grooves where the molten filler metal wets the base metal. For thicknesses over 3/32 in. (2 mm), single- and double-V grooves are prepared with a groove angle between 90 and 120 degrees to provide large weld interface areas between the base metal and the weld metal. Square grooves may be used for a thickness of 3/32 in. (2 mm) or less. In large casting repairs, studs may be inserted into the groove surfaces to increase the groove strength of the repair (Figure 20).

The groove faces and adjacent surfaces of the base metal must be cleaned to remove all oxide, dirt, grease, oil and other foreign material that will inhibit wetting. When braze welding cast iron, the groove faces must also be free of graphite smears caused by prior machining. These graphite smears which have an adverse affect on wetting, can be removed by quickly heating the cast iron to a dull red color with a slightly oxidizing flame and then wire brushing after it cools.

If the casting has been heavily soaked with oil, it must be heated to 700–900°F (370–480°C), to burn off the oil. The surfaces are then wire brushed to remove any residue.

Malleable iron, because of its lower total carbon content and its round graphite nodules, can be readily cleaned by abrasive blasting. Ductile iron, also with round nodules, is more difficult to braze weld because of its higher total carbon content. The graphite flakes in gray cast iron make it the most difficult to braze weld and it requires special surface preparation such as caustic cleaning or decarburization with a slightly oxidizing oxyfuel gas flame.

In production braze welding of cast iron components, the groove faces are usually cleaned by immersion in an electrolytic molten salt bath. This is the most effective method for removing the free graphite present on machined or broken surfaces.

4.3.10.3 Preheating. Preheating depends on the type of cast iron and the size of the part. It may be required to prevent cracking by reducing thermal gradients in large cast iron parts.

Preheating may be local or general, depending upon the size of the part and its thermal conductivity. Preheat temperatures range from 800–900°F (425–480°C) for cast iron. After braze welding is completed, cast iron parts should be covered with heat resistant blankets or vermiculite for slow cooling to room temperature. This will minimize the development of thermally induced stresses in the casting.

4.3.10.4 Flame Adjustment. Braze welding is generally performed with an oxyfuel gas torch. For braze welding of cast irons, a slightly oxidizing flame is required. This is attained by increasing the oxygen/fuel gas ratio until the feather disappears and the cone becomes slightly necked. This type of flame removes the smeared graphite from the cast iron surface, but then is not needed once the surface has been cleaned and wetted.

4.3.10.5 Braze Welding Technique. The joint to be braze welded must be properly aligned and fixtured. Braze welding flux is applied to the preheated filler metal rod (unless flux coated) and also is spread on groove faces of thick joints. Next, the base metal is heated with the flame until the filler metal melts, wets the base metal, and flows onto the groove faces. The groove is filled with one or more passes using techniques similar to oxyfuel gas welding. Note that the cone of an oxyfuel gas flame should not be directed on copper-zinc alloy filler metals nor on iron base metal. Braze welding requires a more diffused heat pattern than welding. The techniques used with arc torches are similar to those described for oxyfuel gas braze welding, except that flux is not generally used.

4.3.10.6 Scope of Process. A wide variety of workpieces can be braze welded with the use of typical weld joint designs. Groove, fillet, and edge welds can be used to join simple and complex assemblies. An effort should be made to avoid sharp corners that are easily overheated and may become points of stress concentrations. Edges should be rounded as shown in Figure 18. To obtain good joint strength, the weld groove should provide adequate groove face area so that the joint will not fail along the weld interfaces.

4.3.10.7 Quality. Braze weld quality will depend on operator skill and technique, and on the care and control exercised during the preparation of the base metal. The strength and soundness of the joint will depend on the filler metal used, cleanliness of the base metal, proper flame adjustment, proper heat input control, and the adequacy of fluxing during braze welding to ensure complete wetting of the base metal. With correct procedures, braze welded joints frequently will be produced that are as strong as the adjacent base metal.

5. Arc Welding Processes

5.1 General. Arc welding may be manual, semi-automatic, or fully automatic. The most widely used processes are shielded metal arc (SMAW), gas metal arc (GMAW), flux cored arc (FCAW), gas tungsten arc (GTAW), and submerged arc (SAW). These processes are described in detail in Volume 2, Seventh Edition, of the *AWS Welding Handbook*.

No single process is the most efficient and economical for every application. Consideration must be given to the specific requirements of the application, the equipment, and personnel available, when choosing a welding process.

5.2 Shielded Metal Arc Welding (SMAW)

5.2.1 Definitions and General Description. Shielded Metal Arc Welding (SMAW) is an arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the workpiece. Shielding is obtained from decomposition of the electrode covering. Pressure is not used, and filler metal is supplied by melting the electrode.

5.2.2 Principles of Operation. Shielded metal arc welding is the most widely used of the various arc welding processes. It employs the heat of the arc to melt the base metal and the tip of a consumable covered electrode. The electrode and the workpiece are part of an electrical circuit known as the welding circuit, as shown in Figure 24. This circuit begins with the electric power source and includes the welding leads, an electrode

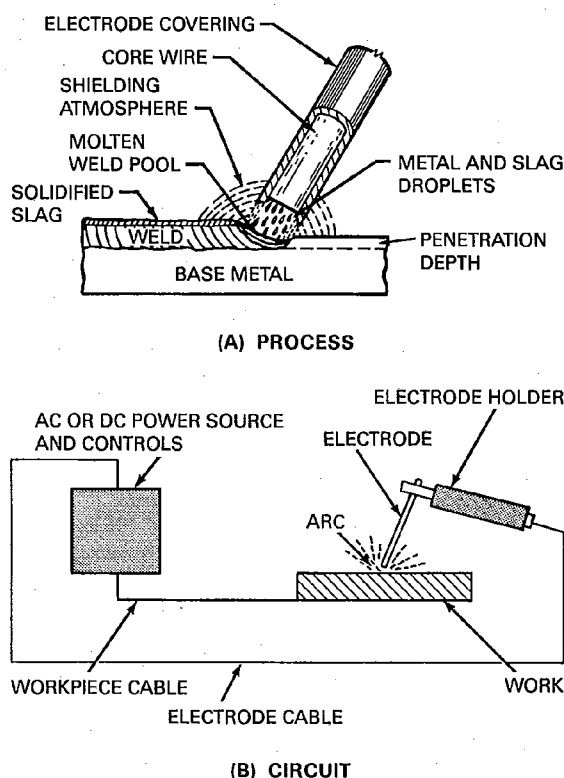


Figure 24 — Elements of a Typical Welding Circuit for Shielded Metal Arc Welding

holder, the workpiece, and an arc welding electrode. One of the two leads from the power source is attached to the workpiece. The other is attached to the electrode holder.

Welding commences when an electric arc is struck between the tip of the electrode and the workpiece. The intense heat of the arc melts the tip of the electrode and the surface of the workpiece beneath the arc. Globules of molten metal rapidly form on the tip of the electrode, then transfer through the arc stream into the weld pool.¹ In this manner, filler metal is deposited as the electrode is progressively consumed. The arc is moved over the work holding an appropriate arc length and travel speed, melting a portion of the base metal and adding filler metal as the arc progresses.

Since the arc is one of the hottest of the commercial sources of heat [temperatures above 9000°F (5000°C) have been measured at its center], melting takes place almost instantaneously, as the arc contacts the metal. If welds are made in either the flat or the horizontal posi-

tion, metal transfer is induced by the force of gravity, gas expansion, electric and electromagnetic forces, and surface tension. For welds in other positions, gravity works against the other forces.

The process requires sufficient heat input to melt both the electrode and a proper amount of base metal. It also requires an appropriate arc length between the tip of the electrode and the base metal or the weld pool.

5.2.3 Welding Equipment. The size and types of electrodes for shielded metal arc welding define the equipment. Any power source capable of supplying the necessary range, type, and polarity of current, and having a suitable open circuit voltage, may be used. The current may be either alternating or direct, but the power source must be able to control the level of current within a reasonable range in order to respond to the requirements of the welding process itself. The user should follow the electrode manufacturer's recommendations for type of current and polarity.

5.2.4 Filler Metals for Shielded Metal Arc Welding. The versatility and ease of operation make SMAW an excellent choice for most cast iron welding. Economic

1. Metal transfer across the welding arc is described in AWS *Welding Handbook*, Chapter 2, Physics of Welding, Vol. 1, 8th Ed., pp. 50–54.

considerations and weld requirements will determine the appropriate electrode for each application.

5.2.4.1 Cast Iron Electrodes. Cast iron rods are covered with fluxes to improve arc stability, reduce porosity, and add alloying elements. The covering normally is applied by dipping rather than extrusion, due to the irregular surface of the cast iron rods. Such electrodes are classified in ANSI/AWS A5.15-82 as ECI (see Table 6). They are of low comparative cost and produce a weld of similar chemical composition, mechanical properties, microstructure and matching color. As with the bare cast iron rods, appropriate procedures must be closely followed to assure weld quality.

5.2.4.2 Steel Electrodes. ESt (Steel) Classification (see Table 6). This covered all-position electrode with carbon steel core wire is designed specifically for the welding of cast iron. It has a low melting-point covering and differs from the ordinary mild steel electrodes included in ANSI/AWS A5.1-81, *Specification for Covered Carbon Steel Arc Welding Electrodes*. Welds made with this electrode are not readily machineable.

Since it is virtually impossible to prevent the formation of a hard weld metal with low ductility using this type of electrode, its use is largely confined to the repair

of small pits and cracks, with some application in the repair of castings that require no machining. Since the shrinkage of steel is greater than that of cast iron, high tensile stresses develop as the weld metal cools. Stress may be severe enough to cause cracking.

For most repair jobs, the groove preparation is the same as described previously. However, the formation of a hard weld metal of low ductility and the possibility of cracking make it generally advisable in welding any sizable casting to employ studs which key the weld to the unaffected base metal below the weld interface, as shown in Figure 20.

Preheating is employed only when necessary to prevent excessive stresses in other parts of the casting. ESt electrodes generally are used at low current to minimize dilution and consequent weld metal and base metal cracking. Recommended welding currents are 60 to 95 A for 3/32 in. (2.4 mm), 80 to 110 A for 1/8 in. (3.2 mm), and 110 to 150 A for 5/32 in. (4.0 mm) diameter electrodes using DCEP (electrode positive) or AC. The beads should be short and widely separated, to distribute the heat, and each bead should be peened lightly.

The slag volume is low but very alkaline; therefore, slag should be removed completely if the weld area is to be painted.

Table 6
Chemical Composition of Filler Metals, Percent^{2,3c}

AWS Classification	C	Mn	Si	P	S	Fe	Ni ^{3a}	Cu ^{3b}	Al	Total Other Elements
Nickel Base Electrodes										
ENi-CI	2.0	1.0	4.0	—	0.03	8.0	85 min	2.5	1.0	1.0
ENi-CI-A	2.0	1.0	4.0	—	0.03	8.0	85 min	2.5	1.0-3.0	1.0
ENi-Fe-CI	2.0	1.0	4.0	—	0.03	remainder	45-60	2.5	1.0	1.0
ENiFe-CI-A	2.0	1.0	4.0	—	0.03	remainder	45-60	2.5	1.0-3.0	1.0
ENiCu-A	0.35-0.55	2.3	0.75	—	0.025	3.0-6.0	50-60	35-45	—	1.0
ENiCu-B	0.35-0.55	2.3	0.75	—	0.025	3.0-6.0	60-70	25-35	—	1.0
Mild Steel Electrodes										
ESt	0.15	0.30-0.60	0.03	0.04	0.04	remainder	—	—	—	—

Notes:

- Analysis shall be made for the elements for which specific values are shown in this Table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "Total Other Elements" in the last column of this Table.
- Single values shown are maximum percentages except where otherwise specified.
- Excerpted from A5.15-82.
 - Nickel plus incidental cobalt.
 - Copper plus incidental silver.
 - Chemical composition requirements for the Electrodes are based on weld metal analysis.

The hardness of the ESt weld metal depends to a great extent upon the amount of dilution, which can be controlled within reasonable limits during welding. Small single beads have high dilution and may have a hardness as high as 500 BHN. Moderately heavy beads, when the dilution is reduced by directing the arc on the weld pool, and later beads of multiple-pass welds, have lower hardness.

Low Hydrogen Electrodes. The low-hydrogen electrodes classified in ANSI/AWS A5.1-87 as E7015, E7016, E7018, E7028, and E7048 are sometimes used for welding cast iron. These electrodes are low in cost, readily available, and offer excellent operability. Color match of the weld metal and base metal is good. When these welding electrodes are used on cast iron, the resulting weld metal will contain 0.8 to 1.5 percent carbon. The weld metal, therefore, will be high carbon steel exhibiting high hardenability. Rapid cooling rate of a weld frequently produces weld metal with a hard, crack sensitive, martensitic microstructure. This condition may be minimized by preheat and slow cooling, or postweld annealing. These electrodes are used most often for cosmetic repair in nonstructural areas and where machining is not necessary and cracking is not a major concern.

5.2.4.3 Stainless Steel Electrodes. Stainless steel electrodes are not recommended for welding cast iron because: (1) precipitation of chromium carbides in grain boundaries results in a crack-prone, brittle microstructure, (2) heat affected zone cracking due to differences in tensile strength between the weld and base metal, and (3) the difference in coefficient of expansion of the dissimilar metals can result in tensile stresses of such magnitude that welds may crack.

5.2.4.4 Nickel Base Electrodes. Electrodes which contain substantial amounts of nickel are used successfully to weld iron castings. Unlike iron, nickel does not form stable carbides and, in the solid state, has a low solubility for carbon. As the weld metal solidifies and cools, carbon is rejected from solution as graphite. This reaction increases the volume of the weld metal, thus reducing shrinkage stresses and lessening the likelihood of weld metal and heat affected zone cracking. Compositions of nickel-base electrodes commonly used to weld iron castings are shown in Table 6.

ENi-CI Electrodes. Electrodes classified by ANSI/AWS A5.15-82 as ENi-CI produce a high nickel weld metal. Thus, even when highly diluted by the cast iron base metal, the weld remains soft and machineable. For this reason, the ENi-CI electrodes are used for surfacing or highly diluted welds which must be machined. Electrodes depositing filler metal that contains more than one percent of aluminum are classified as ENiCI-A.

ENiFe-CI Electrodes. ANSI/AWS A5.15 ENiFe-CI and ENiFe-CI-A electrodes deposit filler metal of approximately equal amounts of nickel and iron. This composition differs from that of the ENi-CI and ENiCI-A electrodes in three important ways.

Welds made with nickel-iron alloy are stronger and more ductile than welds made with essentially pure nickel. Typical mechanical properties are presented in Table 7. The strength of the nickel-iron electrode makes it suitable for welding ductile irons and the high-strength gray irons. The electrode is also used for dissimilar joints such as cast iron containing chromium to carbon steel, stainless steel, and nickel-base alloys. Some chromium containing alloys may require buttering with ANSI/AWS A5.11-83, *Specification for Nickel and Nickel Alloy Covered Welding Electrodes*, ENi-1 electrodes before making the weld. This is to avoid chromium-carbide formation.

Phosphorous is known to cause cracking in high nickel weld metal. The presence of iron in the weld metal increases the tolerance to phosphorous. Thus, these electrodes have been used with some success for welding the higher phosphorous gray cast irons.

The coefficient of expansion of nickel-iron alloys is minimum at a chemical composition of about 30 percent nickel and 70 percent iron. When the ENiFe-CI or ENiFe-CI-A electrodes are deposited on cast iron, composition of the resulting weld metal approximates this 30-70 iron-nickel composition. This low expansion allows these electrodes to be used for welding thicker base metal than is possible with ENi-CI or ENiCI-A electrodes.

When highly diluted, as in a single pass weld, hardness of the nickel-iron weld metal is considerably higher than that of ENi-CI or ENiCI-A electrodes. Thus, if weld machineability is a critical factor, ENi-CI or ENiCI-A electrodes are preferred. In multipass welds, each bead is tempered by the heat of subsequent passes, thus improving machinability. Typical values of weld metal hardness are presented in Table 8.

Nickel-Iron-Manganese Electrodes. The addition of manganese to the nickel-iron alloy commonly used to weld iron castings improves fusion with the base metal, strength, ductility and resistance to cracking. An electrode depositing about 12 percent manganese, 44 percent nickel, and the balance iron is commercially available. The strength of the weld metal is sufficient for joining nodular irons up to the 80-55-06 grades. It is also applicable to surfacing or buildup when improved wear resistance is required.

Since the electrode is patented and proprietary, it is not included in an AWS specification. The supplier should be directly consulted for usage information and welding parameters.

Table 7
Typical Mechanical Properties of All-weld-metal

Electrode	Tensile Strength		Yield Strength 0.2% Offset		Elongation
	ksi	MPa	ksi	MPa	Percent in 2 in.
ENi-CI ^a	40	276	38	263	3-6
ENiFe-CI ^a	58-84	397-579	43-63	296-434	6-13
ENiFe-CI ^b	65-72	449-500	45-52	310-358	8-19
ENiFe-CI ^c	79	544	61-67	420-462	6-10

a. As-welded condition.

b. Annealed at 1650°F (898°C) for 4 hours, furnace cooled.

c. Annealed at 1550-1650°F (845-890°C) for 3 hours, furnace cooled to 1275°F (690°C) for 5 hours, furnace cooled slowly to 1100°F (590°C), air cool.

Table 8
Weld Metal Hardness

Type of Weld Metal	Electrode			
	ENi-CI		ENiFe-CI	
	VHN	BHN	VHN	BHN
Highly diluted bead	220	209	364	345
Moderately diluted bead	182	173	209	199
Multiple layer weld*				
Weld face	—	—	183	174
Root surface	—	—	187	174

*Butt joint of 1/2 in. (12.7 mm) plate using 60 degree V and 3/16 in. (4.8 mm) root opening.

ENiCu-A and -B Electrodes. Nickel-copper electrodes are also used for welding iron castings. They are low penetration in nature since heavy dilution by the base metal may cause weld cracking. Because of this sensitivity to iron dilution, the electrodes have only limited usage.

5.2.4.5 Copper-Base Electrodes. Copper-base electrodes are mainly employed in surfacing applications on cast iron for bearing surfaces, corrosion, or wear resistance, or for joining cast iron to dissimilar metals.

While base metal cleanliness is essential for all successful cast iron welding, extra precautions are essential when welding with copper-base electrodes.

Four covered bronze welding electrodes used for welding cast irons are included in ANSI/AWS A5.6-84, *Specification for Covered Copper and Copper Alloy Arc Welding Electrodes*, and are classified as ECuSn-A, ECuSn-C, ECuAl-A2 and ECuMnNiA1. The coverings on these electrodes, developed for welding the copper alloys, perform satisfactorily on cast iron. Chemical

composition and mechanical property requirements are listed in Table 9.

ECuSn-A and ECuSn-C Electrodes (Tin-Bronze). These electrodes are also called phosphor-bronze types, due to residual phosphorous used for deoxidizing the molten metal during manufacture. Tin-bronze electrodes have a tendency to flow sluggishly, requiring preheat and interpass temperatures of at least 400°F (205°C) on thick base metal. Moisture, both on the workpiece and in the electrode coverings, must be strictly avoided. Baking electrodes at 250 to 300°F (120 to 150°C) may be necessary.

ECuSn-C electrodes have a higher tin content than ECuSn-A electrodes resulting in weld metal with higher hardness, tensile strength, and yield strength. Hardness for weld metal specimens made with the ECuSn-C electrodes range from 85-100 BHN compared to 70-85 BHN for the ECuSn-A electrodes.

ECuAl-A2 Electrodes (Aluminum Bronze). The ECuAl-A2 aluminum bronze electrodes produce weld metal with higher tensile strength, 60 ksi (410 MPa) min.

Table 9
Chemical Composition and Mechanical Property Requirements
for Covered Copper-Alloy Welding Electrodes

(A) Chemical Composition Requirements for Deposited Weld Metal, Percent³

AWS Classification	Cu including Ag	Zn	Sn	Mn	Fe	Si	Ni ⁴	P	Al	Pb	Ti	Total Other Elements ⁵
ECuSn-A	Remainder	c	4.0 to 6.0	c	0.25	c	c	0.05 to 0.35	0.01	0.02 ⁶	—	0.50
ECuSn-C	Remainder	c	7.0 to 9.0	c	0.25	c	c	0.05 to 0.35	0.01	0.02 ⁶	—	0.50
ECuAl-A2	Remainder	c	c	c	0.5 to 5.0	1.0	c	—	7.0 to 9.0	0.02 ⁶	—	0.60
ECuMnNiAl	Remainder	c	c	11.0 to 13.0	2.0 to 6.0	1.5	1.0 to 2.5	—	5.5 to 7.5	0.02 ⁶	—	0.60

(B) Mechanical Property Requirements

AWS Classification	Hardness bhn	Tensile strength, min		Percent Minimum Elongation in 2 in. (50 mm)
		ksi	MPa	
ECuSn-A	70–85 (500 kg load)	35	240	20
ECuSn-C	85–100 (500 kg load)	40	280	20
ECuAl-A2	130–150 (3000 kg load)	60	410	20
ECuMnNiAl	160–200 (3000 kg load)	75	520	15

Notes:

1. Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "total other elements" in the last column in the table.
2. Single values shown are maximum percentages, except where otherwise specified.
3. Excerpted from A5.6.
4. Includes cobalt.
5. Total other elements shall not exceed the value specified.
6. These elements must be included in determining the value for total other elements.

and hardness, 130–150 BHN, compared to the tin-bronze electrodes. As with the tin-bronze electrodes, good preparation of the cast iron base metal by cleaning and removal of surface oxidation and contamination is essential to prevent porous welds with inadequate strength.

ECuMnNiAl Electrodes (Manganese-Nickel-Aluminum-Bronze). Another aluminum-bronze electrode classification listed in Table 9 has been used for repairing iron casting where even higher strength weld metal is desired. These electrodes contain lower aluminum but higher iron with manganese and nickel additions com-

pared to the ECuAl-A2 electrode. This results in weld metal with higher tensile strength 75 ksi (520 MPa) and hardness of 160–200 BHN.

5.3 Gas Metal Arc Welding (GMAW)

5.3.1 Definition and General Description. Gas metal arc welding (GMAW) is an arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the workpieces. Shielding is obtained entirely from an externally supplied gas.

By varying the arc voltage and wire feed speed and in some cases the shielding gas, the process may be varied to produce high deposition, high heat input, deep penetration welds, or altered to produce welds with minimal penetration or minimal heat input such as might be used in the horizontal, vertical, or overhead positions.

Transfer of the molten filler metal across the arc may take place in any of three modes: spray, globular, and short-circuiting. Heat input and shielding gas determine the mode of transfer.

Spray transfer takes place at the highest heat input of the three modes using argon, helium, or mixtures of the two gases. This mode of transfer produces the highest deposition rates with GMAW. It is also the most likely to cause weld metal cracking and produces the widest heat affected zone. Filler metals up to 0.062 in. (1.6 mm) diameter are used with this process. Penetration is deep. Use of this mode is limited to the flat position.

At a somewhat lower heat input, the mode is globular with metal transfer taking place in large droplets. While the deposition rate is somewhat less than spray transfer, the likelihood of cracking is also decreased. Because of the lower heat input, penetration is less. Lower penetration reduces the amount of base metal melting and weld metal dilution. Care must be taken to avoid lack of joint penetration and incomplete fusion defects. This mode of transfer may be used in all positions, though use in the vertical and overhead positions is more difficult and requires a high degree of welder skill.

At still lower heat input, the welding wire actually touches the weld pool and produces a short circuit during which transfer occurs. This mode of transfer occurs at the least heat input of the GMAW processes. Shielding gases may be argon, helium, carbon dioxide, or mixtures. This mode of transfer produces the least penetration and the narrowest HAZ, but care must be taken to avoid incomplete fusion or incomplete joint penetration defects.

The choice of transfer mode will be determined by the base metal being welded, the complexity of the weldment or casting, the deposition rate required, and the weld position. However, in general, lower heat input processes are favored due to their lower penetration, base metal melting, and process severity. Minimizing dilution of the weld metal by the base material will minimize the tendency toward weld cracking. Spray transfer is generally used only for producing simple, low stress welds in the low strength, high ductility grades of ductile iron such as 60-40-18 and 60-45-12. The smaller diameter wires with the lower heat input modes of transfer may be used for most cast iron welding applications.

5.3.2 Principles of Operation. The operation of the gas metal arc system is illustrated in Figure 25. A contin-

uous wire electrode (filler metal) is fed through a gas shrouded contact tube to the workpiece. The high intensity arc between the electrode and the workpiece melts the filler metal and base metal creating the weld metal. A more thorough discussion of the process is found in Chapter 4, "Gas Metal Arc Welding" of Volume Two of the Seventh Edition of the *Welding Handbook*.

5.3.3 Welding Equipment. Gas metal arc welding equipment consists of a welding gun, a wire-drive system, a power source and a shielding gas supply and regulation system. In some cases, a cooling system may be required for the welding gun. A typical GMA system is seen in Figure 26. Constant voltage power sources are most commonly used for welding cast iron.

5.3.4 Filler Metals for GMAW

5.3.4.1 Steel Electrodes. Some of the carbon and low alloy bare steel electrodes (filler metals) used to weld low carbon steels may be used to weld cast iron. A typical application is the repair of casting defects in noncritical areas of the casting which will not be machined. The color match of the weld with the base metal is excellent, and as the weld rusts it may become nearly indiscernible. Since the weld will be hard due to absorption of carbon from the base metal, bare steel electrodes should not be used to weld areas of a casting which will be machined. The hardness of the weld may be minimized by reducing its cooling rate and minimizing the weld metal dilution. Thus, areas to be welded should be preheated, and low penetration procedures are favored. The short circuiting

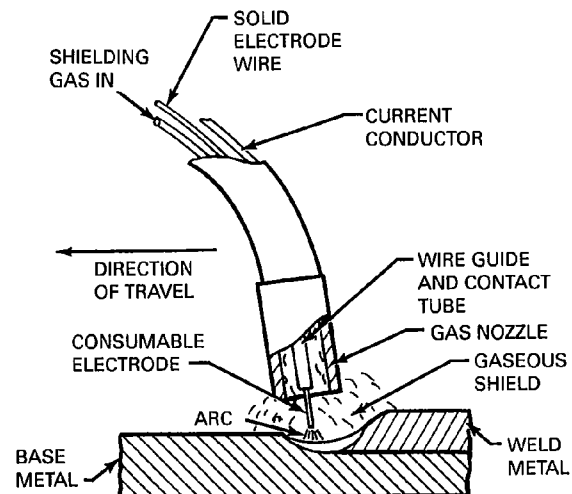


Figure 25 — Gas Metal Arc Welding Process

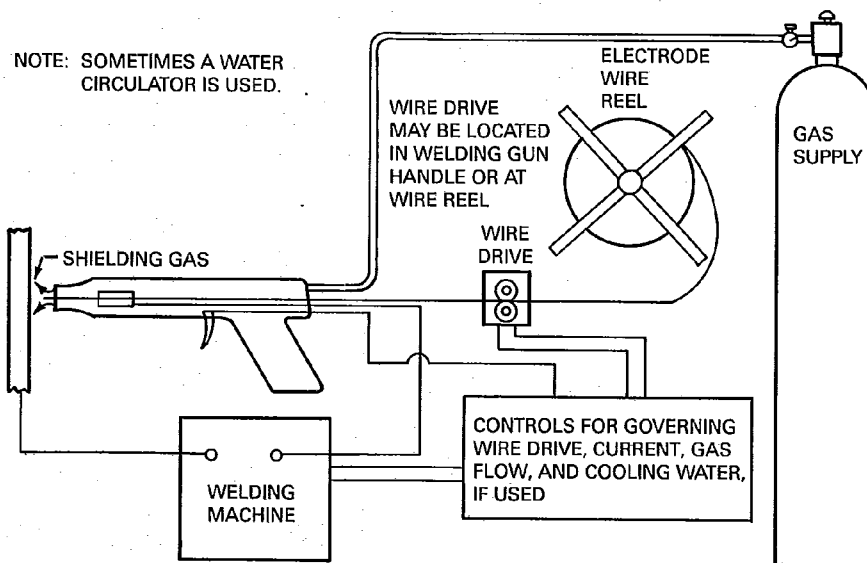


Figure 26 — Gas Metal Arc Welding Equipment

arc transfer is preferred, using small diameter electrodes and carbon dioxide, or a 75 percent argon, 25 percent carbon dioxide mixture as the shielding gas.

Electrode compositions containing significant quantities of deoxidizers are commonly used. Typically A5.18, Classes ER70S-3 and ER70S-6, are used.

5.3.4.2 Nickel Base Electrodes. Bare electrodes containing substantial amounts of nickel are successfully used to weld cast iron for the same reasons cited in section 5.2.4.4 of this document.

Nickel. Electrodes containing over 95 percent nickel are used to weld cast iron when a highly diluted weld must be machined. The most common is essentially a pure nickel (99+ percent) electrode containing no deoxidizers (UNS N02200). Weld hardness is typically 70-80 Rockwell B. ANSI/AWS A5.14-83 Class ERNi-1 is sometimes used; however, this class contains about 4 percent titanium for deoxidation. When carbon from the casting is absorbed into the weld, titanium carbide particles are formed, which may increase the hardness of the weld to 95 Rockwell B.

Nickel-Iron. Electrodes containing near equal amounts of nickel and iron have been used to weld cast iron. However, these products are somewhat more crack sensitive than the higher nickel products. They also tend to be quite hard when highly diluted and, thus, have not gained wide acceptance.

Nickel-Iron-Manganese. The addition of manganese to the nickel iron system greatly increases the crack

resistance and strength of the deposit making it suitable for welding iron castings, especially the higher strength grades of ductile iron such as 65-45-12 or 80-55-06. The fusion of the weld metal and base metal is improved, and operator appeal is good. The hardness of typical weld deposits is 80-95 Rockwell B. The composition of this wire is similar to the electrode described in 5.2.4.4, (12 percent manganese, 44 percent nickel, balance iron).

Welding Conditions. Recommended variables for gas metal arc welding with bare nickel base electrodes are presented in Table 10. These values are presented as a starting point on the development of a procedure.

5.3.4.3 Copper Base Electrodes. Bare electrodes containing significant amounts of copper may be used to join or surface cast iron. The electrodes are classified as ERCuSn-A, ERCuAl-A2, and ERCuMnNiAl in ANSI/AWS A5.7-84, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes*. Refer to paragraph 5.2.4.5 for information on selection and application of these alloys.

Chemical compositions of these alloys are given in Table 11A, and minimum mechanical properties of the weld metal are listed in Table 11B. Typical welding variables for the GMAW process are given in Table 11C.

5.4 Flux Cored Arc Welding (FCAW)

5.4.1 Definitions and General Description. Flux cored arc welding (FCAW), is an arc welding process that produces coalescence of metals by heating them

Table 10
Gas Metal Arc Welding Variables
for Nickel-Base Electrodes

Electrode Diameter	Shielding Gas	Wire Feed Speed		Arc Voltage (Volts)	Current DCEP (Amperes)	Electrode Extension		Travel Speed	
		in./min	(mm/s)			in.	(mm)	in./min	(mm/s)
0.035 (0.9)	75/25 Ar/CO ₂	300	(130)	24	130	1/2	(13)	15	(6.5)
		400	(170)	25	160	1/2	(13)	15	(6.5)
		500	(210)	27	200	1/2	(13)	15	(6.5)
	CO ₂	300	(130)	24	125	1/2	(13)	15	(6.5)
		400	(170)	25	155	1/2	(13)	15	(6.5)
		500	(210)	26	180	1/2	(13)	15	(6.5)
		575	(245)	27	200	1/2	(13)	15	(6.5)
	Argon	300	(130)	26	150	1/2	(13)	15	(6.5)
		400	(170)	27	190	1/2	(13)	15	(6.5)
		500	(210)	28	220*	1/2	(13)	15	(6.5)
		575	(245)	29	250*	1/2	(13)	15	(6.5)
	75/25 Ar/CO ₂	250	(105)	27	180	5/8	(16)	15	(6.5)
		300	(130)	28	190	5/8	(16)	15	(6.5)
		350	(150)	29	220	5/8	(16)	17	(7.0)
		400	(170)	30	240	5/8	(16)	20	(8.5)
		500	(210)	32	280	5/8	(16)	25	(10.5)
	CO ₂	250	(105)	26	165	5/8	(16)	15	(6.5)
		300	(130)	27	180	5/8	(16)	15	(6.5)
		350	(150)	28	220	5/8	(16)	17	(7.0)
		400	(170)	29	230	5/8	(16)	20	(8.5)
		500	(210)	31	270	5/8	(16)	25	(10.5)
	Argon	250	(105)	27	190	5/8	(16)	15	(6.5)
		300	(130)	28	220	5/8	(16)	15	(6.5)
		350	(150)	29	240*	5/8	(16)	17	(7.0)
		400	(170)	30	275*	5/8	(16)	20	(8.5)
		500	(210)	32	310*	5/8	(16)	25	(10.5)
0.062 (1.6)	75/25 Ar/CO ₂	150	(65)	27	235	5/8	(16)	17	(7.0)
		175	(75)	28	235	5/8	(16)	17	(7.0)
		200	(85)	29	285	5/8	(16)	20	(8.5)
		225	(95)	30	320	5/8	(16)	25	(10.5)
	CO ₂	150	(65)	27	220	5/8	(16)	17	(7.0)
		175	(75)	28	245	5/8	(16)	17	(7.0)
		200	(85)	29	265	5/8	(16)	20	(8.5)
		225	(95)	30	285	5/8	(16)	25	(10.5)
	Argon	150	(65)	27	240	5/8	(16)	17	(7.0)
		175	(75)	28	265	5/8	(16)	17	(7.0)
		200	(85)	29	300*	5/8	(16)	20	(8.5)
		225	(95)	30	350*	5/8	(16)	25	(10.5)

*Spray Transfer

Table 11A
Chemical Composition Requirements for Bare Filler Metal

AWS Classification	Cu Including Ag	Zn	Sn	Mn	Fe	Si	Ni Including Co	P	Al	Pb	Total Other Elements ³
ECuSn-A	93.5 min	*	4.0–6.0	*	*	*	*	0.10–0.35	0.01*	0.02*	0.50
ERCuAl-A2	Remainder	0.02	—	—	1.5	0.10	—	—	9.0–11.0	0.02*	0.50
ERCuMnNiAl	Remainder	0.15	—	11.0–14.0	2.0–4.0	0.10	1.5–3.0	*	7.0–8.5	0.02*	0.50

Notes:

1. Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "Total Other Elements" in the last column in the table.
2. Single values shown are maximum percentages except where otherwise specified.
3. Total other elements, including elements marked with an (*), shall not exceed the value specified.

Table 11B
Mechanical Properties of Weld Metal

AWS Classification	Brinell Hardness	Tensile Strength (min)	
		Psi	MPa
ERCuSn-A	70–85 ^a	35 000	240
ERCuAl-A2	130–150 ^b	60 000	415
ERCuMnNiAl	160–200 ^b	75 000	515

a. 500 Kg load

b. 3000 Kg load

Table 11C
GMAW Welding Parameters*

Wire Diameter	Voltage	Amperes (DCEP)
0.035 in. (0.9 mm)	26–27	100–150
0.045 in. (1.2 mm)	27–28	100–200
1/16 in. (1.6 mm)	29–30	250–350
3/32 in. (2.4 mm)	33–34	400–500

*Shielding gas—100% argon @ 40–50 CFH

with an arc between a continuous filler metal electrode and the work. Shielding is provided by a flux contained within the tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

The core of the electrode contains flux ingredients (slag formers, deoxidizers, and arc stabilizers), metallic additions, or both types of materials. Electrodes may be self-shielding or require shielding gas. Depending on the action of the slag formed, the arc may achieve either deep or shallow penetration. Some electrodes may be used in all positions while others are limited to the flat or horizontal positions.

The FCAW process is quite versatile since a flux is used and it has the advantages of a continuously fed filler metal. The core materials may be varied to adjust weld metal analysis or control freezing rate, as is done with fluxes on electrodes for SMAW. Thus, the process combines the best features of the SMAW and GMAW processes.

5.4.2 Principles of Operation. A schematic of the FCAW system is presented in Figures 27 and 28. As is seen, the operation and equipment are very similar to the GMAW process. The sheathing material of the tubular

electrode supplies the filler metal. Alloying elements or additional metal may be added via the core. A thorough discussion of the process is found in Chapter 5, "Flux Cored Arc Welding" of Volume Two of the *Seventh Edition of the Welding Handbook*.

5.4.3 Welding Equipment. Generally, the same equipment used for GMAW may be applied to FCAW. A typical FCAW system is seen in Figure 29.

5.4.4 Filler Metals for FCAW

5.4.4.1 Steel Electrodes. Because of their low cost and availability, some mild steel flux cored electrodes are used to weld iron castings. As discussed in 5.2.4.2, their use is generally limited to repair welds in noncritical areas.

Flux cored electrodes, ANSI/AWS A5.20-79, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, Classification EXX-T1 and EXX-T2, use rutile slag systems. A spray mode of transfer promotes deep penetration. Pickup of carbon and silicon from the cast iron base material increases the hardenability and lowers the crack resistance of the weld metal.

A T-5 class of flux-cored electrode may be preferred over the T-1 and T-2 types for welding iron castings.

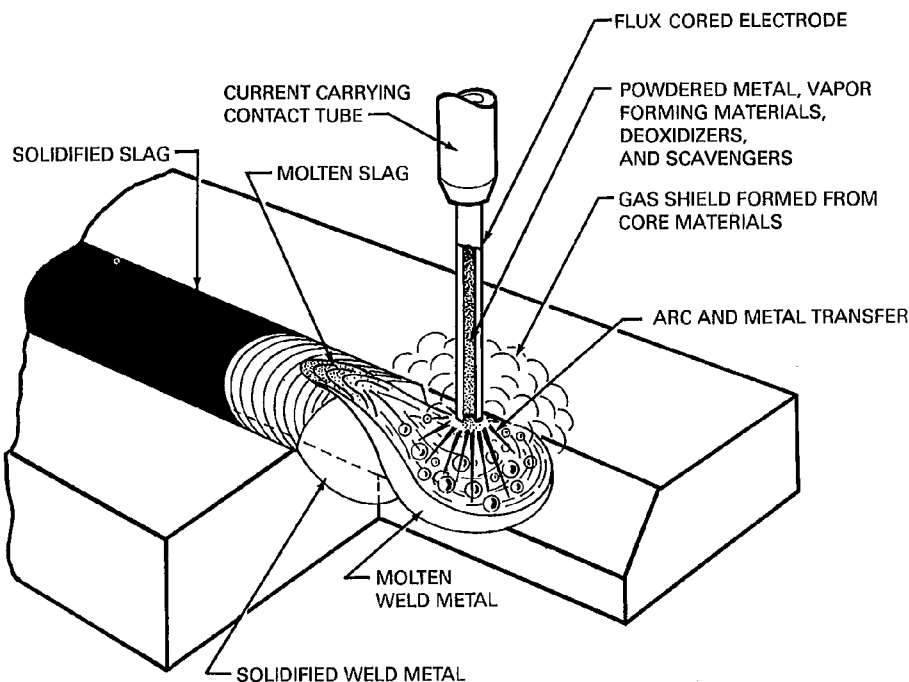


Figure 27 — Self Shielded Flux Cored Arc Welding Processes

Penetration is lower with less dilution from the cast iron. In addition, the basicity of the T-5 flux system makes the weld metal more crack resistant.

Some flux cored electrodes are used in conjunction with carbon dioxide shielding gas. There are also flux cored electrodes with which external shielding is not required. Some of these self shielding types, such as T-4, T-7, and T-8, may be used for welding iron castings.

It must be remembered that welds made on iron castings with any flux cored electrodes will be hardenable carbon steel with relatively little resistance to cracking. The weld metal will be nonmachinable.

5.4.4.2 Iron-Nickel Electrodes. Electrodes of 70 percent iron, 30 percent nickel composition are marketed for the repair of heavy cast iron vessels (such as pouring ladles and molds in foundries and steel plants). Since the major requirement of service is adherence to the vessel wall to fill cavities and maintain contours, the high hardness of the weld metal is not detrimental.

5.4.4.3 Nickel-Iron-Manganese. Flux cored electrodes producing a weld metal composition similar to the ENiFe-CI classification are available for welding iron castings. For added resistance to weld hot cracking the weld metal is enriched with manganese. The composition of a typical weld metal is 1 percent carbon, 5 percent manganese, 40 percent iron, balance nickel.

For the same reasons cited in 5.2.4.4, this filler metal is favored where a high quality weld, exhibiting strength, ductility, and machinability, is required. Nickel-iron-manganese flux cored electrodes have found use in upgrading castings or repair, maintenance, fabrication, surfacing (build-up), and welding dissimilar metals.

Typical welding conditions for nickel iron manganese flux cored electrodes are presented in Table 12.

5.5 Gas Tungsten Arc Welding (GTAW)

5.5.1 General Description of Process. Gas tungsten arc welding (GTAW) is an arc welding process that produces coalescence of metals by heating them with an arc

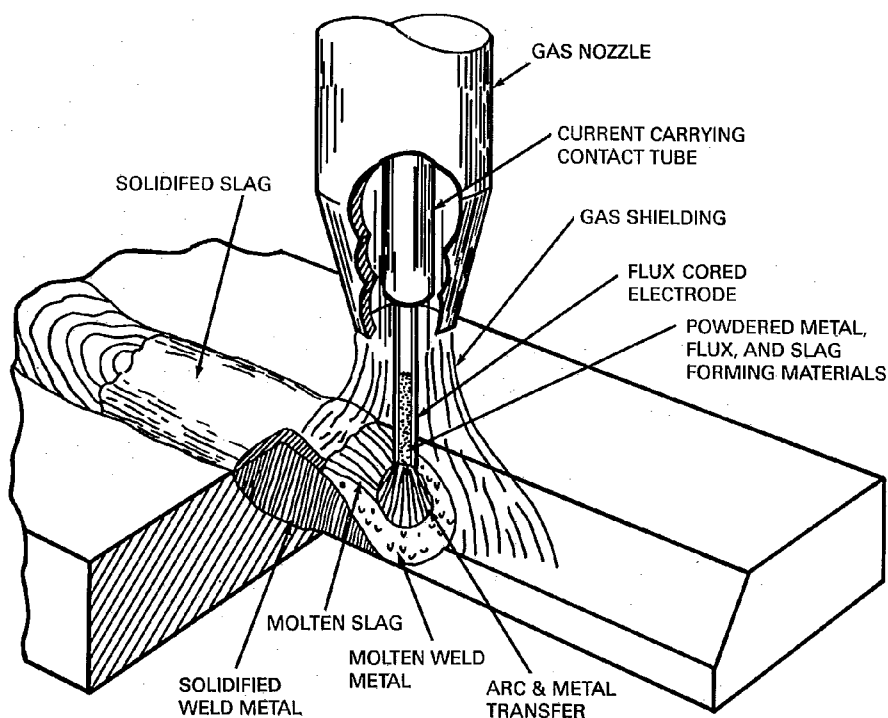
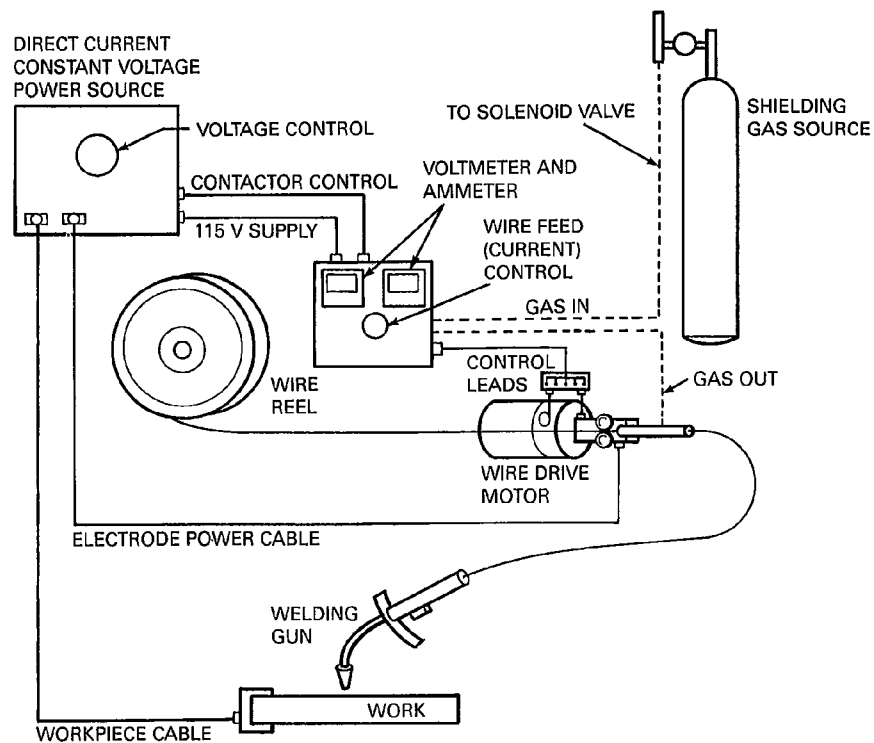


Figure 28 — Gas Shielded Flux Cored Arc Welding Process



NOTE: GAS SHIELDING IS USED ONLY WITH FLUX CORED ELECTRODES THAT REQUIRE IT.

Figure 29 — Flux Cored Arc Welding Equipment

Table 12
Typical Welding Conditions FCAW
Nickel-Iron-Manganese Electrodes

Electrode Diameter		Position or Weld Type	Wire Feed Speed		Current (Amperes/ Polarity)	Voltage (Volts)
in.	(mm)		IPM	(mm/s)		
5/64	(2.0)	flat butt or fillet (1G,F)	240	(101)	300/DCEP	30
5/64	(2.0)	vertical butt or fillet (3G,F)	130	(55)	180/DCEP	18-25
3/32	(2.4)	flat butt or fillet (1G,F)	215	(90)	320/DCEP	32
3/32	(2.4)	flat overlay* — 1st layer	210	(88)	250/DCEN	29-33
		remaining layers	270	(113)	350/DCEP	28-30

*Oscillation recommended — 3/4-1 in. (19-25 mm) width, 26-40 cycles per minute. Overlap previous bead 1/4-3/8 in. (6.4-9.6 mm).

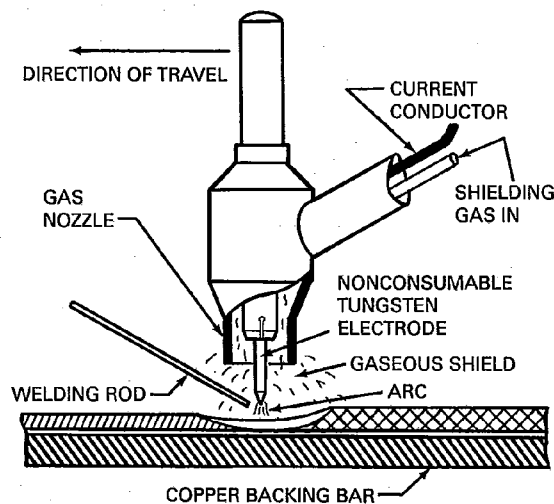
between a tungsten electrode (nonconsumable) and the workpiece. Shielding is obtained from a gas. Pressure may or may not be used, and filler metal may or may not be used. Gas tungsten arc welding is generally done with a single electrode. Shielding of the electrode and weld zone is provided by an inert gas or gas mixture (see Figure 30).

5.5.2 Power Source. The process uses a constant current power source which may be adapted for control of high frequency starting current, gas, and cooling water

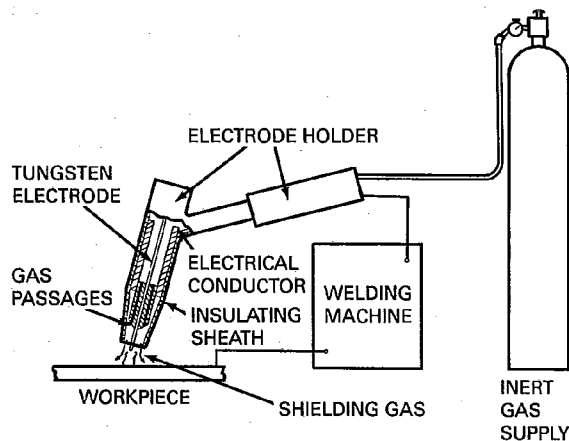
supply. Options include pre and post weld gas flow, and a foot control for variation of welding current.

5.5.3 Welding Torch. The torch is designed to hold the tungsten electrode and allow easy interchange of different sizes. The torch is connected to a conduit carrying power cable, water for cooling, and shielding gas.

5.5.4 Tungsten Electrode. Various sizes of electrode are used for different current ranges, as shown in Table 13.



(A) GAS TUNGSTEN ARC WELDING



NOTE: A WATER-COOLED WELDING TORCH IS USED WHEN COOLING FROM THE INERT GAS SHIELD IS INADEQUATE

(B) GAS TUNGSTEN ARC WELDING EQUIPMENT ARRANGEMENT

Figure 30 — Gas Tungsten Arc Welding and Equipment Arrangement

Table 13
Typical Current Ranges (DCEN)
for Tungsten Electrodes

Electrode diameter		EWTh-1 EWTh-2 A
in.	mm	
0.010	0.3	up to 15
0.020	0.5	5-20
0.040	1.0	15-80
1/16	1.6	70-150
3/32	2.4	150-250
1/8	3.2	250-400
5/32	4.0	400-500
3/16	4.8	500-750
1/4	6.4	750-1000

5.5.5 Procedure. GTAW is used for welding of cast iron using nickel or nickel base filler metal and argon gas for shielding. It is capable of close control of heat input and of the weld pool and is used in applications where those characteristics are important.

Preparation for welding is the same as for other processes. Grease, oil, scale, casting skin, etc. must be removed before welding to prevent weld metal defects. Joint design should be such as to allow manipulation of the torch and retention of shielding gas.

In the GTAW welding of cast iron, the procedures should be those which minimize dilution of the weld deposit by the base metal. (Additional information on the GTAW process can be found in Vol. 2 of the AWS *Welding Handbook*).

5.5.6 Filler Metal. The same bare wires used for GMAW can be used for GTAW, but the wire is usually cut to 36 in. (914 mm) lengths. The most common has been a nickel wire conforming to UNS NO2200. Type ERNi-1, which contains titanium, is not recommended.

5.6 Submerged Arc Welding (SAW)

5.6.1 Definition and General Description. Submerged arc welding (SAW) is an arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the workpieces. The arc and molten metal are shielded by a blanket of granular, fusible material on the workpieces. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

5.6.2 Principles of Operation. A sketch of the SAW system is seen in Figure 31. The operation and equipment are similar to that of the GMAW process except that the flux replaces gas as the shielding medium. The electrode wire is either solid or tubular (powder metal core) and generally becomes the major component of the weld metal. Further alloy additions can be made through

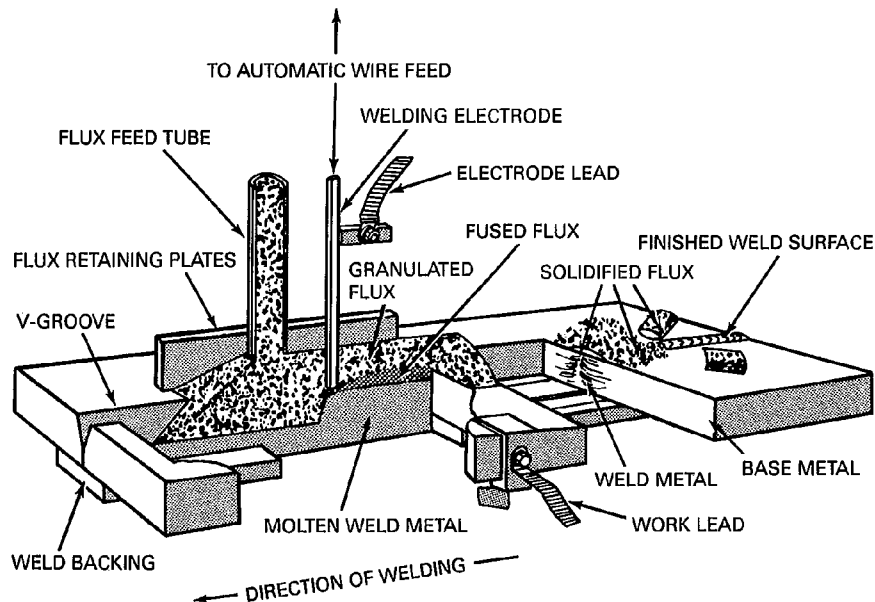


Figure 31 — Automatic Submerged Arc Welding Process

the flux, powdered metals, or with a supplementary welding wire. Upon melting, the flux produces a protective slag which maintains proper weld metal composition, bead shape, and contour.

Submerged arc welding is designed and used for high deposition welding in the flat position. For a more detailed description of the process, see the *AWS Welding Handbook*, Seventh Edition, Vol. 2, Chapter 6.

5.6.3 Welding Equipment. Equipment for SAW is similar to GMAW systems. A power source (usually constant potential type) and wire feed system are necessary. The flux may be added and recovered manually or by an automatic or semiautomatic feed and vacuum system.

5.6.4 Filler Metals and Fluxes for SAW. While in theory any of the previously mentioned types of continuously fed electrodes might be used with the SAW process to join iron castings, the only filler metals in common use are nickel base.

5.6.4.1 Nickel. The nickel electrode used for GMAW may also be used for SAW of iron castings. This electrode is best applied when machinability of a single-pass weld (usually surfacing) is required.

5.6.4.2 Nickel-Iron-Manganese. Nickel-iron-manganese electrodes (either solid or flux cored) are used for general purpose SAW for groove, fillet, or surfacing applications. This filler metal is more resistant to cracking than higher nickel alloys and thus is more widely applied.

5.6.4.3 Flux Selection. The selection of flux for submerged arc welding greatly influences the quality of the weld and thus should be made with the same care as the selection of the filler metal. Since fluxes may be either active or neutral, it is recommended that manufacturers be consulted for matching flux and filler metal combinations.

Welding Variables. Typical conditions for submerged arc welding with nickel-base bare electrodes are presented in Table 14. These variables were developed for

1/16 in. (1.6 mm) diameter electrode with an active flux designed for this application.

6. Surfacing and Overlaying

Surfacing processes are used to buildup undersize or otherwise unserviceable parts due to corrosion, spalling, or wear. Welding and thermal spraying processes are used to restore surfaces or to enhance the surface properties of iron castings.

6.1 Processes. Any welding process used for fabrication, maintenance, or repair welding of iron castings may also be used for surfacing. Thermal spraying processes are successfully used to apply spray deposits of metals and ceramics.

6.1.1 Oxyfuel Gas Welding (OFW). Oxyfuel gas welding (OFW) was first used for buildup and represents a considerable amount of the surfacing work done in the maintenance and repair market. The total heat input to the base metal is generally large, resulting in a wide heat affected zone. Conversely, the cooling rate is slow, thereby reducing the residual stresses and the tendency to form hard martensitic microstructures.

OFW affords good control of the deposited metal size, shape and thickness, requiring less expensive or sophisticated equipment. The principal disadvantage of OFW is the low deposition rate.

6.1.2 Arc Welding. The arc welding processes are the most commonly used methods for surfacing cast iron. SMAW, FCAW, GMAW, PAW, and SAW processes are commercially used. The choice of process depends upon the application, surfacing metal, degree of dilution control, thickness of deposit, and the intended service. The processes and applications are discussed elsewhere in this publication.

6.2 Thermal Spraying. The thermal spraying processes are employed for surfacing to impart wear or corrosion resistant properties, to salvage mismachined parts, and to enhance the service life of a component. The AWS

Table 14
Submerged Arc Welding Recommendations for Nickel-Base Electrodes

Weld Type	Current (Amperes)	Voltage (Volts)	Electrode Extension		Travel Speed		Oscillation		Frequency (Cycles per Minute)
			in.	(mm)	in. per Minute	(mm/sec)	Width in.	(mm)	
Overlay	250	32-34	1	(25)	4-1/2	(2)	1-1/8	(29)	60
Groove/ Fillet	250	32	1	(25)	10	(4.3)	NA		NA

document entitled *Thermal Spraying: Practice, Theory, and Application* provides a detailed description of the various processes, their selection, and application.

6.2.1 Flame Spraying. Flame spraying utilizes the heat from a chemical reaction of oxygen and a fuel gas to melt surfacing material in the form of cord, powder, rod or wire. Compressed air is used to propel the molten particles onto the substrate. The fuel gas is usually acetylene. Propane and commercially produced gases are also used. Bond strengths of 2500 (17 500 kPa) to 6000 psi (42 000 kPa) are achieved depending on the surfacing material used.

The principal variations of the flame spraying process are shown schematically in Figures 32 and 33. Other variations include high energy compressed gas and detonation gun systems. These thermal spray deposits are

claimed to have bond strengths in excess of 10 000 psi (70 000 kPa), in addition to greater density and lower oxide content.

Powder alloys containing boron and silicon may be fused after spraying, thereby forming a homogenous metallurgical structure with the substrate.

6.2.2 Arc Spraying. Arc spraying uses the heat generated by an arc between two electrically conductive wires. Compressed air is used to atomize and propel the molten surfacing metal particles to the substrate surface, as shown in Figure 34. Arc spraying deposition rates are the highest of all the processes. Bond strengths of 5000 to 10 000 psi (35 000 to 70 000 kPa) are common and vary according to the surfacing metal. Its main limitation is that both wires must be electrically conductive.

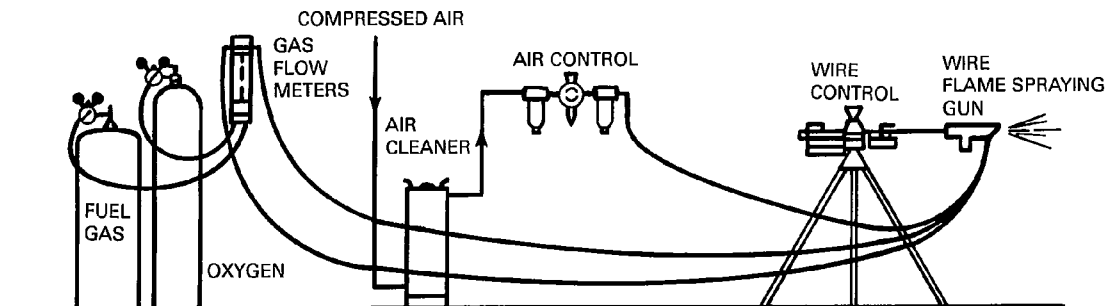


Figure 32A — Typical Wire Flame Spraying Installation Adaptable to Rod and Cord

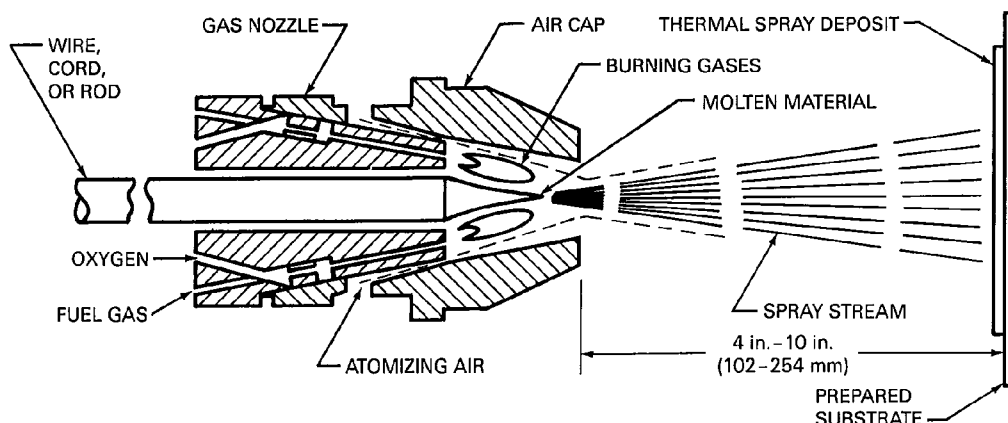


Figure 32B — Cross Section of Typical Wire Rod or Cord Flame Spray Gun

6.2.3 Plasma Spraying. Plasma spraying, shown schematically in Figure 35, consists of a watercooled gun assembly containing a tungsten cathode surrounded by a copper anode nozzle. The arc generated inside the gun between the tungsten and copper electrodes creates a superheated plasma which is forced through the small orifice in the copper nozzle by the flow of an ionized shielding gas.

An outer envelope of inert or mixed carrier gas is added to the stream as it passes out of the gun. The metal or ceramic powders are pressure fed into the gas stream, melted, and propelled to the substrate.

Surface cleanliness is paramount to achieving a good bond between the thermal spray deposit and the substrate. Surface roughening by grit blasting is beneficial and used for all the thermal spraying processes.

6.3 Other Processes. Laser and electron beams are used to melt surfacing material to produce layers of deposited metal. The surfacing material can be in the form of powders, rod, wire, or strip which are fed into the beam. Laser remelting is used on thermal spray deposits when a denser deposit with a metallic bond is required.

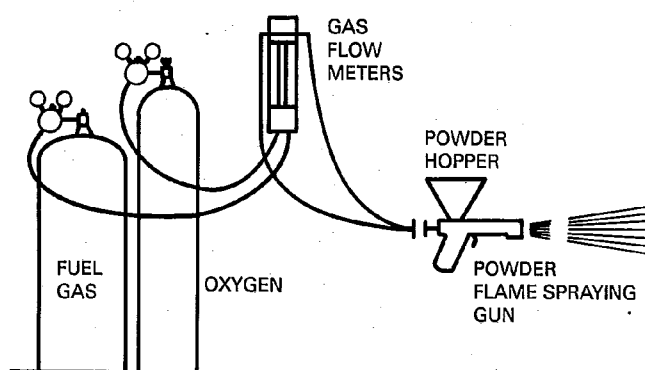


Figure 33A — Typical Installation of a Powder Flame Spray Process

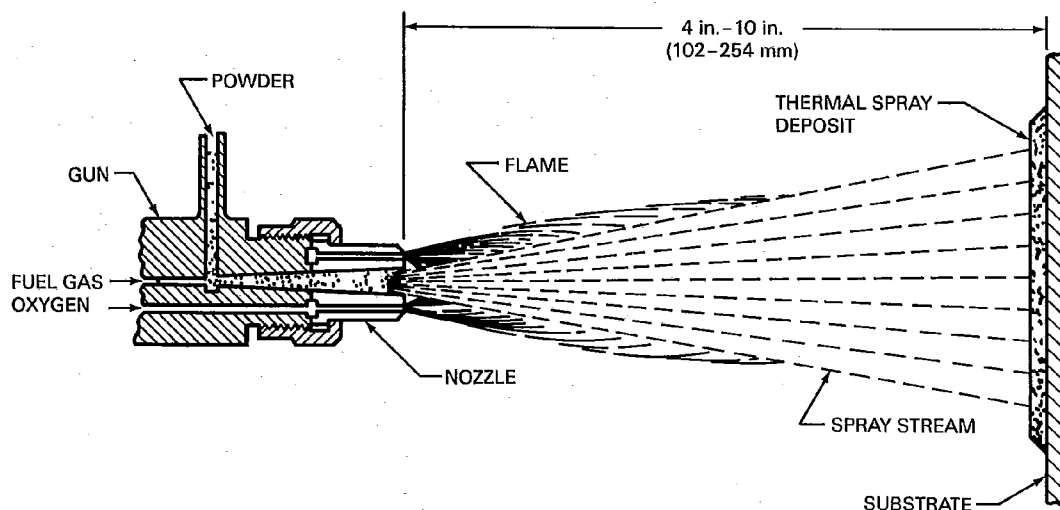


Figure 33B — Cross Section of a Powder Flame Spray Gun

6.4 Surfacing Materials. Any brazing or welding filler metal used to join iron castings may also be used as a surfacing material. Ceramic powders and hardfacing alloys, which are not normally associated with fabrication of iron castings, are gaining wider acceptance.

6.4.1 Copper Alloys. Copper base alloys can be used to clad iron castings to develop a corrosion resistant barrier or to buildup surfaces subject to wear. Filler metal chemical compositions that have good corrosion resistance are included in ANSI/AWS specifications A5.6 and A5.7. Classifications CuSn-A, CuSn-C, CuAl-A2 and CuNiAl are all used for this purpose.

Hardfacing classifications discussed in ANSI/AWS A5.13-80, *Specification for Solid Surfacing Welding Rods and Electrodes*, can be used to build up and hardface wear surfaces. CuAl grades B, C, and D are used for bearing surfaces. It is suggested that, where practical, a "butter layer" of CuAl-A2 be used before applying CuAl grades B, C, and D. If several layers of the harder grades are required, stress relieving at 600°F (315°C) between layers is recommended.

6.4.2 Stainless Steels. Although stainless steels are not recommended for joining cast iron, they are used to improve the corrosion and oxidation resistance of iron castings.

The stainless steels used for weld cladding contain a large volume of ferrite in an austenite matrix. This mixture of microstructures provides resistance to cracking and microcracking. Carbon absorption from the cast iron substrate reduces the volume of ferrite. Overall, with the formation of chromium carbides and reduction of ferrite, the cladding will become more crack sensitive. Carbon absorption will also lower the corrosion resistance of the cladding.

Carbon absorption can be eliminated by first surfacing with a low carbon nickel electrode (99% Ni) before using the stainless steel weld metal. In this case, the stainless steel weld metal will increase in nickel content from dilution, which will lower the volume of ferrite in the weld metal, thereby lowering its resistance to cracking. However, the depletion of chromium as chromium carbides will have been eliminated. Dilution can be minimized by overlapping the beads.

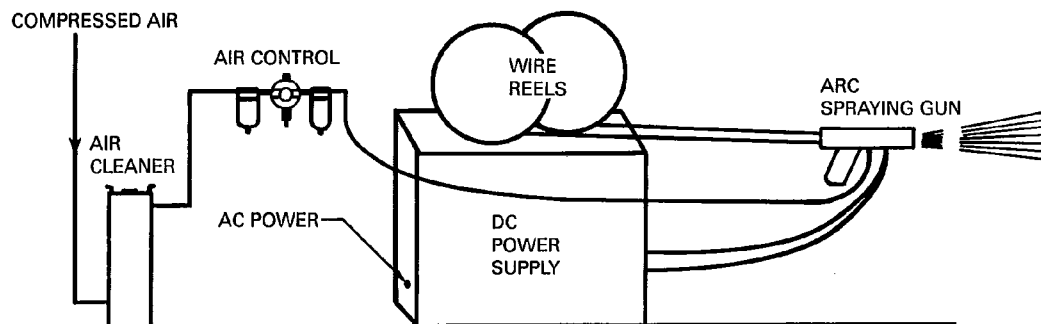


Figure 34A — Arc Spray Components Combined Into a Single Unit

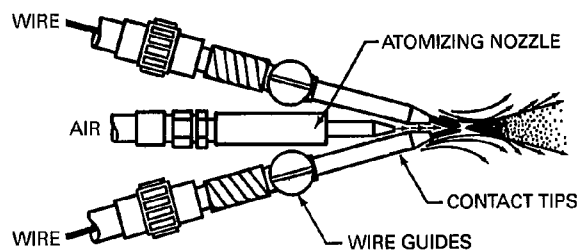


Figure 34B — Cross Section Schematic of an Arc Spray Gun

Another concern in stainless steel cladding on a cast iron substrate is the difference in coefficients of thermal expansion. The stainless steels will contract more than cast iron on cooling, creating significant residual stresses. The cladding may separate away from the substrate on concave surfaces. A convex shaped substrate contributes to a successful weld.

6.4.3 Nickel Alloys. Nickel base alloys are used to correct machining errors, to minimize cracking due to high phosphorus contents, and to deter caustic attack. American Welding Society's A5.15-82 Classifications ENiFe-CI and ENiFe-CI-A electrodes are preferred for

economics and greater tolerance for higher phosphorus contents. Classifications ENi-CI and ENi-CI-A are used when machinability is of prime importance. Other nickel base alloys are included in ANSI/AWS A5.11 and A5.14.

6.4.3.1 Corrosion Resistance. Nickel base alloys are applied for corrosion resistance. They may contain carbide forming elements which can increase the cracking susceptibility when diluted by a cast iron substrate. To achieve good corrosion resistance, dilution of the nickel base alloy by iron and carbon from the cast iron substrate should be minimized. This is accomplished by overlapping beads up to 1/2 the bead width. Stringer

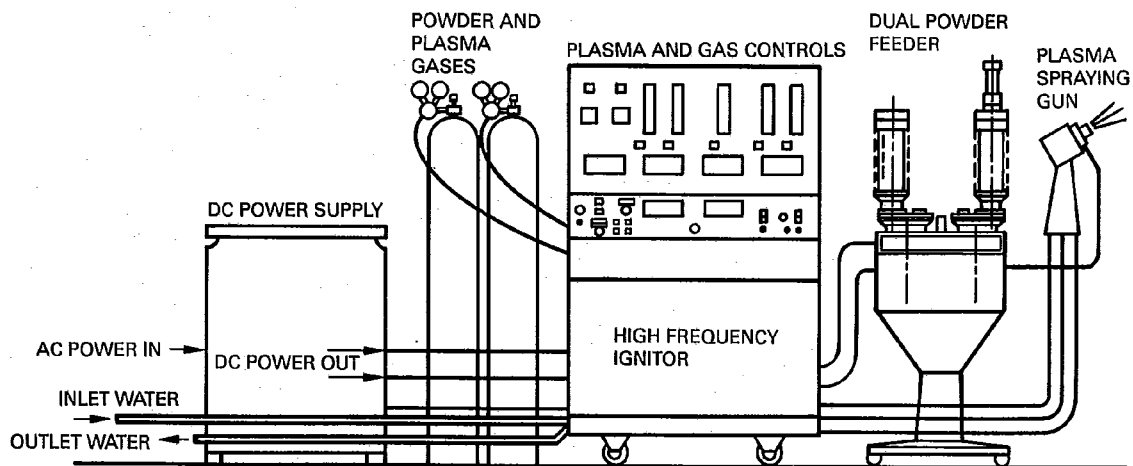


Figure 35A — Complete Installation Plasma Spray System

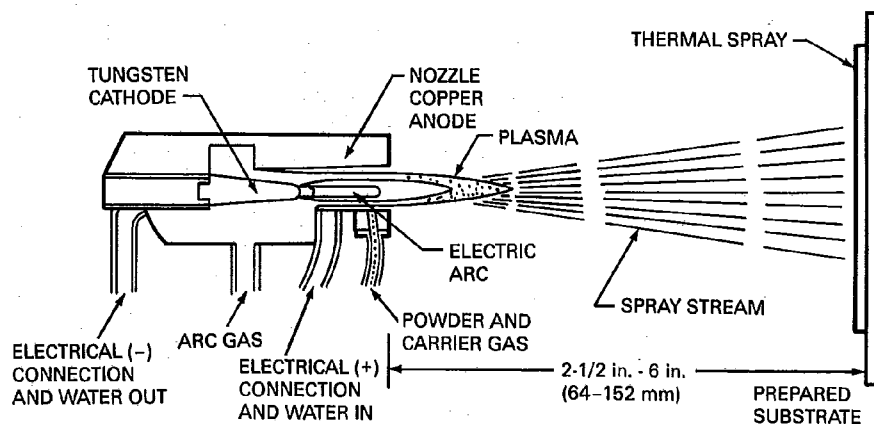


Figure 35B — Sectional View of Plasma Spraying Torch

beads are preferred for all welding except SAW. Wide, oscillated beads made with direct current, electrode negative are used for SAW. Multiple layers of weld metal are used to offset iron dilution; generally, three layers are considered to be optimum.

An initial layer of low carbon nickel electrode (99 percent Ni) will reduce dilution of the nickel alloy by carbon and iron. The thermal coefficient of expansion of nickel alloys is generally similar to cast iron. Therefore, a nickel cladding is less likely to separate from the substrate, but this can still be a problem depending on the shape of the substrate.

6.4.4 Cast Iron Buildup. Cast iron alloys are used for surfacing buildup when comparable microstructures are necessary. Electrodes and welding rods are available in gray, ductile and malleable iron compositions. Preheating, maintaining proper interpass temperatures, and, in some cases, postweld heat treatment, are necessary and advisable to prevent cracking and reduce martensite formation.

6.4.5 Hardfacing Alloys. Hardfacing alloys, as specified in ANSI/AWS A5.13-80 and A5.21-80, are used in specific wear applications. They increase low stress abrasion resistance, and in some cases, hot hardness and corrosion resistance.

For noncorrosive, low temperature applications, iron base alloys provide the necessary protection. For more demanding applications, nickel or cobalt base alloys are used.

6.4.5.1 High Chromium Alloys. There are a number of electrodes on the market which produce carbides in the deposited metal for resistance to abrasive wear. The most common electrodes deposit chromium carbides in an austenitic matrix. The large chromium carbide particles result in low ductility, therefore, the deposited metal will crack, thus relieving the residual stresses. One method of controlling the depth of cracking is to surface the casting with two or three layers of ENiFe-CI electrode. The stress relief cracks should be arrested by this intermediate layer. Preheat is necessary when welding with hardsurfacing electrodes. The welding technique should be such as to minimize dilution (e.g., overlapping of beads).

6.4.6 Refractory Thermal Spray Deposits. Ceramic and other refractory deposits are applied when a thin, hard coating will suffice, especially when thermal distortion is detrimental. Alumina and chromium oxide are used when high temperature wear and corrosion resistance is required. Tungsten carbides are used for elevated temperature applications up to 1000°F (540°C) or when abrasive wear is of principal concern.

6.5 Technique. When surfacing for corrosion or wear resistance, dilution of the deposited metal by iron, carbon, or other impurities must be minimized. The degree to which dilution may be detrimental depends upon the surfacing material.

There are three primary considerations for minimizing dilution. First, the amount of deposited metal per unit length of weld should be maximized. The deposition ratio, that is, the ratio of surfacing metal feed rate to the travel speed, should be as high as possible. Concurrently, the beads should overlap as much as possible, preferably up to 1/2 the bead width. Second, the amount of base metal melting (depth of fusion) must be kept to a minimum by reducing the heat input per unit length of weld. Using DCEN will increase the melting rate of the electrode. Third, multiple layers of deposited metal will reduce considerably the amount of base metal which is diluted into the outer layer of the weld.

Caution must be exercised when reducing the amount of dilution. In order for the deposited layers to adhere to the substrate, some base metal melting must occur. The procedure used must allow for normal process variations and yet insure adequate fusion with the substrate. Depending upon the process chosen, a 5 to 10 percent dilution is generally considered a lower limit to ensure complete fusion.

7. Applications

Iron castings are welded for numerous reasons and under many varied circumstances. The need for weld repair of iron castings may be due to various defects which are discussed in this section. Several application examples are presented in Appendix B.

7.1 Casting Defect Repair. Several conditions may lead to defects which require welding of an iron casting, and special precautions should be noted depending on the type of service. Improper conditions in the foundry can cause porosity, shrinkage, sand entrapment, and cracks. These defects may be of a nonlinear (rounded) or a linear nature. Repair welding of defects having a linear nature are more critical because the sharp ends, such as cracks or tears, have a greater tendency to propagate in the weld than a nonlinear defect. Preparation techniques for repair welding of these defects are discussed in section 3, General Considerations When Welding Iron Castings.

Small defects in noncritical or nonmachined areas can be repaired by any technique giving a sound weld. It is in this type of application that steel filler metals are most often used, where the hardness of the deposit is not critical.

Defects located in a load bearing or machined area require more care and may require some preparation

work before welding. A liquid penetrant inspection can be used to assure complete removal of the defect. The choice of welding technique and filler metal is critical. A nickel-iron electrode is generally used to assure a sound, strong weld. Welds which may be heavily diluted and require machining upon completion should be welded with a high nickel filler metal. Another technique is to postweld heat treat the welded area to soften the area for machining.

7.2 Repair of Machining Defects. Defects caused by design change or machining errors may be repaired by welding. Mislocated holes are best repaired by using a bare wire technique to limit the chance of slag entrapment. Grinding the sharp corners of a hole can help in achieving a complete penetration. Where only one or two passes are required for build up, a nickel base surfacing metal should be used. Where more than two passes are required, a nickel-iron or nickel-iron-manganese surfacing metal is recommended. Post-weld heat treatment may be used to reduce the hardness and increase the machinability of the welded area. Processes, such as GMAW, FCAW, and SAW, may be used to repair incorrectly machined areas, saving time and money.

7.3 Repair of Castings After Service. Conditions may develop during service which render an iron casting no longer usable. Such castings can often be salvaged if the remaining metal is sound and is weldable.

Precautions must be taken to prepare the castings before welding. (See section 3, General Considerations When Welding Iron Castings.)

7.3.1 Broken or Cracked Castings. A casting may break through the wall thickness, either partially or completely, due to overstress, impact, or crack propagation. Such castings are best repaired by welding a double U-groove as presented in 3.2. If only one side of a joint is accessible, in the case of a complete break in the casting, a single U-groove is used.

Since, in most cases, the weld metal is considerably stronger than the cast iron, complete penetration of the casting thickness is not always necessary. Welding a partial thickness will result in lower residual stress and reduce the likelihood of cracking. However, if the casting is subjected to cyclic loading in service, the area having partial penetration may act as a crack which will propagate under stress.

If the section being prepared is a heavy section, the groove designs discussed in 3.2.2 should be used.

7.3.2 Casting Build-up. Casting build-up is required when a part is worn, when extended service life is required, or special corrosion properties are needed.

Rotating or rubbing parts tend to wear in service and may eventually need to be repaired. It is usually econom-

ical to repair them by rebuilding the worn area. These parts are most economically repaired using automatic arc welding processes such as GMAW, FCAW, and SAW. Nickel and nickel-iron-manganese filler metals are generally the surfacing metals used for the repair. (Examples: See Appendix B)

To extend the service life of a casting, it is often surfaced with a dissimilar surfacing metal. This can impart better wear resistance, improved corrosion resistance, or both.

High nickel weld cladding provides good resistance to caustic solutions. This cladding also provides a suitable base for additional deposits of corrosion resistant alloys.

When cladding to improve corrosion resistance, the dilution of the nickel surfacing metal with iron and carbon from the casting should be minimized. This can be done by overlapping previously deposited beads up to 1/2 the width of that bead using stringer beads, except when using a SAW process. Wide oscillated beads using DCEN are used for the SAW process. Multiple layers of weld metal are used to offset the iron dilution; generally, three layers are considered minimum.

7.4 Fabrication. Iron castings may be welded to other castings or to wrought shapes to form parts. Iron castings may be preferred to steel castings because of cost, machinability, damping characteristics, and improved lubricity.

Drive shafts and hydraulic cylinder arms have been fabricated by welding ductile iron castings to lengths of steel tubing. Filler metals are usually of the nickel or nickel-iron-manganese types utilizing the GMAW, FCAW, or SAW process.

The use of automatic processes for the welding of iron castings makes fabrication economically attractive.

Ductile iron water pipe was one of the first attempts at automatic arc welding of ductile iron castings. The flux cored arc welding process was used with a nickel-iron-manganese filler metal. Welding was accomplished by revolving the pipe under the welding torch. Post-weld heat treatment restored ductility to acceptable levels.

This automation, coupled with excellent properties and weldability of many grades of ductile (nodular) iron, seems to have opened a new field of construction.

8. Welding Procedure and Performance Qualification

8.1 General. Manufacturers or users of iron castings are responsible for the welding done by their organization or under their direction. On critical castings or fabrications where the internal soundness or properties of a weld are of concern, it is advisable to prepare

detailed welding procedure specifications, qualify the procedures, qualify the welders (and welding operators) who are to perform the welding, and maintain written records of all qualifications. This not only verifies before welding that a procedure is suitable for the application and that welders can produce sound welds, but maintains a record of what was actually done for future reference.

The need for or extent of qualification, records, adherence, etc. shall be as agreed upon between the party responsible for the welding and the customer. This section describes examples of procedure and welder qualifications for welding iron castings.

For some applications, where no requirements for quality, properties, or customer requirements exist, qualification of procedures or welders may not be necessary. As an example, cosmetic welds in noncritical areas to repair surface porosity or slight surface imperfections may be one case where qualification is not necessary. Another case may be to repair worn and broken machinery parts of unknown compositions that have been in service a number of years and require trial-and-error testing with various techniques on the actual casting to determine if it is at all weldable. However, it is still essential that the welders should understand the various techniques of welding cast iron; and the characteristics of the filler metals used. They should be fully competent to perform the work.

8.2 Welding Procedure Qualification. Recommendations for the qualification of welding procedures are detailed in Appendix C. A summary of the main points are given below.

8.2.1 Essential Variables. For procedure qualification, any variable that can affect the soundness of the weld is considered essential, and requalification of the procedure is required if the variable is changed. Essential variables include the base metal carbon equivalent and thickness, filler metal type and classification, deposit thickness, penetration, joint details, position, preheat temperature, post weld heat treatment, welding parameters, and technique.

8.2.2 Welding Processes. Only the more commonly used processes for welding iron castings are included; i.e., OFW, SMAW, GMAW, FCAW, GTAW, SAW, PAW.

8.2.3 Requirements. Procedures may be qualified on the basis of soundness or on the basis of soundness and mechanical properties. Procedures qualified on soundness may require (1) visual examination, (2) magnetic particle or liquid penetrant tests, or (3) macroetch examination of weld cross sections. When a procedure is qualified on the basis of soundness and mechanical

properties, a transverse tension test is also required. The tensile strength must be equal to or greater than 80 percent of that of the base metal.

Welds may be classified by type of service or application into one of the three classes which are listed in Appendix D. These classes range from the most to the least critical type of welds, and recommended quality levels are given for each classification.

8.3 Welder and Welding Operator Performance Qualification. Recommendations for the performance qualification of welders and welding operators are detailed in Appendix C. Essential variables include the base metal type and thickness, filler metal F Number, weld metal thickness, the process, and the welding position.

9. Quality Control

9.1 General. Some iron castings used in parts such as pressure vessels or boilers are covered in specifications or codes that specify the extent of welding allowed, the nondestructive test methods, and acceptance criteria. This guide applies only to those cases where the welding and quality control of iron castings are not covered by such documents.

The inspection method and acceptance criteria for welds in iron castings are dependent upon the type and grade of iron casting material, the magnitude of the repair or fabrication, and the requirements of the intended service. Visual, liquid penetrant, and magnetic particle tests (VT, PT, and MT) are the most common nondestructive methods used in the repair of iron castings. These methods will detect surface discontinuities, and for magnetic particle tests (MT) only, those that lie slightly below the surface.

For detection of internal discontinuities, usually for repairs in critical casting sections or for major weld repairs, radiographic tests (RT) are sometimes specified. Work is also being done with ultrasonic test (UT) techniques for the detection of internal discontinuities in iron castings and welds in iron castings. However, problems remain to be solved due to inconsistent refraction, reflection, and transmission of sound beams caused by high alloy weld metals, irregular groove faces, dissimilar metal weld interface, and by graphite nodules and flakes. UT is not covered in this section.

9.2 Quality Control Practices and Procedures. The welding of iron castings requires several basic elements of a quality control program. These basic elements are qualification of procedures and welders, visual surveillance and proper documentation of all welds, and examination for weld defects. Welding qualification requirements are given in section 8, Welding Procedures

and Performance Qualification. Guidelines for surveillance documentation, and examination methods are given in this section.

The following standard definitions taken from ANSI/AWS A3.0, *Standard Welding Terms and Definitions* are included for purposes of clarity:

Crack. A fracture type discontinuity characterized by a sharp tip and high ratio of length and depth to opening displacement.

Defect. A discontinuity or discontinuities which by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term denotes rejectability.

Discontinuity. An interruption of the typical structure of a weldment such as a lack of homogeneity in the mechanical, metallurgical, or physical characteristics of the material or weldment. A discontinuity is not necessarily a defect.

Incomplete fusion. A weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads.

Overlap. The protrusion of weld metal beyond the weld toe, or weld root.

Porosity. Cavity type discontinuities formed by gas entrapment during solidification.

Slag inclusion. Nonmetallic solid material entrapped in weld metal or between weld and base metal.

Undercut. A groove melted into the base metal adjacent to the toe or root of a weld and left unfilled by weld metal.

Incomplete Joint Penetration. Joint penetration that is unintentionally less than the thickness of the weld joint.

9.2.1 Surveillance and Documentation. Visual surveillance of a weld repair while in progress and its proper documentation are essential ingredients of a quality control program. Some items recommended for surveillance are listed in Table 15.

A form recommended for the documentation of repair welds in iron castings is given in Appendix D.

9.2.2 Inspection Methods. Nondestructive examination is used in the quality control of welds in iron castings since this type of testing can detect discontinuities without impairing the usefulness of the material. A visual test or surveillance, as discussed in the previous section, is used prior to welding during removal of the casting defect, during welding for the detection of defects such as cracks or incomplete fusion, and on the completed weld.

Depending on the materials involved, either liquid penetrant or magnetic particle tests are used in the excavation prior to welding to insure removal of defects, and on the completed weld. In special cases, radiographic tests can be used prior to excavating the defects to establish their extent, after excavation to insure their removal, and to examine the completed repair. The latest edition of ANSI/AWS B1.10, *Guide for the Nondestructive Inspection of Welds* should be referred to for further information on the specific methods. The following sections give guidelines for applying the PT, MT, and RT test methods to iron casting weld repairs. The extent of required examinations on a particular casting must be agreed upon between the supplier and purchaser.

9.2.2.1 Liquid Penetrant Tests. As mentioned in the previous section, a liquid penetrant test is often used in the excavation prior to welding to insure removal of the casting defect. However, if the casting is porous in the area being repaired, the penetrant becomes absorbed into the casting and causes porosity in the weld metal. If this causes a problem, the liquid penetrant test should not be used prior to welding, or the penetrant should be

Table 15
Surveillance Recommendations for Weld Repairs

Prior to Welding	During Welding	After Welding
1. Mark defect locations	1. Check compliance with details of welding procedure such as type of filler metal, preheat and interpass temperatures, welding parameters and technique, interpass cleaning	1. Postweld heat treatment
2. Removal of defects		2. Surface appearance
3. Material cleanliness		3. Presence of defects
4. Joint preparation		
5. Size, location of repair	2. Inspection of successive layers, especially root pass	
	3. Base metal response (see 2.4.3)	

burned off by heating the casting or excavation area to 900°F (482°C) for 15 to 30 minutes.

The liquid penetrant test is used on the finished weld for surface defects when filler metal and base metal are dissimilar. When cast iron filler metal similar to the composition of the base metal is used, either the liquid penetrant or magnetic particle test can be used for final weld surface examination.

ASTM E165, *Liquid Penetrant Inspection Method*, should be followed as a base reference document. The liquid penetrant test method only detects discontinuities that are open to the surface. Fluorescent penetrant methods shall be used if required by an applicable specification.

Use of the standard penetrant materials requires that the temperature of the casting be between 60–125°F (16–52°C). Where a penetrant test is required on castings at elevated temperatures, special penetrant materials and procedures will be required.

Contaminants such as oil, scale, weld slag, spatter and dirt which prevent the penetrant from entering discontinuities, must be removed from the adjacent area [within 1 in. (25 mm) of the weld edge] prior to inspection.

Weld surface irregularities that might trap the penetrant and result in false indications must be removed by grinding or machining prior to inspection. *Especially critical* is the weld toe and base metal heat affected zone region where cracking is most likely to occur. All undercut at the weld toe must be removed prior to the liquid penetrant test.

Since peening or blasting of the completed weld area can close or fill discontinuities open to the surface, grinding with light pressure to minimize metal smearing must be done after final peening or blasting but before the liquid penetrant test.

Visual examination of the weld surface being inspected shall be made immediately after the developer has dried, and again after at least 15 minutes.

9.2.2.2 Magnetic Particle Test. Dry powder magnetic particle tests can be used to examine excavations prior to welding to insure removal of the casting defects. Magnetic particle tests can also be used to examine the completed weld only when the filler metal chemical composition is similar to that of cast iron base metal.

With dissimilar filler metals such as nickel-base alloy electrodes, magnetic particle tests should not be used because the difference in magnetic permeability between the filler and base metals causes powder to be attracted to the weld interface, and results in a false indication. ASTM E709, *Standard Practice for Magnetic Particle Examination* should be used as a basic reference. Only the dry powder method is applicable to cast iron in welding situations.

The repair excavation or weld being examined shall be dry and free from contaminants such as oil, sand, scale, rust, and slag. Weld surface irregularities such as undercut or overlap that would mechanically trap powder must be removed by light grinding prior to examination.

Special care shall be taken to prevent arcing between prods and cast iron surface. This could cause hard spots and cracking.

9.2.2.3 Radiographic Tests. When radiographic tests are specified, the repair area should be radiographed prior to welding. This establishes a reference radiograph of the base metal surrounding the repair which can then be compared to the radiograph of the completed weld repair to distinguish weld defects from the casting background. In some cases, it is advisable to radiograph the area to be repaired before excavation to determine the extent of repairs necessary. ASTM E 94, *Standard Guide for Radiographic Testing*, and ASTM E142, *Standard Method for Controlling Quality of Radiographic Testing*, can be used as basic references.

The image quality of radiographic examination shall be determined by using a standard ASTM penetrometer of at least a 2-2T (2 percent) sensitivity level based on the section thickness of the casting. Weld surface reinforcements shall be ground to remove irregularities that might mask or cause misinterpretation of defects.

9.3 Acceptance Criteria. In general, welds in critical areas (as defined between the purchaser and supplier) tested with the nondestructive methods given in this document shall be free of linear defects (cracks, incomplete fusion, etc.). Linear indications are defined as those indications in which length is more than three times the width and major dimensions are greater than 1/16 in. (1.6 mm).

Inspection criteria other than those stated above, may be as agreed upon between the purchaser and supplier. Appendix D provides for a recommended system of classifying welds and gives recommended quality levels.

10. Safety and Health

Use of the welding processes and consumables described in this document is safe provided proper procedures are followed and precautions taken. If these procedures and precautions are followed, welding can be done safely with minimal health risk.

10.1 Fumes and Gases. Fumes and gases can be dangerous to health. The welder's head should be kept out of the fumes. Use of enough ventilation, exhaust at the work, or both, to keep fumes and gases from the breathing zone and the general area is essential.

10.2 Radiation. Arc rays can injure eyes. Infrared (heat) radiation can cause burns. Ultraviolet radiation can cause skin injury similar to sunburn.

10.3 Electric Shock. Electric shock can kill. Contact with live electrical components should be strictly avoided. Reading and understanding the manufacturer's instructions and employer's safety practices should be mandatory.

10.4 Fire Prevention. A high-temperature heat source is always present in arc and oxyfuel welding processes. Sparks can travel horizontally up to 35 ft (11 m) and fall much greater distances. They can pass through or lodge in cracks or holes in floors and walls. Combustibles should always be removed from the work area or shielded from the welding operation.

10.5 Explosion. Flammable gases, vapors and dust can form explosive mixtures with air or oxygen. Welding should never be done in an atmosphere where such materials could possibly be present.

10.6 Burns. Burns of the eye and body are serious hazards in arc and oxyfuel welding. Recommended eye protection, welding helmets, and appropriate protective clothing should always be worn.

10.7 Further Information. It should be recognized that the above paragraphs give only a very brief coverage of the subject of safety in welding. Detailed coverage is available in the publications listed in Appendix F. The primary source is ANSI/ASC Z49.1, *Safety in Welding and Cutting*, available from the American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Appendix A

Weldability Test

(This appendix is not a part of ANSI/AWS D11.2-88, *Guide for Welding Iron Castings*, but is included for information purposes only.)

A1. Introduction

This Appendix details the test program used by the Welding Iron Castings Committee to evaluate the relative weldability of various types and grades of iron castings.

The test for each type or grade of casting requires a minimum of eight (8) and a maximum of twelve (12) two-sided specimens (see Figures A1 and A2). Three separate series of tests are conducted with at least 24 hours between each series. The series sequence is as follows (see caution note):

A1.1 First Run. Five specimens are required, with one weld on each. Test temperatures are room temperature, 250°F (121°C), 500°F (260°C), 750°F (400°C), and 1000°F (540°C). After 24 hours, evaluate per section A4, steps 11 through 14, and determine highest temperature at which cracking still occurs. This is temperature "X".

A1.2 Second Series. Four specimens are required including those from first series with temperatures higher than "X", using second weld test surface, and remaining unwelded specimens. These temperatures are "X" + 50°F (28°C), "X" + 100°F (56°C), "X" + 150°F (83°C), and "X" + 200°F (111°C). Again, evaluate results after 24 hours per section A4, steps 11 through 14, and determine highest temperature at which cracking still occurs. This is temperature "Y".

A1.3 Third Series. Four specimens are required including those from second series with temperatures higher than "Y" using second weld surface, and remaining unwelded specimens. Test temperatures are "Y" + 10°F (6°C), "Y" + 20°F (11°C), "Y" + 30°F (17°C), and "Y" + 40°F (22°C).

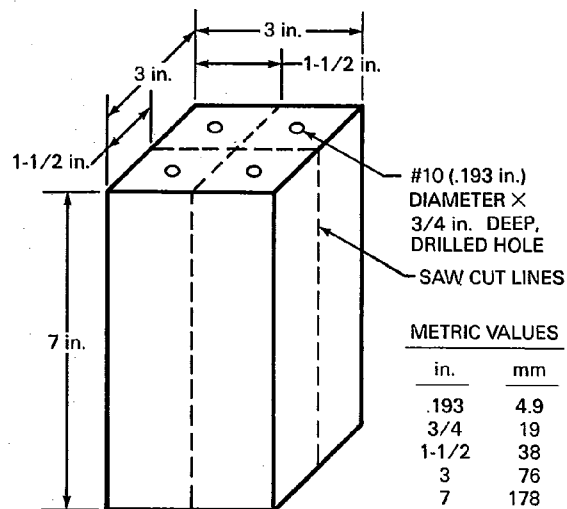
The lowest temperature at which cracking does not occur is defined as the no-crack temperature.

Caution: At no time should the second weld surface of a specimen be used if it involves preheating to a temperature (new test temperature plus 20 percent, as defined in section A4, step 3) higher than the test temperature of the first weld surface.

A2. Equipment Required

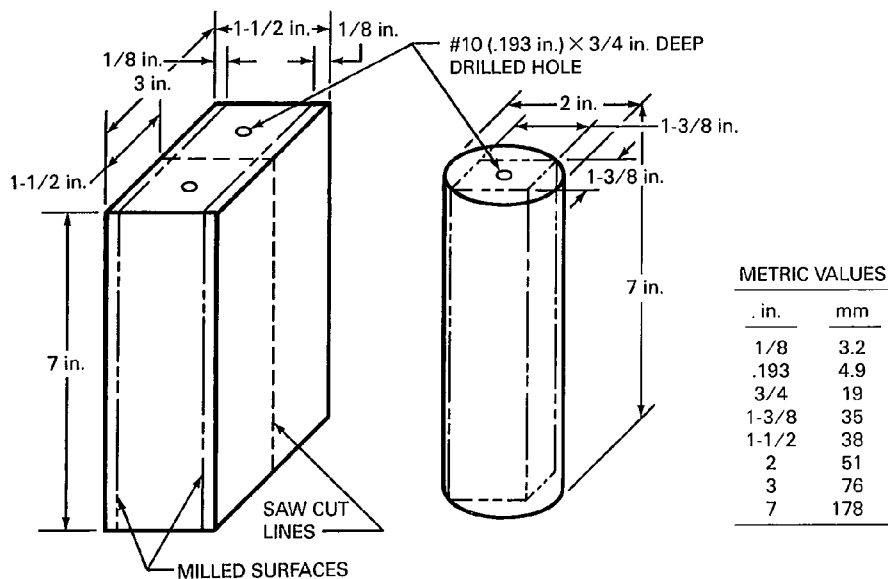
The basic equipment used to perform the test with the GTAW process is as follows:

- (1) Power source: 300 ampere DC (constant current)
- (2) Torch: GTAW welding torch with 5/32 in. (4.0 mm) diameter tungsten and collets.
- (3) Controls: Automatic feedback control capable of holding parameters within the tolerances specified.
- (4) Travel: Mechanized in horizontal direction.
- (5) Heat source: Capable of heating specimens to 1200°F (650°C).
- (6) Temperature measurement: Capability of direct and continuous reading during preheat and welding.



1. Dry saw cut on dotted lines to make four test bars.
2. Grind all saw cut surfaces smooth for weld test (125 μ in.) (.003 mm).
3. Drill hole in end of each bar.

**Figure A1 — Test Block
for Gray and Ductile Iron**



RECTANGULAR BLOCK

ROUND BLOCK

1. Dry saw cut on dotted line.
2. Mill 1/8 in. from surfaces indicated for weld test (125 μ in.) (.003 mm).
3. Drill hole in end of each bar.
4. Use two milled faces of each bar for weld test.

1. Mill four sides to obtain 1-3/8 in. square bar (125 μ in.) (.003 mm).
2. Drill hole in end of bar.
3. Use four milled faces for weld test.

Figure A2—Test Blocks for Malleable Iron

A3. Welding Conditions

The specific conditions and numerical values used in the weldability test program are as follows:

- (1) Process: Gas Tungsten Arc Welding (GTAW)
- (2) Arc voltage: 14 ± 0.5 volts
- (3) Current: 250 ± 10.0 A
- (4) Polarity: Direct Current Electrode Negative (DCEN)
- (5) Travel speed: 13 ± 0.5 in./min (5.5 ± 0.2 mm/s)
- (6) Tungsten: 5/32 in. (4 mm) Dia. A5.12 Class EW-Balled End
- (7) Start technique: High Frequency
- (8) Heat input: 16 ± 2 kJ/in. (630 ± 80 kJ/m)
- (9) Shielding gas: 100% Argon @ 40 cfh (19 L/min)
- (10) Gas cup: 5/8 in. (16 mm) dia.
- (11) Weld length: 4.5 ± 0.25 in. (114 ± 6 mm)
- (12) Preheat temperature: Room temperature to $1200^\circ \pm 10^\circ\text{F}$ ($650 \pm 5^\circ\text{C}$)
- (13) Filler metal: None

- (14) Thermocouple: Type K (Chromel-Alumel) 3/16 in. (4.8 mm) Diameter Stainless Steel Sheath

- (15) Specimens: Per Figure A1 or A2

A4. Test Procedure

Each individual test is run as follows:

- (1) Prepare test specimen as shown in Figures A1 or A2 by dry sawing and grinding (Figure A1), or dry sawing and milling (Figure A2). Properly identify each test piece.
- (2) Drill #10 .193 in. (4.9 mm) diameter by 3/4 in. (19 mm) deep hole in center of one end face of each specimen.
- (3) Place specimen on or in heating device, and heat to a temperature about 20 percent above desired test temperature, with thermocouple in hole.
- (4) While specimen is heating, verify welding conditions described in section A3 on scrap metal.
- (5) When specimen reaches test temperature, plus 20 percent, remove from heat source and place on welding table with thermocouple still attached.

(6) Align welding torch to start about 1 in. (25 mm) from end of specimen where thermocouple is located. Path of welding is on the centerline of the 7 in. (178 mm) long milled or ground face.

(7) Carefully monitor temperature as specimen cools and initiate arc as soon as test temperature is reached.

(8) As soon as the arc is established, initiate travel and make weld bead $4.5 \pm .25$ in. (114 mm) long.

(9) Stop arc and travel simultaneously. Crater fill or controlled arc decay is not required.

(10) Remove thermocouple and set specimen aside (uncovered) to cool in still air at room temperature for at least 24 hours.

(11) After 24 hours, lightly polish surface containing weld bead with 240 grit paper, until surface is shiny and smooth enough for liquid penetrant test.

(12) Apply liquid penetrant and allow to soak for a minimum of 15 minutes.

NOTE: If photographs of indications are to be taken, have camera ready before proceeding to next steps. If indications appear quickly, photograph within 30 seconds after developer dries to get clearest results.

(13) Clean surface per penetrant manufacturer's instruction and apply developer.

(14) Record any transverse or centerline indications in weld, disregarding all fusion line indications and any indications in the first 1/2 in. (12.7 mm) start or last 1/2 in. (12.7 mm) crater of weld bead. Allow developer to set at least 20 minutes so that any minute indications will surface.

Table A1 lists the mechanical properties of the various cast iron base metals used in the test evaluation. Table A2 lists the actual results of the welding tests conducted in the program. Tables A3, A4 and A5 list the hardness values measured on cross sections of selected weld specimens.

Table A1
Mechanical Properties

Specimen No.	Grade	Tensile Strength		Yield Strength		Hardness BHN	Reduction in Area %	Elongation %	Condition
		ksi	MPa	ksi	MPa				
Gray Iron									
G1	40	46	317	—	—	179	—	—	As cast
G2	50	52	359	—	—	241	—	—	As cast
G3	45	45	310	—	—	229	—	—	As cast
G4	35	36	248	—	—	187	—	—	As cast
Ductile Iron									
D1	80-55-06	109	752	55	379	255	3.9	7	As cast
D2	100-70-03	97	669	69	476	269	2.3	2.5	As cast
D3	120-90-02	132	910	111	765	311	2.7	2.5	Heat treated
D4	65-45-12	64	441	48.5	334	179	—	5.5	As cast
Malleable Iron									
M1	50005	78	537	50	345	196	4.5	7.5	Heat treated
M2	32510	47	324	31	214	121	13	12.5	Heat treated
M3	M5503	106	730	66	455	241	—	4.5	Heat treated
M4	M5003	95	655	59	407	228	—	4.0	Heat treated

Table A2
Test Results

Temperature		Samples											
°F	°C	G1	G2	G3	G4	D1	D2	D3	D4	M1	M2	M3	M4
1000	540	C	C	C	C	N/C	N/C	N/C	N/C	—	—	—	—
750	400	C	C	C	C	N/C	N/C	N/C	N/C	—	—	—	—
700	370	—	C	—	C	—	N/C	—	—	—	—	—	—
690	365	—	—	—	—	—	N/C	—	—	—	—	—	—
680	360	—	—	—	—	—	N/C	—	—	—	—	—	—
670	355	—	—	—	—	—	N/C	—	—	—	—	—	—
660	350	—	—	—	—	—	N/C	—	—	—	—	—	—
650	345	—	C	—	C	—	N/C	—	—	—	—	—	—
640	340	—	—	—	—	—	N/C	—	—	—	—	—	—
630	330	—	—	—	—	—	N/C	—	—	—	—	—	—
620	325	—	—	—	—	—	T1	—	—	—	—	—	—
600	315	—	C	—	C	—	—	—	—	—	—	—	—
550	290	—	C	—	C	—	—	—	—	—	—	—	—
540	280	—	C	—	C	—	—	—	—	—	—	—	—
530	275	—	C	—	C	—	—	—	—	—	—	—	—
520	270	—	C	—	C	—	—	N/C	—	—	—	—	—
510	265	—	C	—	CT1	—	—	T3	—	—	—	—	—
500	260	C	C	C	CT1	N/C	T4	T2	N/C	—	—	—	—
490	255	C	C	—	—	—	—	T1	N/C	—	—	—	—
480	250	C	C	—	—	—	—	—	N/C	—	—	—	—
470	245	C	C	—	—	—	—	—	N/C	—	—	—	—
460	240	C	C	—	—	—	—	—	N/C	—	—	—	—
450	230	CT1	C	—	—	N/C	—	T2	N/C	—	—	—	—
440	225	—	C	—	—	T2	—	—	T3	—	—	—	—
430	220	—	C	—	—	T3	—	—	—	—	—	—	—
400	205	—	C	—	—	T2	—	—	—	—	—	—	—
300	150	—	C	C	—	T6	—	T7	T8	—	—	—	—
290	145	—	C	—	—	—	—	—	—	—	—	—	—
280	140	—	CT1	—	—	—	—	—	—	—	—	—	—
270	130	—	CT2	—	—	—	—	—	—	—	—	—	—
250	120	—	—	—	—	—	—	—	—	—	—	—	—
200	95	—	CT2	C	—	—	—	—	—	—	—	—	—
150	65	—	—	C	—	—	—	—	—	—	—	—	—
120	50	—	—	C	—	—	—	—	—	—	—	—	—
110	45	—	—	C	—	—	—	—	—	—	—	—	—
100	40	—	—	CT1	—	—	—	—	—	—	—	—	—
70	20	—	—	CT3	—	—	—	—	—	N/C	N/C	N/C	N/C

Legend

C = Circumferential Indication (Disregard)*

N/C = No Crack

TX = Transverse Crack (x = number of cracks in test length of weld)

— = No Test

* All gray iron tests, regardless of test temperature (including preheats of over 1100°F), had this circumferential indication. It did not appear on any ductile or malleable specimens.

Table A3
Hardness Tests on
Specimens Welded at No-Crack Temperature

Material Specification	Class or Grade	Weld (R _A)	HAZ (R _A)	Base Metal (R _B)	No-Crack Temp.
<u>Gray</u>					
ASTM A48	Class 35	78.5–80	65.5–68.5	91.5–93	520°F (270°C)
ASTM A48	Class 40	77.5–80	64–69.5	80–84	460°F (240°C)
ASTM A48	Class 45	79–79.5	73–76	87.5–96.5	110°F (40°C)
ASTM A48	Class 50	78.5–80.5	73.5–77.5	102.5–104.5	290°F (140°C)
<u>Ductile</u>					
ASTM A536	Grade 65-45-12	78–80	57–63	86–87	450°F (230°C)
ASTM A536	Grade 80-55-06	79–81	62–74	95–98	450°F (230°C)
ASTM A536	Grade 100-70-03	75–81	64–65	94–98	630°F (330°C)
ASTM A536	Grade 120-90-02	80–81	68–74	106	520°F (270°C)

Note: For comparison purposes
60 (R_A) = 97 (R_B) = 20 (R_C)

Table A4
Hardness Tests on
Specimens Welded Below No-Crack Temperature

Material Specification	Class or Grade	Test Temp.	Weld (R _A)	HAZ (R _A)	Base Metal (R _B)	No-Crack Temp.
<u>Gray</u>						
ASTM A48	Class 35	500°F (260°C)	80.5–82	65–71.5	90–92.5	520°F (270°C)
ASTM A48	Class 40	300°F (150°C)	76.5–83.5	71.5–72.5	59.5–79.5	460°F (240°C)
ASTM A48	Class 45	70°F (20°C)	76.5–79	75–78	96.5–97	110°F (40°C)
ASTM A48	Class 50	200°F (95°C)	78–79	74.5–77	102–102.5	290°F (140°C)
<u>Ductile</u>						
ASTM A536	Grade 65-45-12	300°F (150°C)	78–81	67–75	85–86	450°F (230°C)
ASTM A536	Grade 80-55-06	300°F (150°C)	79–81	63–70	98.5	450°F (230°C)
ASTM A536	Grade 100-70-03	500°F (260°C)	80–86	70–83	100	630°F (330°C)
ASTM A536	Grade 120-90-02	450°F (230°C)	87–81	68–74	100–105	520°F (270°C)

Note: For comparison purposes
60 (R_A) = 97 (R_B) = 20 (R_C)

Table A5
Hardness Tests on Malleable Iron Specimens

Material Specification	Class or Grade	Weld Test Temperature	Weld (R _A)	HAZ (R _A)	Base Metal (R _B)	No-Crack Temp.
ASTM A47	Grade 32510	70°F (20°C)	78–79	53–59	68.5–70	<70°F (20°C)
ASTM A220	Grade 50005	70°F (20°C)	78.5–79	68–74	91–92	<70°F (20°C)

Note: For comparison purposes
60 (R_A) = 97 (R_B) = 20 (R_C)

Appendix B

Examples of Applications

(This appendix is not a part of ANSI/AWS D11.2, *Guide for Welding Iron Castings*, but is included for information purposes only.)

The nineteen examples of welding iron castings presented in this Appendix were submitted by committee members, and they represent a wide range of industrial experience. The American Welding Society cannot guarantee the accuracy of details of the procedures used, or the results of using them on other similar applications.

<u>Type of Casting</u>	<u>Welding Process</u>	<u>Type of Repair</u>	<u>Application No.</u>
Ductile Iron	FCAW	Build-up	1
Gray Iron	FCAW	Casting Defect	2
Gray Iron	FCAW	Build-up	3
Ductile Iron	GMAW	Fabrication	4
Gray Iron	GMAW	Build-up	5
Gray Iron	SMAW	Build-up	6
Gray Iron	SMAW	Build-up	7
Gray Iron	SMAW	Build-up	8
Gray Iron	SMAW	Fabrication	9
Gray Iron	SMAW	Build-up	10
Gray Iron	SMAW	Repair	11
Gray Iron	SMAW	Repair	12
Ductile Iron	FCAW	Fabrication	13
Unknown	FCAW	Crack in casting	14
Gray Iron	GMAW	Buildup	15
Gray Iron	FCAW	Part Maintenance	16
Gray Iron	GMAW	Part Maintenance	17
Ductile Iron	SMAW	Fabrication	18
Gray Iron	SMAW	Part Maintenance	19

Application No. 1 — Foundry Shakeout Table

A ductile iron shakeout table was unevenly worn and some areas were 1-1/4 in. (32 mm) undersize. The table was salvaged by weld build-up of the low spots and adding abrasion resistant ribs to the top. Welding was done in place during non-operating hours. Substantial savings were realized when salvage costs were compared to replacement cost.

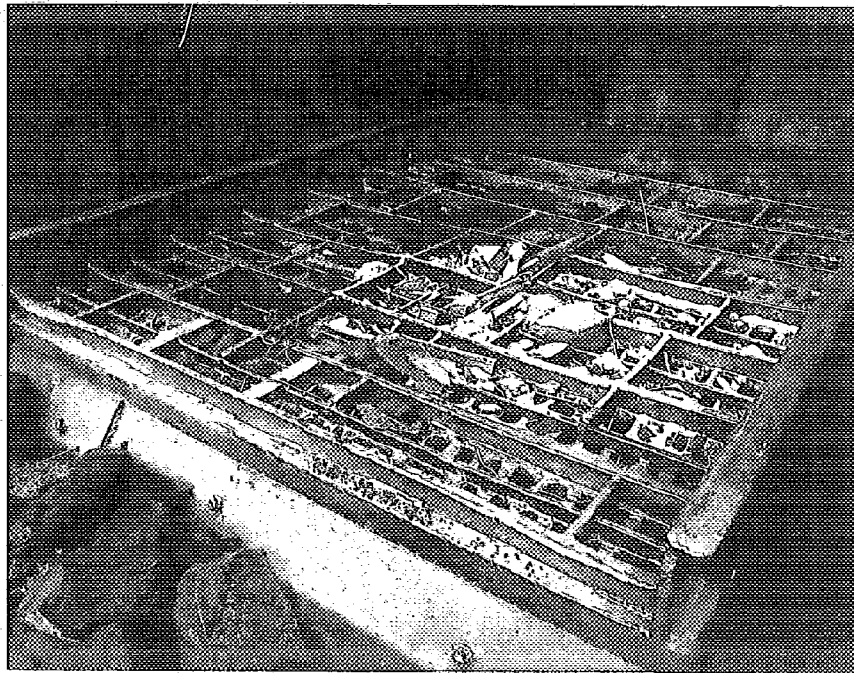
Procedure

Base metal — Ductile iron

Process — FCAW

Filler metal — Nickel-iron -manganese flux cored, 3/32 in. (2.4 mm) dia.

Welding conditions — 350 A, DCEP, 32 V, carbon dioxide shielding gas at 40 ft³/h (19 L/min), 3/4 in. (20 mm) electrode extension, weave technique

Illustration

Submitted by:
Dresser-Rand, Turbo Products Div., Olean, NY

Application No. 2 — Ingot Mold Repair

Gray cast iron molds deteriorate due to damage to inside surfaces caused by erosion and "sticking" during mold stripping. The molds can be salvaged by use of the FCAW process with substantial savings over replacement cost.

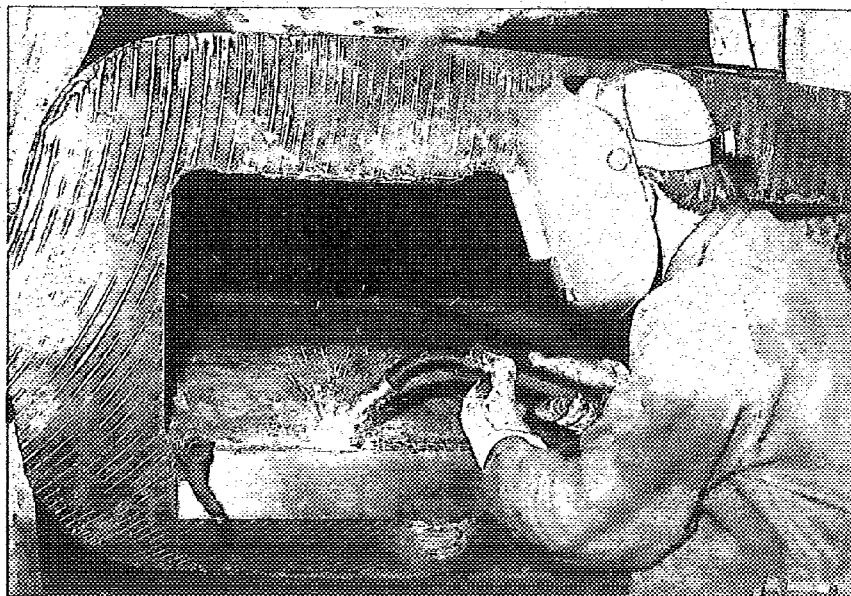
Procedure

Base metal — Gray cast iron

Process — FCAW (semi-automatic)

Filler metal — Nickel-iron-manganese, self-shielding electrode 3/32 in. (2.4 mm) or 1/8 in. (3.2 mm) dia.

Welding conditions — 350 + A, DCEP, 32 V, electrode extension 1 to 1-1/4 in. (25 to 32 mm)

Illustration

Submitted by:
Inco Alloys International, Inc.

Application No. 3 — Crane Hoist Drum Repair

The guide grooves of a 30 in. (762 mm) diameter by 108 in. (2743 mm) long cast iron crane hoist drum had worn about 1 in. (25 mm). Due to high cost and long delivery time for replacement, a multiple layer weld buildup was performed to salvage the drum.

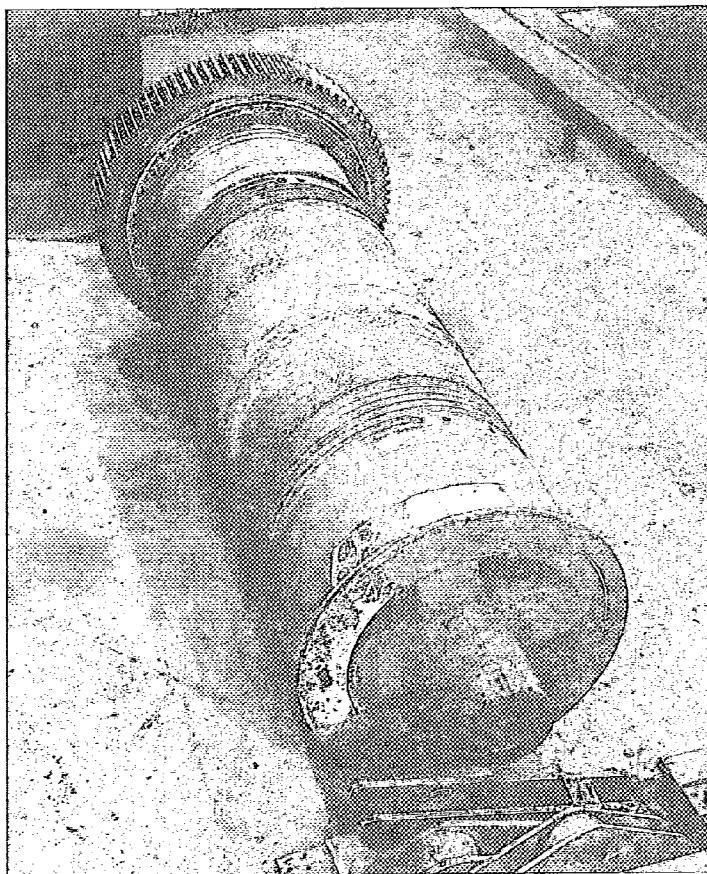
Procedure

Base metal — Gray iron

Process — FCAW

Surfacing metal — Nickel-iron-manganese, self-shielding flux-cored electrode, 3/32 in. (2.4 mm) dia.

Welding Conditions — 320–350 A, DCEP, 32 V, 1 in. (2.5 mm) electrode extension

Illustration

Submitted by:
Inco Alloys International, Inc.

Application No. 4 — Fabrication of Driveshafts

Automotive drive shafts were fabricated by welding 60-40-18 ductile iron yokes to a low carbon steel tube. The cost of the finished part was significantly less than if made from a steel casting.

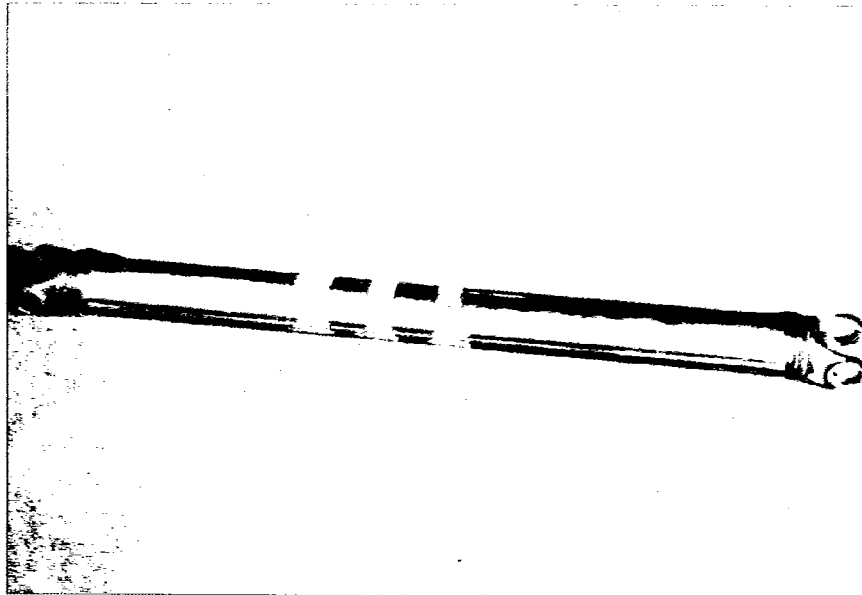
Procedure

Base metal — ASTM A536, Grade 60-40-18 ductile iron to low carbon steel

Process — GMAW — Shielding gas 75 Argon/25 CO₂, 40 to 50 ft³/h (19 to 24 L/min.)

Filler metal — Nickel-iron-manganese bare electrode, .045 in. (1.15 mm) dia.

Welding conditions — 260 A, DCEP, 29 V, travel speed 40–45 in./min. (17–20 mm/s),
1/2 in. (13 mm) electrode extension, wire feed speed 450 in./min. (190 mm/s)

Illustration

Submitted by:
Inco Alloys International, Inc.

Application No. 5 — Salvage of Cast Iron Dam Wheels

The hubs of two cast iron wheels (sheaves) used in dam gate operating mechanisms, were mismachined. They were successfully salvaged by weld buildup with aluminum bronze surfacing metal.

Procedure

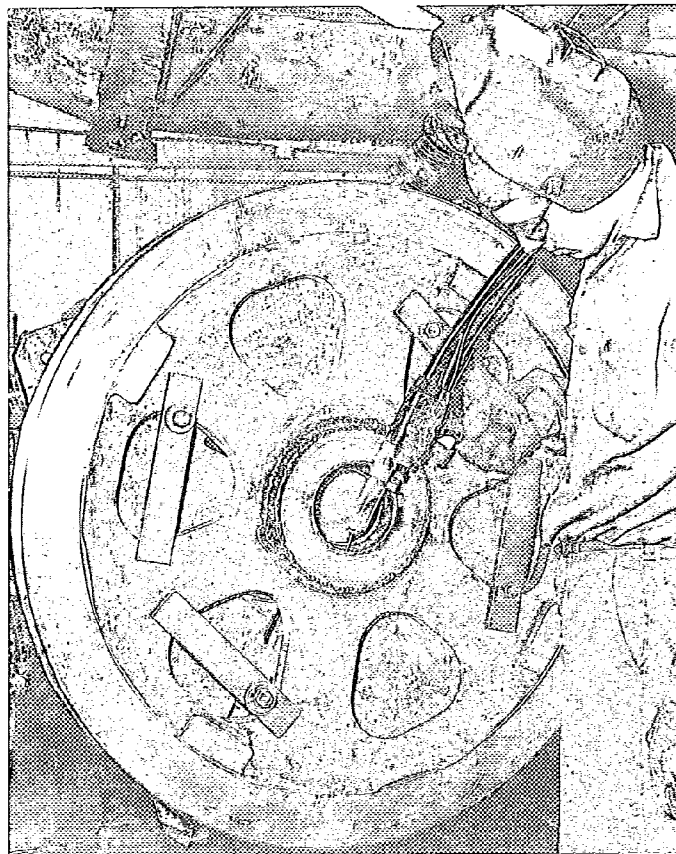
Base metal — Gray iron

Process — GMAW

Surfacing metal — Aluminum bronze, ER CuAl-A2, .062 in. (1.6 mm) dia.

Welding conditions — 300–350 A, 30 V, DCEP, shielding-argon at 45 ft³/h (21 L/min)

Preheat temperature — 400° F (205° C), slow cool after welding

Illustration

Submitted by:
Ampco Metal Div.

Application No. 6 — Repair of Cast Iron Conveyor Sprockets

Wear and abrasion had worn down the working surfaces of the sprocket teeth. The sprockets were salvaged and their service life increased by weld buildup with a wear resistant aluminum bronze surfacing metal.

Procedure

Base metal — Gray iron

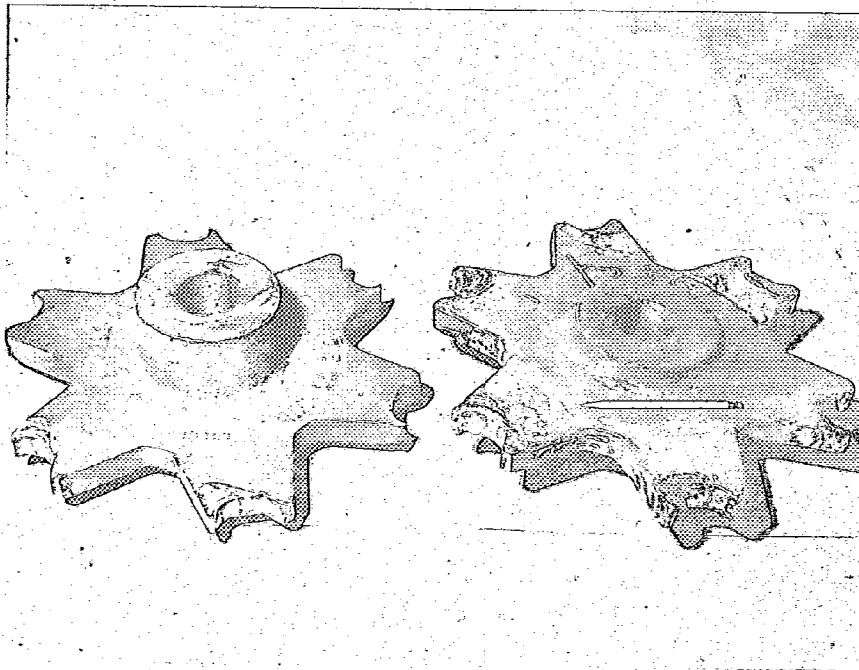
Process — SMAW

Surfacing metal — Buildup layer — ECuAl-A2, 5/32 in. (4 mm) dia.

Wear layer — ECuAl-D, 5/32 in. (4 mm) dia.

Welding conditions — 150-180A DCRP

Preheat temperature — 300°F (150°C) — Slow cool after welding

Illustration

Submitted by:
Ampco Metals Div.

Application No. 7 — Repair of Cast Iron Bathtub Die

The cavity in a large die was mismachined. It was salvaged by weld buildup. The surfacing metal was chosen to resist high compressive stress and galling. Repair areas were ground to allow for 3/16 in. (4.8 mm) buildup (two layers).

Procedure

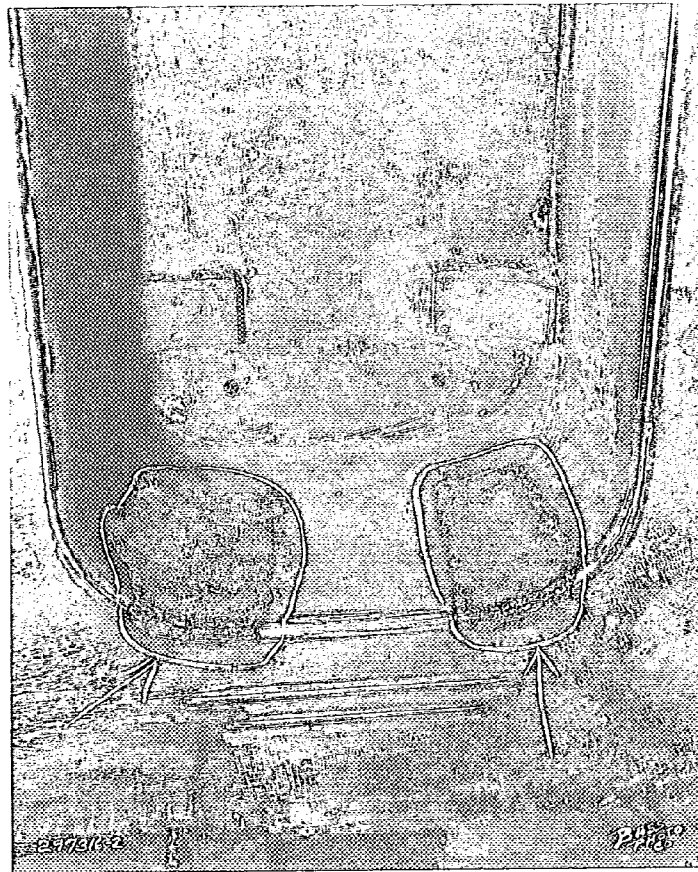
Base metal — Gray iron

Process — SMAW

Surfacing metal — ECuAl-E, 3/16 in. (4.8 mm) dia.

Welding conditions — DCEP, 180–200 A

Preheat temperature — 300°F (150°C), slow cool after welding

Illustration

Submitted by:
Ampco Metals Div.

Application No. 8 — Salvage of Cast Iron Columns

The ways on the columns of a large drop-hammer were badly worn in service. They were salvaged by weld buildup with an abrasion resistant aluminum bronze surfacing metal. The cost was significantly less than replacing the castings.

Procedure

Base metal — Gray iron

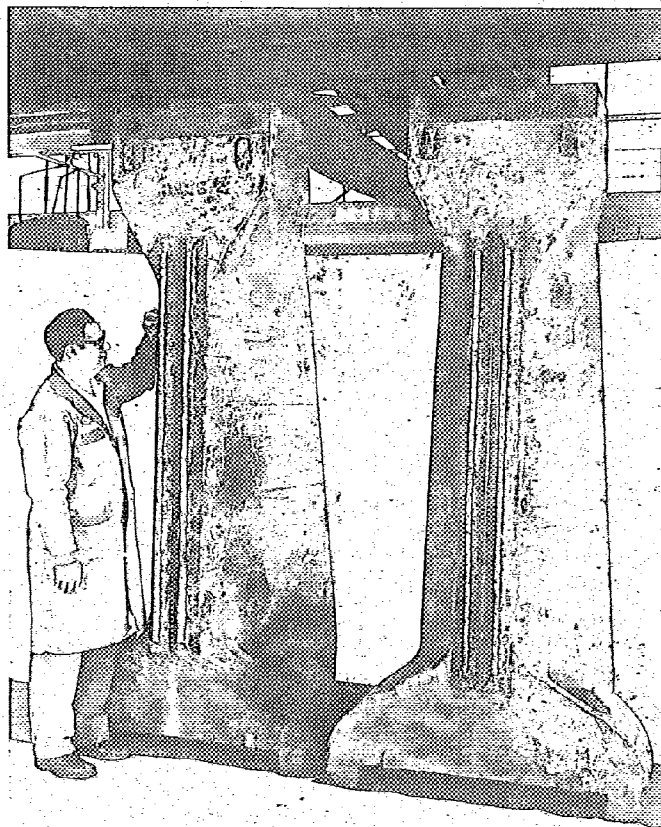
Process — SMAW

Surfacing metal — First layer — ECuAl-A2, 1/4 in. (6.4 mm) dia.

2-3 layer — ECuAl-C, 1/4 in. (6.4 mm) dia.

Welding conditions — 200 A, 30 V, DCEP

Preheat temperature — 800°F (425°C), slow cool after welding

Illustration

Submitted by:
Ampco Metals Div.

Application No. 9 — Fabrication of a Heat Exchanger Header

A heat exchanger was fabricated by cutting down the end of a cast iron unit and welding on a steel end plate. A hydraulic pressure test at 300 psi (2070 kPa) was used to examine the welds.

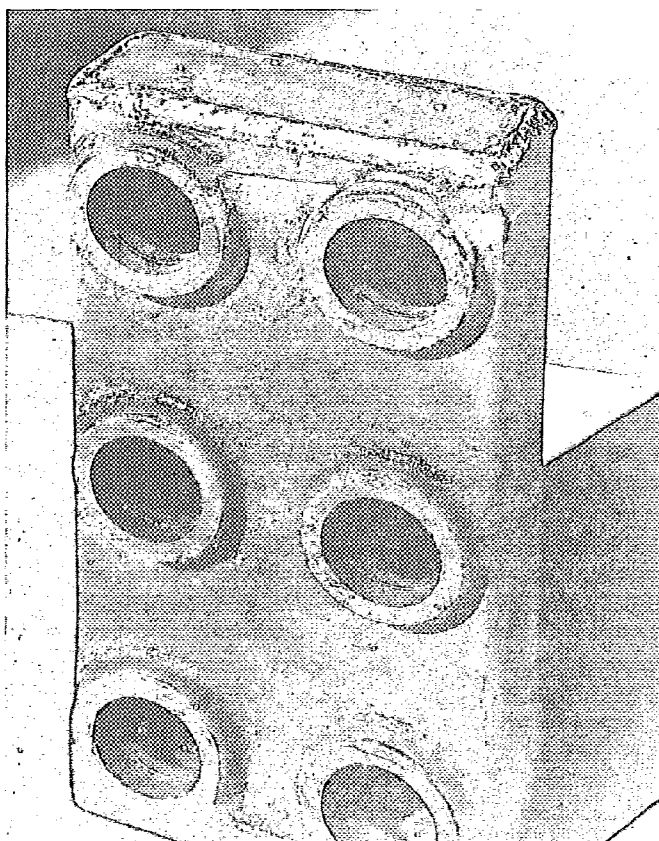
Procedure

Base metal — Gray iron to steel plate

Process — SMAW

Filler metal — ECUAl-A2, 1/8 in. (3.2 mm) dia.

Welding conditions — 100–120 A, DCEP

Illustration

Submitted by:
Ampco Metals Div.

Application No. 10 — Salvage of Steel Mill Rolls

The unhardened “wobbler” ends of cast iron steel mill rolls become worn and damaged. They are salvaged by weld buildup with aluminum bronze surfacing metal. This is economical and provides improved bearing surfaces.

Procedure

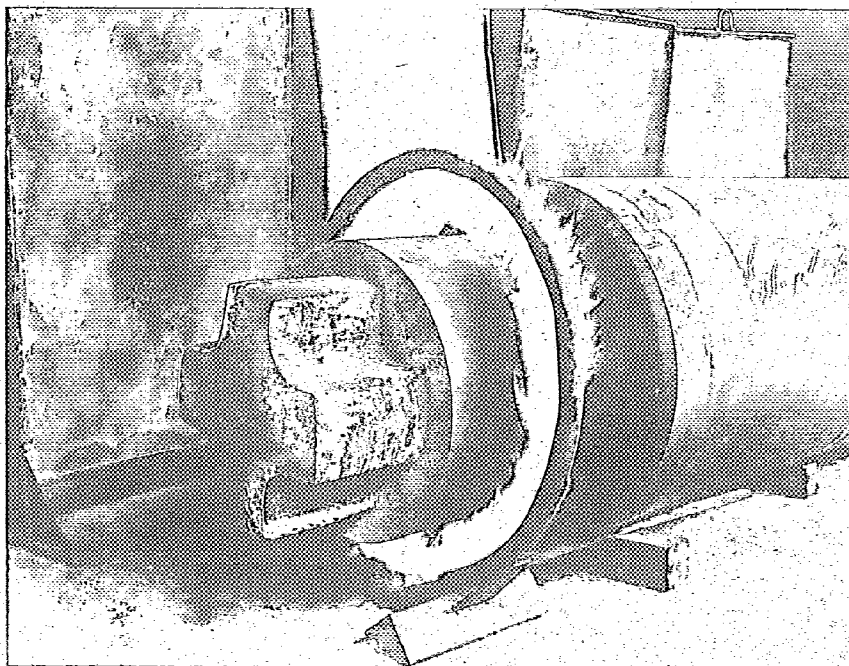
Base metal — Gray iron, ASTM A48

Process — SMAW

Surfacing metal — First layer — ECuAl-A2, wear layers — ECuAl-D, 3/16 in. (4.8 mm) dia.

Welding conditions — 180–200 A, DCEP

Preheat temperature — 700–800°F (370–425°C), Slow cool after welding

Illustration

Submitted by:
Ampco Metals Div.

Application No. 11 — Repair of Coupling Plate

A cast iron coupling plate broke as it was being removed with a pulley puller. Repair was necessary because a replacement part was not available. A complete joint penetration weld of good quality was needed to transmit torque at 1750 rpm.

Procedure

Base metal — Gray iron

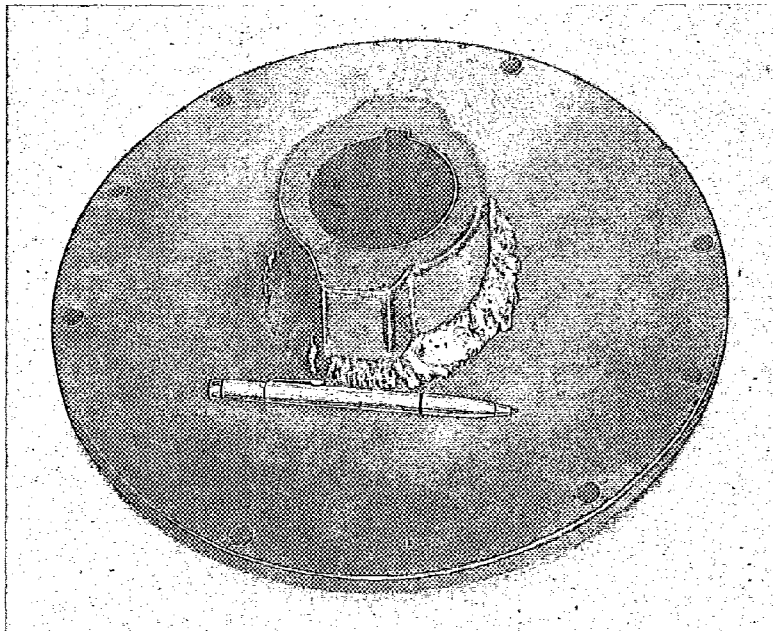
Process — SMAW

Preparation — Plate was ground to a 40° bevel, aligned and tacked

Filler metal — ECUAl-A2, 5/32 in. (4 mm) dia.

Welding conditions — 140–160 A, DCEP

Preheat temperature — 300°F (150°C), slow cool after welding

Illustration

Submitted by:
Ampco Metals Div.

Application No. 12 — Repair of a Cast Iron Lathe Bed

The lathe bed was broken in service and a replacement was not available. Holes were drilled at the ends of the crack to arrest it, and it was ground out to a 90° V-groove. The repair weld was made in less than three hours and the lathe returned to service.

Procedure

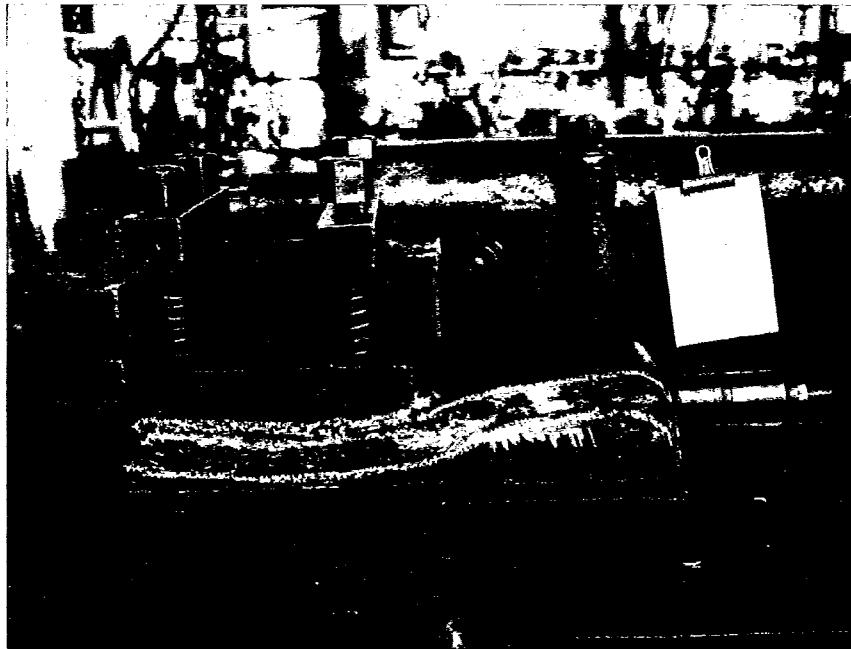
Base metal — Gray iron

Process — SMAW

Filler metal — ECuAl-A2, 5/32 in. (4 mm) dia.

Welding conditions — 145 A, DCEP

Preheat temperature — 400°F (205°C), slow cool after welding

Illustration

Submitted by:
Ampco Metals Div.

Application No. 13 — Fabrication of Air Cylinder

An air cylinder was fabricated by welding cast ductile iron end caps to a low carbon steel pipe. A cost reduction was realized by using ductile iron instead of cast steel.

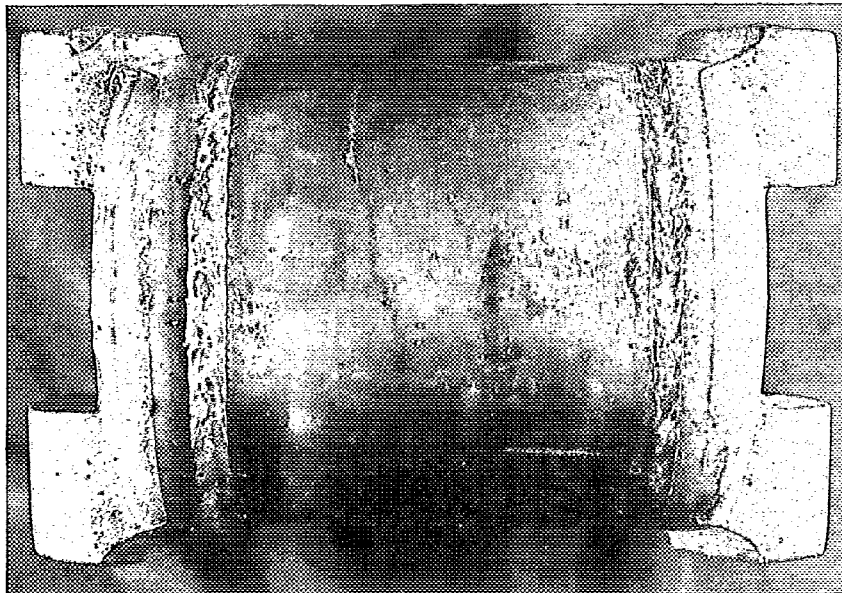
Procedure

Base metal — ASTM A536, Grade 60-40-18 to low carbon steel pipe

Process — FCAW

Filler metal — Nickel-iron-manganese flux cored electrode,
5/64 in. (2 mm)

Welding conditions — 350 A, DCEP, 28V — 26 ipm (11 mm/s) travel speed, electrode
extension 3/4 in. (19 mm).

Illustration

Submitted by:
Anonymous

Application No. 14 — Repair of Cast Iron Water Pump Housing

The water pump housing cracked during a cold weather freeze up. The 6 in. (153 mm) thick wall was excavated 4 in. (102 mm) deep in a U-groove. Welding was with short beads in block sequence. Each bead was peened. The completed weld was stress relieved at 1150°F (620°C) for six hours.

Procedure

Base metal — Not known

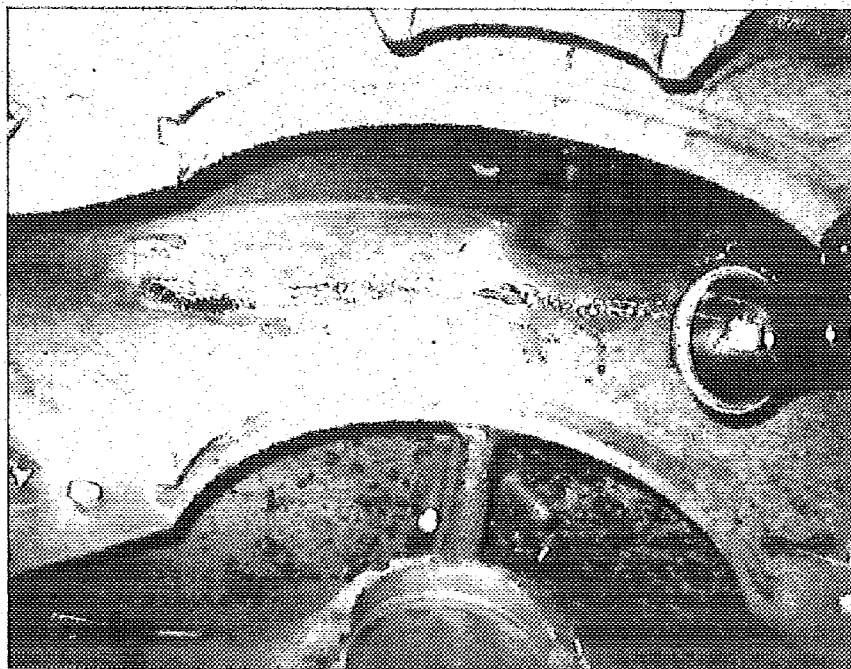
Process — FCAW

Filler metal — Nickel-Iron, Flux-Cored — 3/32 in. (2.4 mm) dia.

Welding conditions — 220–300 A, DCEP, 27–30 V, electrode extension 3/4 in. (20 mm), Shielding gas-carbon dioxide

Preheat temperature — 750°F (400°C)

Interpass temperature — 850°F (455°C)

Illustration

Submitted by:
Weld-Met International, Inc.

Application No. 15 — Surfacing of Axial Compressor Rotor

The screw type rotor was severely eroded by corrosive gases. It was salvaged by weld buildup with ERCuAl-A2 surfacing metal. The rotor was baked three hours at 900°F (510°C) before welding, to drive off volatile contaminants.

Procedure

Base metal — Gray iron

Process — GMAW

Filler metal — ERCuAl-A2, .045 in (1.2 mm) dia. Shielding gas — argon oxygen,
electrode extension 3/4 in. (20 mm) travel speed — 10–15 in/min (4–6 mm/s)

Welding conditions — 125–175 A, 24–26 V, DCEP

Illustration

Submitted by:
Weld-Met International, Inc.

Application No. 16 — Repair of Broken Cast Iron Motor Support

Two legs were broken off the casting during a lift. The legs were beveled and welded. A low-carbon steel plate was welded to each side of the legs as reinforcement. Temper-bead technique was used, and each leg was postheated at 900°F (480°C) for one hour.

Procedure

Base metal — Gray cast iron

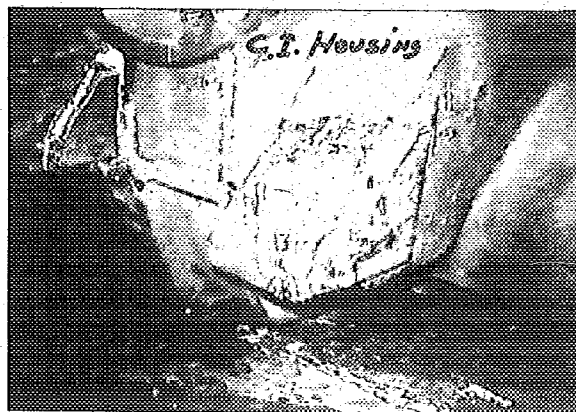
Process — FCAW

Filler metal — Nickel-iron, flux cored, 3/32 in. (2.4 mm) dia.

Welding conditions — 325–350 A, DCEP, 28 V, Shielding gas — Carbon dioxide

Preheat temperature — 600°F (315°C)

Interpass temperature — 750°F (370°C)

Illustration

Submitted by:
Weld-Met International, Inc.

Application No. 17 — Repair of Cast Iron Pump Housing

The housing had become worn in service, and cavitation had penetrated the wall in some areas. All other worn areas were also repaired by weld buildup. The casting was stress-relieved at 1150°F (620°C) after welding.

Procedure

Base metal — Gray cast iron

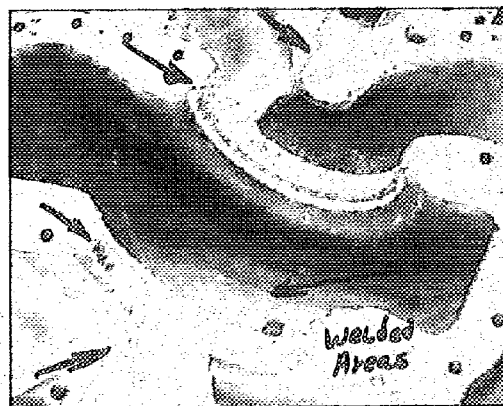
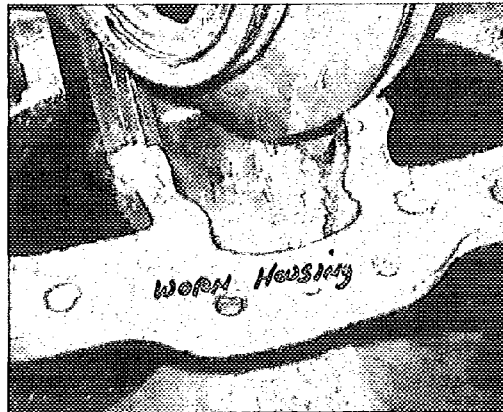
Process — GMAW

Filler metal — Nickel-iron-manganese, bare wire, .045 (1.2 mm) dia.

Welding conditions — 180–225 A, DCEP, 24–28 V, shielding gas-argon/oxygen, electrode extension 5/8 in. (16 mm)

Preheat Temperature — 300°F (150°C)

Interpass Temperature — 500°F (260°C)

Illustration

Submitted by:
Weld-Met International, Inc.

Application No. 18 — Repair of Cast Iron Gear Housing

The housing cracked in service causing severe oil leakage. A new base was fabricated from steel plate and welded to the casting. Steel gusset plates were added to reinforce the repaired housing.

Procedure

Base metal — Ductile cast iron welded to low-carbon steel

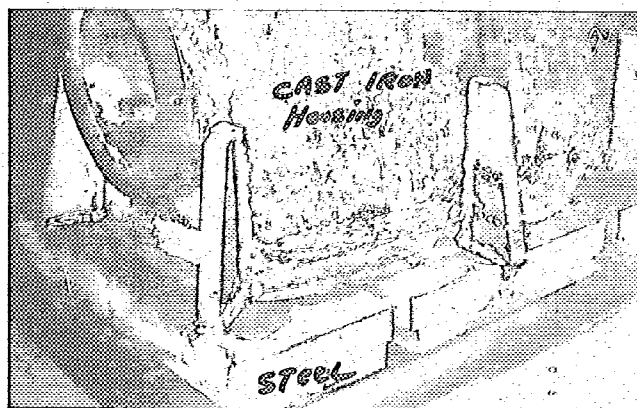
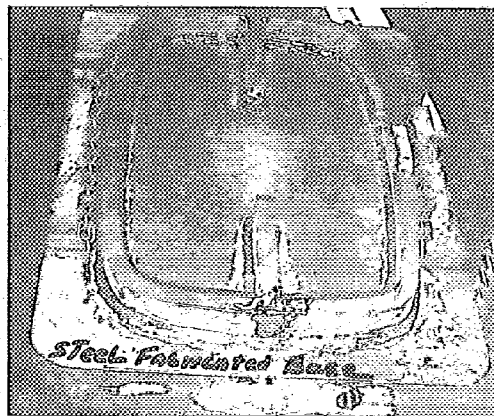
Process — SMAW

Filler metal — ENiFeCI — 1/8 in. (3.2 mm) and 5/32 in. (4 mm) dia.

Welding conditions — 95–150 A, 22–25 V, DCEP

Preheat temperature — 600°F (315°C)

Interpass temperature — 700°F (370°C), slow cool after welding

Illustration

Submitted by:
Weld-Met International, Inc.

Application No. 19 — Salvage of VTL Table

The lower edge of a 52 in. (1321 mm) diameter vertical turret lathe table was worn away. The table was restored by rolling a low-carbon steel ring into the table edge, then welding the ring to the table.

Weld segments were staggered to minimize distortion. Each bead was peened.

Procedure

Base metal — Gray cast iron to low-carbon steel

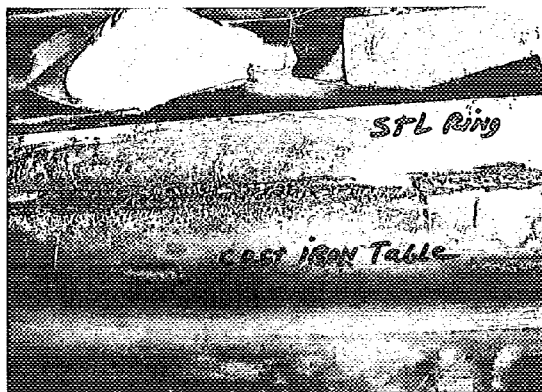
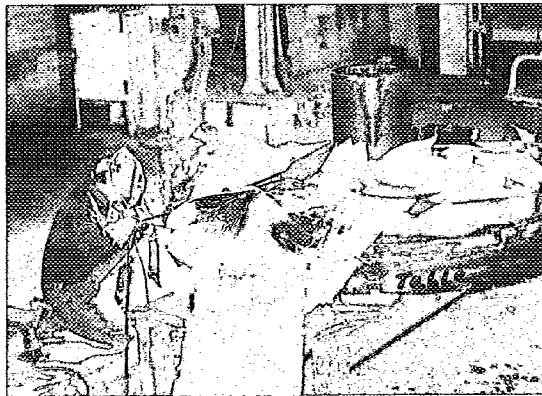
Process — SMAW

Filler metal — ENiFeCl, 1/8 in. (3.2 mm) and 5/32 in. (4 mm) dia.

Welding conditions — 22–23 V, DCEP

Preheat temperature — 600°F (315°C)

Interpass temperature — 700°F (370°C), very slow cool after welding

Illustration

Submitted by:
Weld-Met International, Inc.

Appendix C

Welding Procedure and Performance Qualification

(This appendix is not a part of ANSI/AWS D11.2, *Guide for Welding Iron Castings*, but is included for information purposes only.)

This section sets forth recommendations for the qualification of welding procedures and the performance qualification of welders and welding operators for welding cast irons. It is intended for use in any welding situation where qualified procedures and welders are desired for an application. It is not intended to replace the qualification requirements of AWS or other recognized product codes and specifications.

C1. General

C1.1 Definitions. The terms *plate* and *pipe*, as used in this Appendix, describes a cast shape, and not a wrought product. The term *groove weld* describes a weld made in a casting repair excavation as well as a weld made in the groove between two members to be joined.

C1.2 Welding Procedure Qualification. Each manufacturer or contractor shall be responsible for the welding done by their organization. Detailed written welding procedure specifications shall be maintained along with the necessary qualification test records, as specified herein, to assure the criteria of this document are met. Procedure qualification information shall be recorded on a Procedure Qualification Record (PQR) form. Typical forms for a PQR and a Welding Procedure Specification (WPS) are given at the end of this Appendix. The purpose of qualifying a welding procedure in accordance with this document is to demonstrate that the procedure will produce a sound weld with acceptable tensile properties when required. The PQR shall be signed and dated by an authorized representative of the manufacturer or contractor as being an accurate record.

C1.3 Performance Qualification. Each manufacturer or contractor shall be responsible for conducting the performance tests necessary to qualify welders and welding operators who will apply these weld procedures. Evaluation of the test assemblies may be made by the manufacturer, the contractor, or an outside agency. A typical form for a welder or welding operator performance qualification is given at the end of this Appendix.

The purpose of qualifying welders is to demonstrate their ability to deposit a sound weld with the type of cast iron, welding process, and filler metal in the positions specified by the WPS.

C1.4 Records. Each manufacturer or contractor shall maintain the applicable WPS, PQR, and welder performance qualification records at the job site. These records shall be available to those authorized to inspect them.

C1.5 Welding Processes. The following welding processes may be used to weld cast irons, and qualification requirements for them are detailed herein:

- (1) Oxyfuel gas welding (OFW)
- (2) Shielded metal arc welding (SMAW)
- (3) Gas metal arc welding (GMAW)
- (4) Gas tungsten arc welding (GTAW)
- (5) Flux cored arc welding (FCAW)
- (6) Submerged arc welding (SAW)
- (7) Plasma arc welding (PAW)

C1.6 Classification of Welds. Appendix D describes a classification system of welds in iron castings. Performance and procedure qualifications shall be performed for Class I or Class II welds. Class III welds do not require qualification.

C2. Welding Procedure Qualification

C2.1 WPS Essential Variables are those in which a change is considered to affect the soundness or mechanical properties of the weldment and shall require requalification of the WPS.

C2.2 Essential Variables

C2.2.1 Process. A change from one welding process to another requires requalification of the procedure.

C2.2.2 Base Metals

(1) Group. The various groups of cast irons are listed in Table C1 and are based on the type of material (gray, ductile, malleable, etc.). Use of a material not in the same group requires requalification.

Table C1
Base Metals for Procedure Qualification

Group	Specification	Classification	Tensile Strength (Minimum)	
			Ksi	MPa
A. Gray Iron	ASTM A48	Class 20	20	138
		Class 25	25	172
		Class 30	30	207
		Class 35	35	241
		Class 40	40	276
		Class 45	45	310
		Class 50	50	345
		Class 55	55	379
		Class 60	60	414
	ASTM A74	—	21	145
	ASTM A126	Class A	21	145
		Class B	31	214
		Class C	41	283
	ASTM A159	Grade G1800	18	124
		Grade G2500	25	172
		Grade G3000	30	207
		Grade G3500	35	241
		Grade G4000	40	276
	ASTM A319	Grade I	25	172
		Grade II	30	207
		Grade III	40	276
	SAE J431	Grade G1800	18	124
		Grade G2500	25	172
		Grade G3000	30	207
		Grade G3500	35	241
		Grade G4000	40	276
B. Ductile Iron	SAE J434C	Grade D4018	60	414
		Grade D4512	65	448
		Grade D5506	80	552
		Grade D7003	100	689
	ASTM A536	Grade 60-40-18	60	414
		Grade 65-45-12	65	448
		Grade 80-55-06	80	552
		Grade 100-70-03	100	689
		Grade 120-90-02	120	827
	ASTM A716		60	414
	ASTM A746		60	414

Table C1 (Continued)

Group	Specification	Classification	Tensile Strength (Minimum)	
			Ksi	MPa
C. Malleable Iron				
	ASTM A47	Grade 32510	50	345
		Grade 35018	53	365
	ASTM A197	—	40	276
	ASTM A220	Grade 40010	60	414
		Grade 45006	65	448
		Grade 45008	65	448
		Grade 50005	70	483
		Grade 60004	80	552
		Grade 70003	85	586
		Grade 80002	95	655
		Grade 90001	105	724
	ASTM 602	Grade M3210	50	345
		Grade M4504	65	448
		Grade M5003	75	517
	SAE J158a	Grade M3210	50	345
		Grade M4504	65	448

(2) Carbon equivalent. The carbon equivalent of the base metal used in the procedure qualification shall be determined by actual chemical analysis of the test plates and the following formula:

$$CE = C + 0.31 (Si) + 0.33 (P) + 0.45 (S) \\ - 0.028 (Mn) + Mo + Cr \\ - 0.02 (Ni) - 0.01 (Cu)$$

The procedure shall then be valid for use on all metals within the same group with a CE lower than the CE of the test plates or with a CE no more than 1.1 times the CE of the test plates. Base metals with CE's greater than 1.1 times the CE of the test material require requalification.

(3) Base metal thickness. Requalification is required when a change is made in the range of base metal thickness "T" beyond that qualified as follows:

$$T < 3/8 \text{ in. (9.5 mm)} \\ 3/8 \text{ in.} \leq T < 3/4 \text{ in. (19 mm)} \\ T \geq 3/4 \text{ in.}$$

Qualification on 3/4 in. (19 mm) or thicker base metal qualifies for unlimited base metal thickness.

(4) Preparation. A change in the method of preparing the joint faces and casting surface for welding requires requalification. Such a change might be from a mechanical to a thermal method or vice-versa.

(5) Form of base metal. Welding procedure qualification on cast iron piping shall also qualify for plate, subject to the limitations of the remaining essential variables.

C2.2.3 Filler Metals

(1) General. Selection of the electrode or rod is based on a careful consideration of the requirements of the application and the characteristics of the base metal involved. Due to the broad range of coating composition of covered electrodes which fall under AWS classifications, it is recommended that if qualification is established with Brand "X", the performance of Brand "Y" should be tested before use to help reduce potential problems.

(2) Electrode/rod specifications. The following AWS specifications provide detailed requirements and general applicability of some electrodes used to weld iron castings. Applicability of these materials for welding of iron castings was discussed in section 5. A change in filler material from one specification to another specification, from one classification to another within the same specification, or to a filler metal not covered by a specification, requires requalification of the procedure.

A5.1 Specification for Covered Carbon Steel Arc Welding Electrodes

- A5.2 Specification for Iron and Steel Oxyfuel Gas Welding Rods
- A5.6 Specification for Covered Copper and Copper Alloy Arc Welding Electrodes
- A5.7 Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes
- A5.11 Specification for Nickel and Nickel Alloy Covered Welding Electrodes.
- A5.14 Specification for Nickel and Nickel Alloy Bare Welding Rods and Electrodes
- A5.15 Specification for Welding Rods and Covered Electrodes for Cast Iron
- A5.18 Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding
- A5.20 Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
- A5.27 Specification for Copper and Copper Alloy Rods for Oxyfuel Gas Welding

(3) Deposit thickness. Requalification is required when a change is made in deposit thickness "t" (see Figure C6) beyond that qualified as follows:

- $t < 3/8$ in. (9.5 mm)
- $3/8$ in. $\leq t < 3/4$ in. (19 mm)
- $t \geq 3/4$ in.

Qualification of a $3/4$ in. (19 mm) thick deposit qualifies for all deposit thicknesses greater than $3/4$ inches.

C2.2.4 Joints. Requalification is required when the following applies:

- (1) Groove type. The type of groove (i.e., square, bevel, V-, J-, and U- groove) is changed.
- (2) Groove angle. There is a decrease in the included angle of a groove.
- (3) Groove radius. For a J-groove or U-groove, there is a decrease in the groove radius.
- (4) Root opening. There is a decrease in the root opening of a joint.
- (5) Backing. The backing is deleted.

C2.2.5 Positions. See C2.6 for definitions of welding positions covered by this document.

- (1) Each procedure shall be tested for each position for which it is to be qualified. Within the limits given in C2.6.1, C2.6.2 and C2.6.3, welding in the horizontal position also qualifies for flat position welding, and welding in the 6G position qualifies for all positions.
- (2) A change in the direction (uphill or downhill) specified for vertical position welding requires requalification.

C2.2.6 Preheat and Interpass Temperature. Requalification is required when the following applies:

- (1) There is a decrease in the minimum specified preheat temperature.

(2) There is a change in the specified interpass temperature range.

C2.2.7 Post Weld Heat Treatment (PWHT). Requalification is required when the following applies:

- (1) There is the addition or deletion of PWHT.
- (2) There is a change in the PWHT schedule (time, temperature, heating or cooling rates).

C2.2.8 Welding Technique. Requalification is required when the following applies:

- (1) There is a change from multipass per side to single pass per side.
- (2) There is a change from the stringer bead technique to the weave bead technique or vice versa.
- (3) There is an increase in the maximum length of each weld bead deposited, when specified by the WPS.
- (4) Backgouging for a complete penetration joint is deleted, or the method of backgouging is changed from mechanical to thermal or vice versa.
- (5) Peening is added or deleted.

C2.3 Essential Variables Applicable to Specific Processes

C2.3.1 OFW. Requalification is required when the following applies:

- (1) There is a change in the type of fuel gas.
- (2) There is a change in the type of flame (neutral, oxidizing, or reducing).
- (3) There is an addition or deletion of flux and a change in the brand name or composition of the flux.

C2.3.2 SMAW. Requalification is required when the following applies:

- (1) There is a change in the type of current (AC or DC) or polarity.
- (2) There is a change in the current range for each electrode diameter specified in the WPS.
- (3) There is an increase in the electrode diameter.

C2.3.3 GMAW/FCAW. Requalification is required when the following applies:

- (1) For FCAW, there is a change in the method of shielding (self-shielded versus gas-shielded).
- (2) There is change in the type or composition of the shielding gases.
- (3) There is a change in the polarity or mode of metal transfer across the arc.
- (4) There is an increase in the electrode diameter.
- (5) There is a change in the range of current (wire feed speed) or range of voltage specified by the WPS.

C2.3.4 GTAW. Requalification is required when the following applies:

- (1) There is any change in the type or composition of shielding gases.

- (2) There is a change in polarity.
- (3) There is an increase in the welding rod diameter.
- (4) There is a change in the range of current specified by the WPS.
- (5) There is a change in the type and size of the tungsten electrode.
- (6) There is an addition or deletion of pulsing.
- (7) There is a change in the range of voltage.

C2.3.5 SAW. Requalification is required when the following applies:

- (1) There is a change in composition of the welding flux/wire combination.
- (2) There is a change in range of current (or wire feed speed) or range of voltage specified by the WPS.
- (3) There is a change in range of travel speed.
- (4) There is an increase in the electrode diameter.
- (5) There is a change in type of current (AC or DC) or polarity.
- (6) There is a change in electrode configuration, (i.e., solid wire, tubular cored wire, strip, etc).

C2.3.6 PAW. Requalification is required when the following applies:

- (1) There is any change in the type or composition of shielding gases.
- (2) There is a change in polarity.
- (3) There is an increase in welding rod diameter.
- (4) There is a change in the range of mesh analyses of powder filler materials.
- (5) There is a change in the range of current.
- (6) There is a change in the type and size of the tungsten electrode.
- (7) There is a change in the range of voltage.
- (8) There is the addition or deletion of pulsing.

C2.4 Type of Tests and Purpose. The types of tests outlined below are to determine the soundness and mechanical properties of welds made in accordance with a specific WPS. Testing shall be in accordance with the latest edition of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

C2.4.1 Groove Welds. The following tests shall be used to qualify groove weld procedures.

- (1) Visual inspection
- (2) Magnetic particle or liquid penetrant tests
- (3) Transverse tension test
- (4) Macroetch test for soundness

NOTE: Groove weld procedures qualified with tension tests and macroetch specimens shall also qualify for use with fillet welds in all thicknesses of metal, and all sizes of the fillet welds, within the other essential variables.

C2.4.2 Fillet Welds. The following tests shall be used to qualify fillet weld procedures.

- (1) Visual inspection
- (2) Magnetic particle or liquid penetrant tests
- (3) Macroetch test for soundness

C2.4.3 Overlays. The following tests shall be used to qualify procedures for weld overlays.

- (1) Macroetch test for soundness
- (2) Chemical analysis for applications where control of surface composition is required by a referencing document
- (3) Hardness tests for applications where control of surface composition is required by a referencing document

C2.5 Base Metal Preparation

C2.5.1 The base metal and its preparation for welding shall comply with the WPS. The test weld may be made on a portion of a sample casting, a specially cast test block, a cast iron pipe, or two cast test plates for groove welding. For all types of test welds, the length of the weld and dimensions of the base metal shall provide sufficient material for test specimens required by this document, and provide sufficient restraint to be applicable to production welding conditions.

C2.5.2 Base metal for groove welds shall be radiographically tested (RT) prior to welding. Any defects which would have a detrimental effect on subsequent welding or testing, identified prior to start of welding, shall be cause for rejecting the test plate from further consideration.

C2.6 Position of Test Welds. The following are the standard positions for making weld tests.

C2.6.1 Test Position for Groove Welds. Groove welds may be made in test material which is oriented in any of the positions shown in Figures C1, C2, C3, and described in the following paragraphs. An angular deviation of plus-or-minus 15 degrees from the specified plane is permitted during qualification test welding. Refer to Figure C1 for definitions of welding positions.

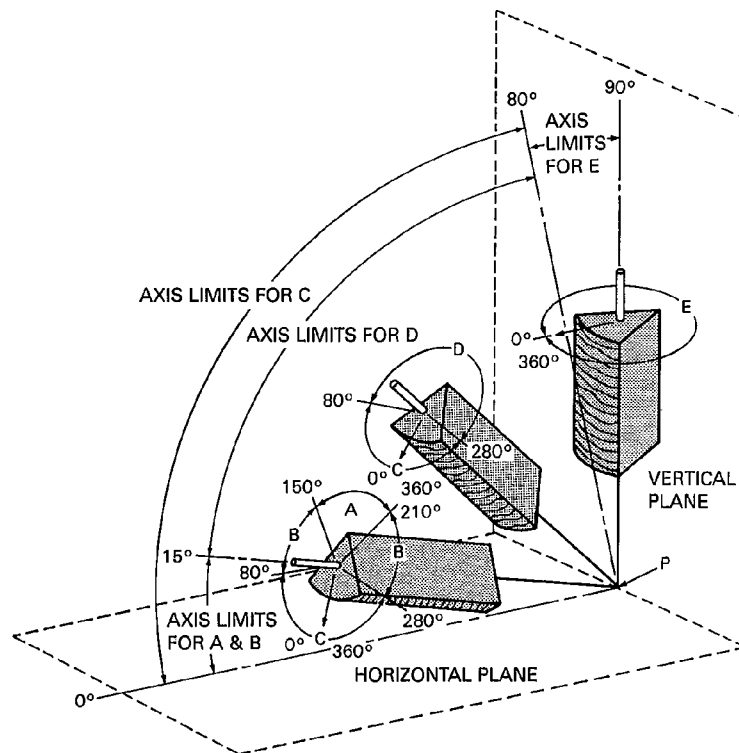
(1) Plate Positions

(a) Flat Position 1G. The plate is in a horizontal plane with the weld metal deposited from above. Refer to Figure C2(A).

(b) Horizontal Position 2G. The plate is in a vertical plane with the axis of the weld horizontal. Refer to Figure C2(B).

(c) Vertical Position 3G. The plate is in a vertical plane with the axis of the weld vertical. Refer to Figure C2(C).

(d) Overhead Position 4G. The plate is in a horizontal plane with the weld metal deposited from below. Refer to Figure C2(D).



TABULATION OF POSITIONS OF GROOVE WELDS			
POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° TO 15°	150° TO 210°
HORIZONTAL	B	0° TO 15°	80° TO 160° 210° TO 280°
OVERHEAD	C	0° TO 80°	0° TO 80° 280° TO 360°
VERTICAL	D	15° TO 80°	80° TO 280°
	E	80° TO 90°	0° TO 360°

Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure C1 — Position of Groove Welds

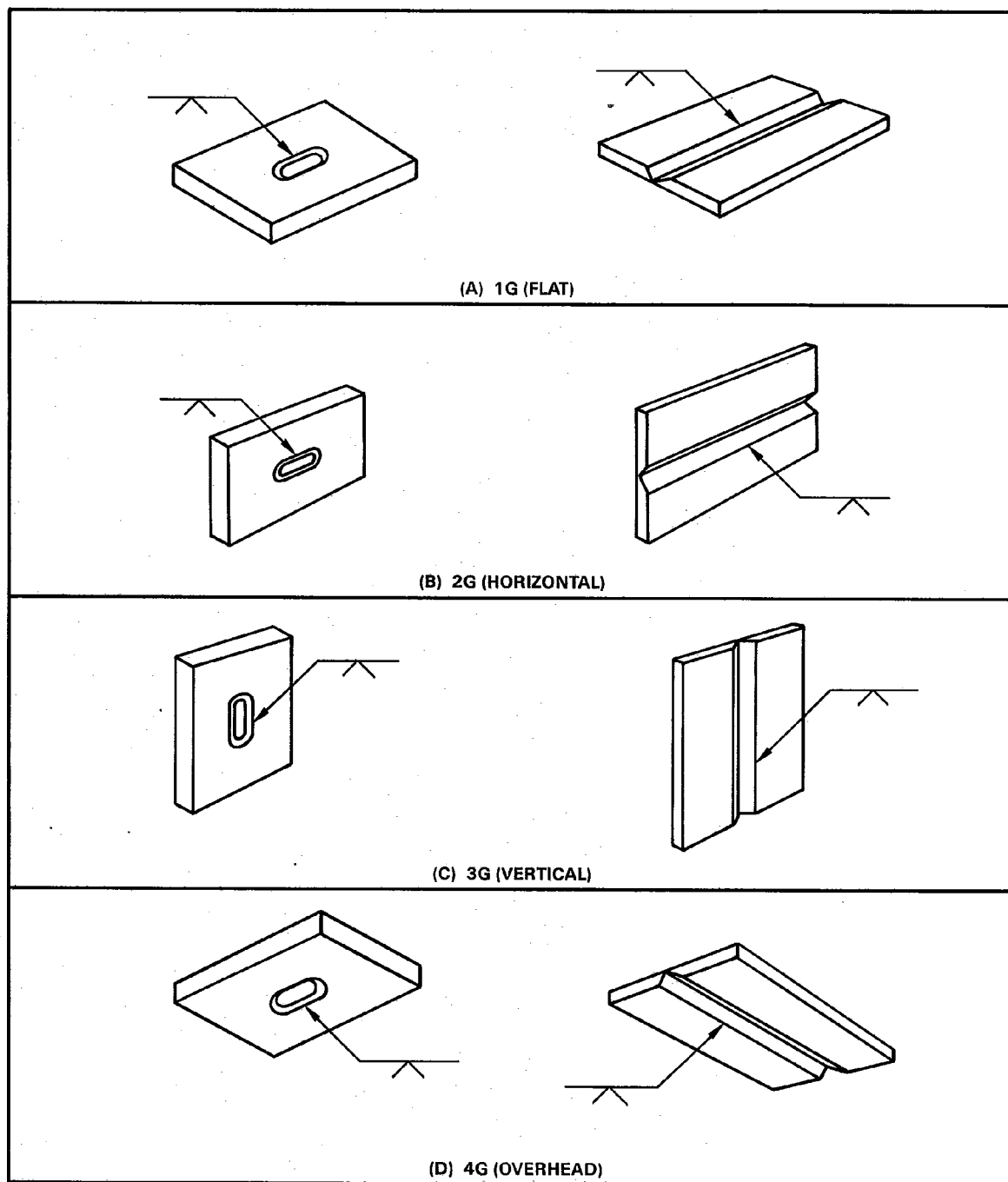


Figure C2 — Test Positions for Groove Welds

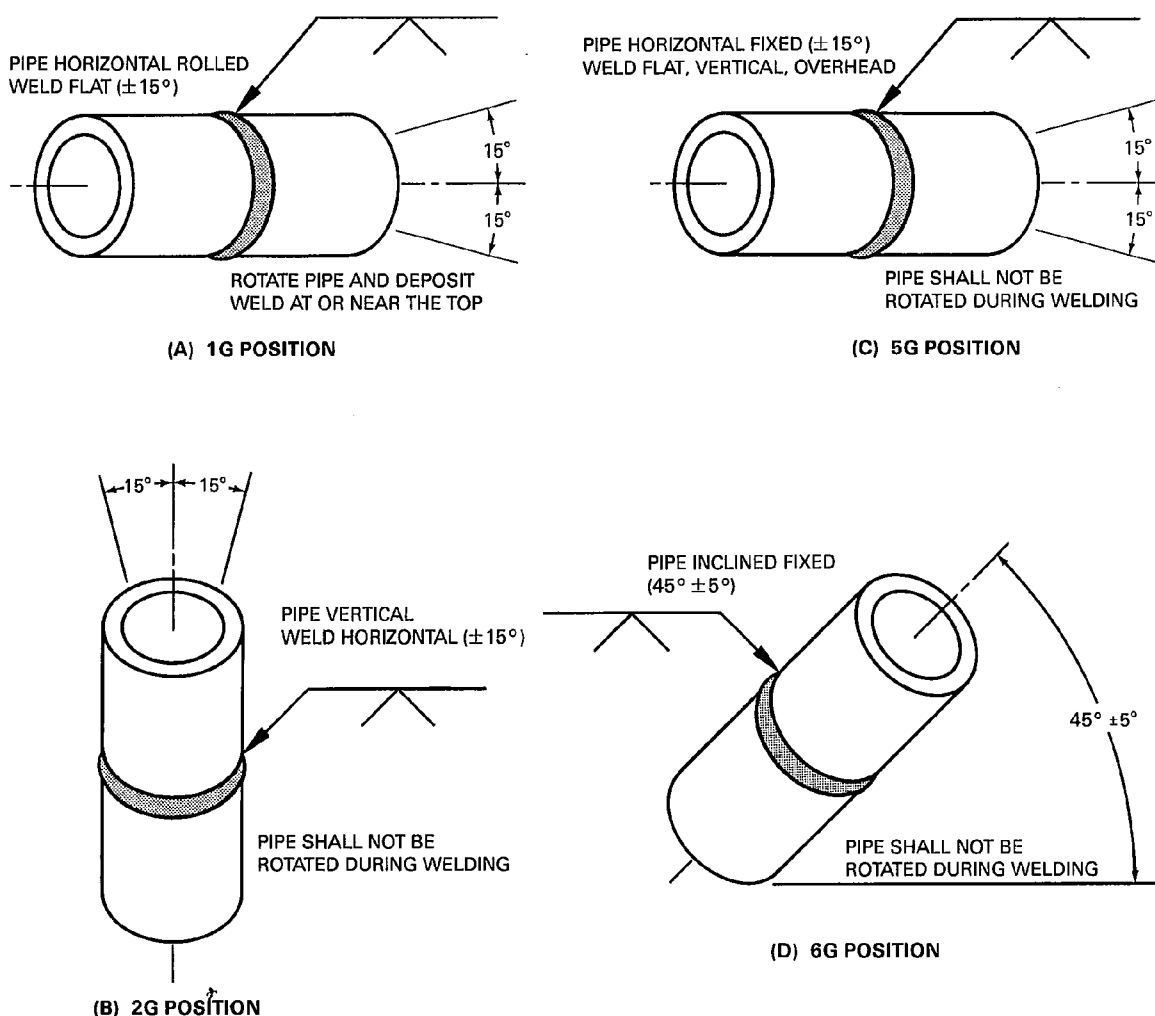


Figure C3 — Positions of Test Pipes for Groove Welds

(2) Pipe Positions

(a) Position 1G. The pipe is rolled during welding with its axis horizontal so that the weld metal is deposited from above. Refer to Figure C3(A).

(b) Position 2G. The pipe axis is vertical, and the axis of the weld is in a horizontal plane. The pipe shall not be rotated during welding. Refer to Figure C3(B).

(c) Position 5G. The pipe axis is horizontal. The pipe shall not be rotated during welding. Weld metal is deposited from a combination of flat, vertical, and overhead positions. Refer to Figure C3(C).

(d) Position 6G. The pipe axis is 45 degrees from the horizontal. The pipe shall not be rotated during welding. Refer to Figure C3(D).

C2.6.2 Test Positions for Fillet Welds. Fillet welds may be made in test material oriented in any of the positions shown in Figures C4 and C5 as described in the following paragraphs. An angular deviation of plus-or-minus 15 degrees from the specified horizontal and vertical planes is permitted during welding.

(1) Plate Positions

(a) Flat Position 1F. Plates are so placed that the weld is deposited with its axis horizontal and its throat vertical.

(b) Horizontal Position 2F. Plates are so placed that the weld is deposited with its axis horizontal and its throat at an angle of 45 degrees to both the horizontal and vertical.

(c) Vertical Position 3F. Plates are so placed that the weld is deposited with its axis vertical.

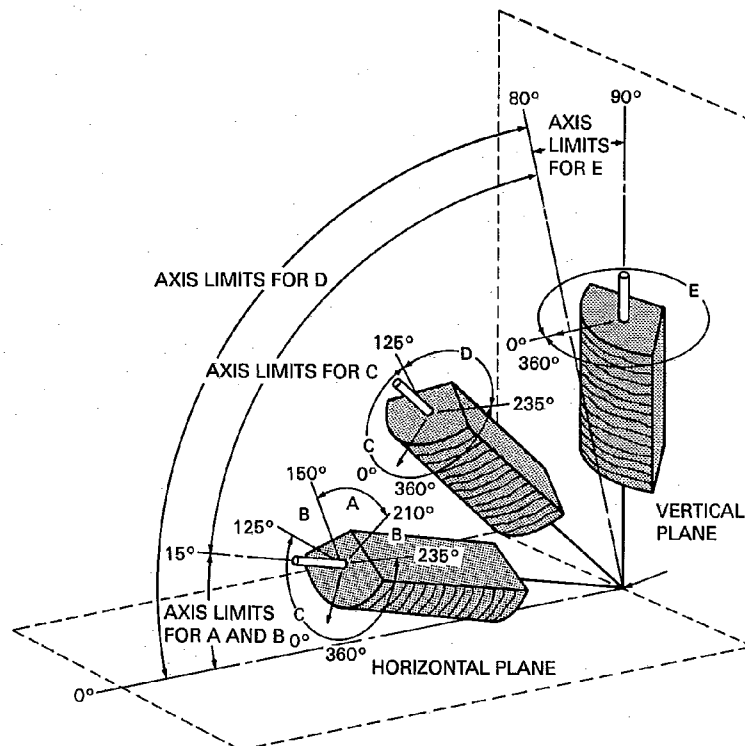
(d) Overhead Position 4F. Plates are so placed that the weld is deposited with its axis horizontal and its throat at an angle of 45 degrees to both the horizontal and vertical. The weld metal is deposited from below.

(2) Pipe Positions

(a) Position 1F. Pipe axis is inclined at 45 degrees to horizontal, and the pipe is rotated during welding so that the weld metal is deposited from above and at the point of deposition the axis of the weld is horizontal and the throat vertical.

(b) Positions 2F and 2FR. In position 2F, the pipe axis is vertical so that the weld is deposited on the upper side of the horizontal surface and against the vertical surface. The axis of the weld will be horizontal and the pipe is not rotated. Refer to Figure C5. In position 2FR, the pipe axis is horizontal and the axis of the deposited weld is in the vertical plane. The pipe is rotated during welding.

(c) Position 4F. The pipe axis is vertical so that the throat of the weld is at an angle of 45 degrees to both the horizontal and vertical planes. The pipe is not rotated and the weld metal is deposited from below.



TABULATION OF POSITIONS OF FILLET WELDS			
POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° TO 15°	150° TO 210°
HORIZONTAL	B	0° TO 15°	125° TO 150° 210° TO 235°
OVERHEAD	C	0° TO 80°	0° TO 125° 235° TO 360°
VERTICAL	D	15° TO 80°	125° TO 235°
	E	80° TO 90°	0° TO 360°

Figure C4 — Position of Fillet Welds

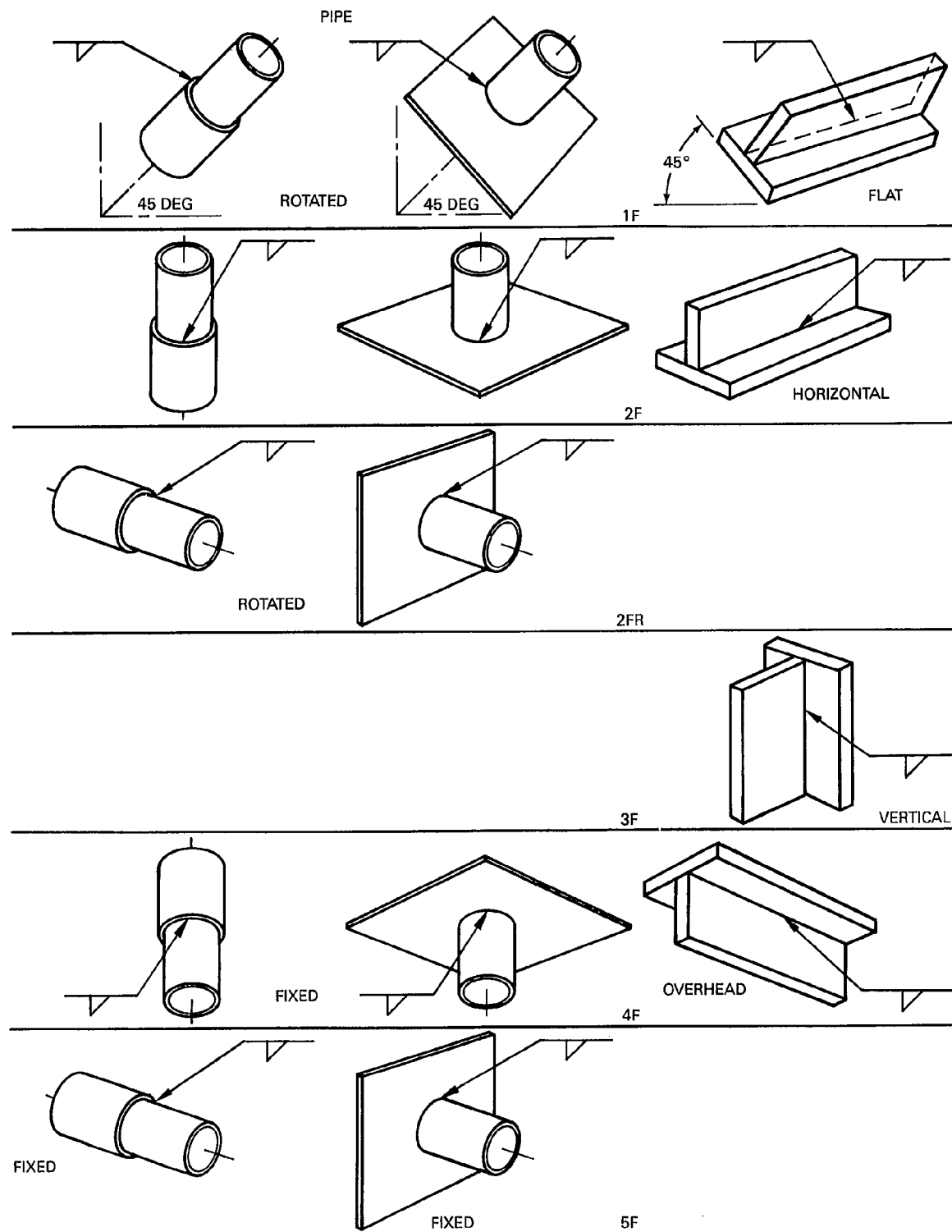


Figure C5—Standard Fillet Weldment Test Positions

(d) Position 5F. The pipe axis is horizontal as with position 2FR. The pipe is not rotated so that weld metal is deposited from a combination of flat, vertical, and overhead positions.

C2.6.3 Test Positions for Surfacing. Surfacing welds may be used on test material which is oriented in any of the positions described in the following paragraphs. An angular deviation of plus-or minus 15 degrees from the specified horizontal and vertical planes and from the specified inclined plane are permitted during qualification test welding. Refer to Figure C1 for definitions of welding positions which are thereby qualified.

(1) Plate Positions

(a) Flat Position 1G. The plate is in a horizontal plane with the weld metal deposited from above.

(b) Horizontal Position 2G. The plate is in a vertical plane with the axis of the weld horizontal.

(c) Overhead Position 4G. The plate is in a horizontal plane with the weld metal deposited from below.

(2) Pipe Positions

(a) Position 1G. The pipe axis is horizontal, and the pipe is rolled during welding so that the weld metal is deposited from above.

(b) Position 2G. The pipe axis is vertical, and the axis of the weld is in a horizontal plane. Pipe shall not be rotated during welding.

(c) Position 5G. The pipe axis is horizontal. The pipe shall not be rotated during welding. Weld metal is deposited from a combination of flat, vertical, and overhead positions.

C2.7 Joint Welding Procedure. The test joint welding procedure shall comply in all respects with the WPS. Weld cleaning shall be done with the test assembly in the same position as the welding position being qualified.

C2.8 Test Plate Requirements. Following are the requirements for testing groove and fillet weld test plates.

C2.8.1 Base materials for procedure and performance qualifications utilizing groove welds shall be radiographically tested (RT) prior to and after completion of welding.

C2.8.1.1 Any defects identified after completion of welding, shall be compared to the preweld radiographs. If an indication or flaw was present prior to welding, and is now considered detrimental, the welded test plate shall be rejected without penalty to the welder or welding operator.

C2.8.1.2 Any defects identified after completion of weld test, that were not present prior to welding, shall be cause for rejection as defined in D2.1. The welder or welding operator may be given an immediate retest, or

additional training prior to retest as determined by the governing authority.

C2.8.2 Procedure Qualification for Groove Welding for Soundness Only. When groove weld joints or repairs in iron castings are not required to meet mechanical properties, the welding procedure may be qualified on the basis of soundness only. However, all the essential variables previously described in sections C2.2 and C2.3 still apply, as a change could be detrimental to the weld soundness.

C2.8.2.1 The surface of the completed test weld shall be visually inspected. Then the weld shall be examined by the magnetic particle or the liquid penetrant method depending on the magnetic properties of the filler metal used.

C2.8.2.2 Three macroetch cross section specimens shall be removed transverse to the test weld as shown in Figure C6(A), (B) or (C) for plate or Figure C6(D) for pipe.

C2.8.3 Procedure Qualification of Groove Welds for Soundness and Mechanical Properties. For groove weld joints and casting repair welds where a minimum tensile strength is required, the welding procedure must be qualified on the basis of both soundness and tensile properties.

C2.8.3.1 The surface of the completed test weld shall be visually inspected and then examined either by magnetic particle or liquid penetrant methods.

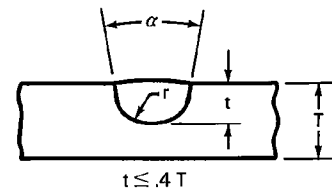
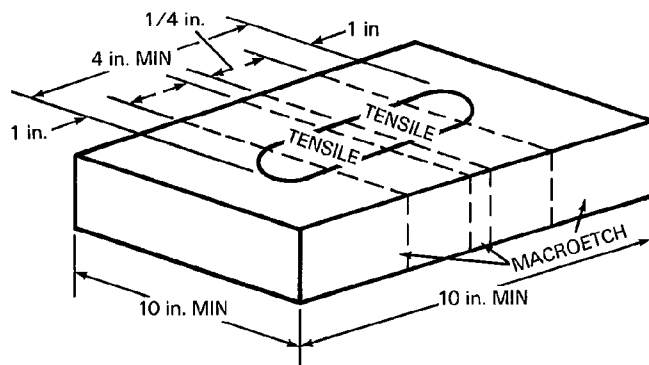
C2.8.3.2 Two transverse tension specimens and three macroetch cross section specimens shall be removed from the test weld as shown in Figure C6(A), (B), or (C) for plate or Figure C6(D) for pipe.

C2.8.4 Fillet Welds. A fillet welded T-joint, as shown in Figure C7 for plate or Figure C8 for pipe (detail A or detail B), shall be made for each procedure and position to be used in construction. One test weld shall be the maximum size single-pass fillet weld, and one test weld shall be the minimum size multiple-pass fillet weld used in construction. The weldment shall be cut perpendicular to the direction of welding at locations shown in Figure C7 or C8, as applicable.

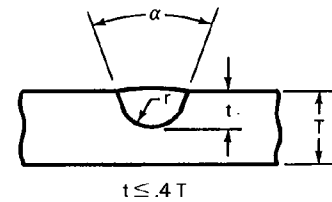
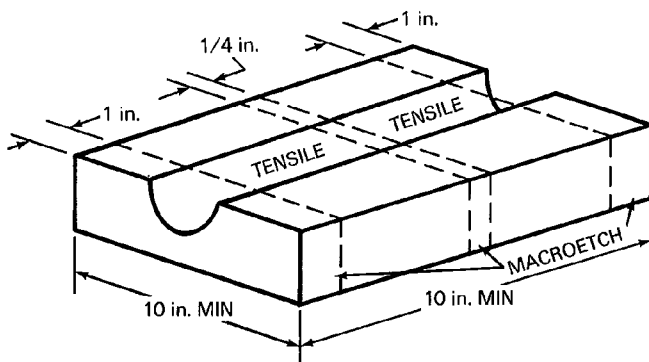
C2.8.5 Nondestructive Examination Methods. The methods for visual, magnetic particle, and liquid penetrant examination are given in section 9, Quality Control. The entire length of the completed test weld, except for the discarded length at each end, shall be examined. For piping or tubing, the entire circumference of the completed weld shall be examined.

C2.8.6 Mechanical Testing. The tension specimens shall be prepared for testing in accordance with Figure

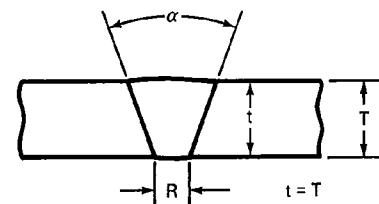
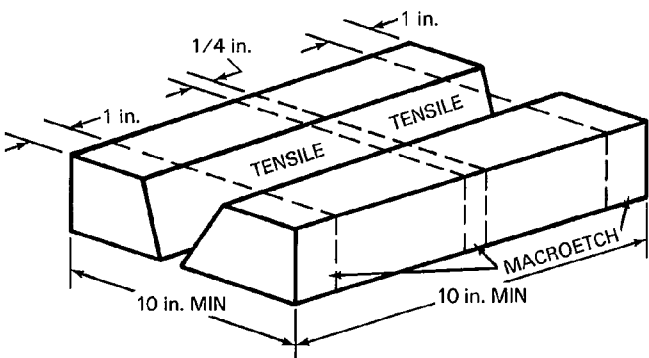
94



(A)



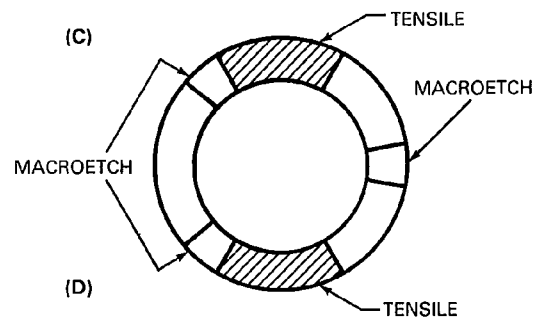
(B)



(C)

FOR METRIC USE

1/4 in.	=	7 mm
1 in.	=	25 mm
4 in.	=	100 mm
10 in.	=	250 mm



(D)

NOTES:

1. When qualification tests are for soundness only, the minimum width of the test plate shall be 5 in. (125 mm).
2. Test plates for joint C must be fully restrained to prevent angular distortion.

Figure C6 — Groove Weld Procedure Qualification Tests for Soundness and Tensile Properties

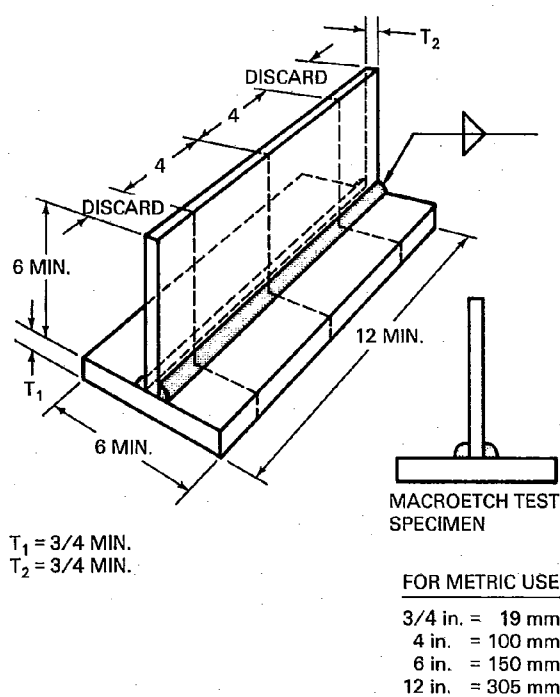


Figure C7 — Fillet Weld Soundness Test for Procedure Qualification

C9 or C10. Specimens representing one face of each cut shall constitute a macroetch test specimen. For weld deposits less than 3/4 in. (19 mm) thick, tension specimens shall be prepared in accordance with Figure C10.

C2.9 Procedure Qualification of Surfacing for Soundness, Chemistry, and Hardness. A surfaced area 2 in. (50 mm) wide by 6 in. (150 mm) long shall be welded on plate of 3/4 in. (19 mm) minimum thickness or on pipe of 1/4 in. (6.4 mm) minimum wall thickness. The thickness of the overlay shall be the maximum thickness qualified.

C2.9.1 Macro-Examination. Three cross sections shall be polished and etched to provide a clear definition of the surfacing metal and heat affected zone. One cross section shall be taken between 1 in. (25 mm) and 1-1/2 in. (40 mm) from the start of the weld. Another shall be taken at approximately 3 in. (75 mm) from the start of the weld. The third shall be taken from between 4-1/2 in. (120 mm) and 5 in. (130 mm) from the start of the weld. Visual examination of the etched surfaces shall be without magnification.

C2.9.2 Chemical Composition. When required by a referencing document, a chemical analysis of the surfacing shall be performed. To be qualified, the surfacing

composition shall meet the minimum requirements of the referencing document.

C2.9.3 Hardness. When required by a referencing document, a minimum of three readings shall be taken at the area of minimum weld thickness. To be qualified, none of the readings shall be less than the hardness specified in the referencing document.

C3. Inspection Results Required

C3.1 Nondestructive Examination. Visual, magnetic particle, and dye penetrant examination results shall meet the requirements of Appendix D, Table D2, Class I or Class II.

C3.2 Tension Test. The tensile strength shall be as follows:

C3.2.1 Gray iron base metals: 80 percent of the minimum specified base metal strength.

C3.2.2 Ductile iron and white heart malleable iron base metals: 100 percent of the minimum specified base metal strength.

C3.3 Macroetch Test for Joint Weld and Fillets. The macroetch test specimen shall conform to the following requirements:

C3.3.1 All welds shall meet the requirements of Appendix D, Table D2, Class I or Class II.

C3.3.2 Partial penetration groove joint welds shall have the designated effective throat.

C3.3.3 Fillet welds shall show complete fusion, freedom from cracks, and no more than 1/8 in. (3 mm) difference in the fillet leg lengths.

C3.4 Macroetch Test for Overlays

C3.4.1 Overlays for Build-up or Corrosion Resistance, or Both. The macroetch test specimen shall conform to the following requirements:

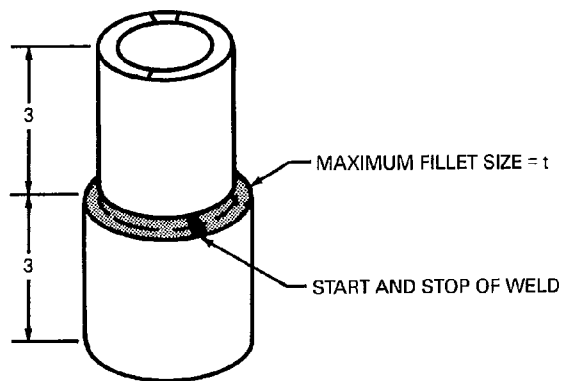
(1) Those listed in Appendix D, Table D2, Class I or Class II.

(2) Separations along the fusion line are not permitted.

C3.4.2 Overlays for Wear Resistance. The macroetch test shall conform to the following requirements:

(1) No areas of separation along the fusion line or incomplete fusion are permitted.

(2) Cracks are permitted, provided that the cracks are confined to the overlay and the heat affected zone.

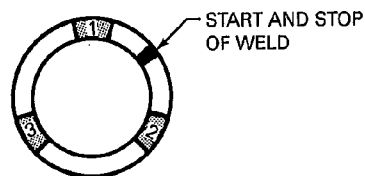


DETAIL A—PIPE-TO-PIPE ASSEMBLY



MACROETCH TEST SPECIMEN

NOTE: PIPE SHALL BE OF SUFFICIENT THICKNESS TO PREVENT MELT-THROUGH.

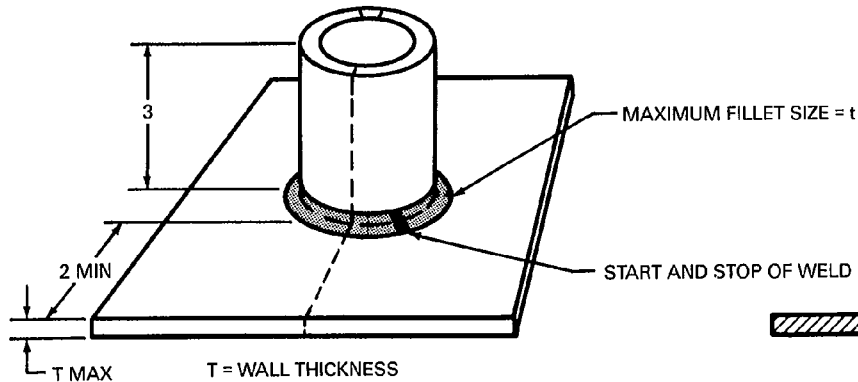


1F ROLLED, 2F, 2F ROLLED

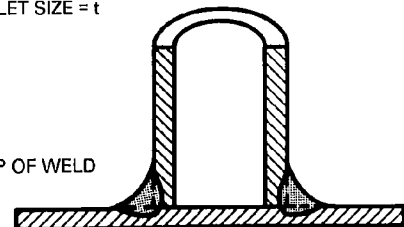
METRIC VALUES

2 in.	50 mm
3 in.	75 mm

LOCATION OF TEST SPECIMEN ON WELDED PIPE—PROCEDURE QUALIFICATION.
THE MACROETCH SPECIMENS ARE TO BE TAKEN FROM AREAS FREE OF
STARTS AND STOPS.



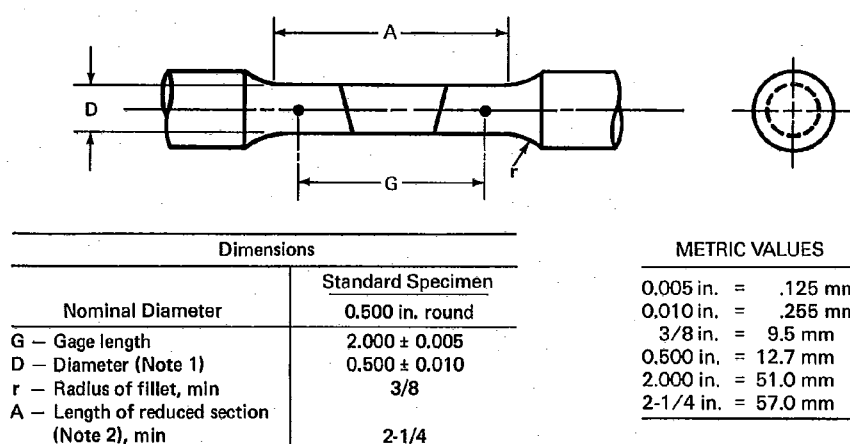
DETAIL B—PIPE-TO-PLATE ASSEMBLY



MACROETCH TEST SPECIMEN

NOTE: PIPE SHALL BE OF SUFFICIENT THICKNESS TO PREVENT MELT-THROUGH.

Figure C8 — Pipe Fillet Weld Soundness Test — Procedure and Performance Qualification

**Notes:**

1. The reduced section may have a gradual taper from the ends toward the center, with the ends not more than one percent larger in diameter than the center (controlling dimension).
2. If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should be spaced at the indicated gage length.
3. The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in wedge grips, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.

Figure C9 — Round Tension Specimens

C4. Welder and Welding Operator Qualification

C4.1 General. The performance qualification tests described herein are devised to determine the welder's or welding operator's ability to produce sound welds. The welder or welding operator shall follow a qualified welding procedure specification in performing the test.

C4.2 Essential Variables. The essential variables listed below shall apply to all processes.

C4.2.1 Qualification shall be for each process used.

C4.2.2 The qualification test plate shall be of the base material group to be joined in production (i.e., gray, ductile, etc.).

C4.2.3 For groove welds, the base metal thickness shall be qualified as follows:

$T < 3/8$ in. (9.5 mm)
 $3/8$ in. $\leq T < 3/4$ in. (19 mm)
 $T \geq 3/4$ in.

Qualification on $3/4$ in. (19 mm) thick base metal qualifies for all base metal thicknesses greater than $3/4$ in.

C4.2.4 A change from one filler metal F-number in Table C2 to any other F-number or to any other filler metal not listed in Table C2 shall require requalification.

C4.2.5 The weld deposit thickness, *t*, shall be qualified as follows:

$t < 3/8$ in. (9.5 mm)
 $3/8$ in. $\leq t < 3/4$ in. (19 mm)
 $t \geq 3/4$ in.

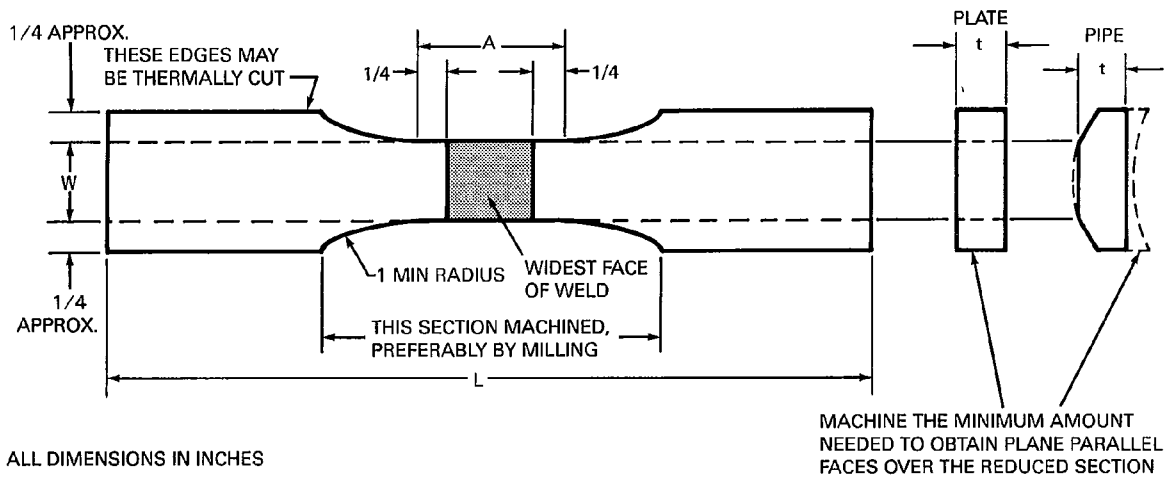
Qualification of a $3/4$ in. (19 mm) thick deposit qualifies for all deposit thicknesses greater than $3/4$ inches.

C4.2.6 A change in welding position requires requalification, except welding in the horizontal position also qualifies for the flat position, and welding in the 6G position qualifies for all positions.

C4.2.7 A change in the direction specified for welding in the vertical position (uphill or downhill) shall require requalification.

C4.3 Specific Essential Variables. Following are the essential variables which shall require requalification of each listed process.

C4.3.1 Oxyfuel Welding. For this process, requalification shall be required by a change in the type of fuel gas or the addition of backing to a joint.



ALL DIMENSIONS IN INCHES

	Dimensions				METRIC VALUES	
	Plate Test		Pipe Test		in.	mm
	$T \leq 1$ in.	$T \geq 1$ in.	2 in. & 3 in. Diameter	6 in. & 8 in. Diameter or Large Job Size Pipe		
A - Length of reduced section, in.	Widest face of weld + 1/2, 2-1/4 min		Widest face of weld + 1/2 in., 2-1/4 min		1/4	6.3
L - Overall length, approximate	10" or as required by testing equipment		10" or as required by testing equipment		1/2	12.7
W - Approximate, in.	1-1/2	1	1/2	3/4	3/4	19
t - Specimen thickness	T	T	Maximum possible with plane parallel faces within length A		1	25.4
					1-1/2	38
					2	51
					2-1/4	57
					3	76
					6	152
					8	203
					10	254

Notes:

1. T = thickness of the plate.
2. The ends of the reduced section shall not differ in width by more than 0.004 in. There may be a gradual decrease in width from the ends to the center, but the width at either end shall not be more than 0.015 in. larger than the width at the center.

Figure C10 — Reduced Section Tension Specimens

Table C2
Filler Metal Classification

AWS F No.	AWS A5.X/ Spec. No.	AWS Classification No.
<u>Steel and Steel Alloys</u>		
1	1	EXX20, EXX24, EXX27, EXX28
4	1	EXX15, EXX16, EXX18
6	2	RX
6	18	ERXXS-X
<u>Copper and Copper Alloys</u>		
33	6	ECuSn-A, ECuSn-C
33	7	ERCuSn-A
35	7	RBCuZn-A, RBCuZn-B, BCuZn-C, RBCuZn-D
36	6	ECuAl-A2
36	7	ERCuAl-A2
37	6	ECuNiAl, ECuMnNiAl
38	27	ERCuNiAl, ERCuMnNiAl
<u>Nickel and Nickel Alloys</u>		
41	11	ENi-I
41	14	ERNi-1
71	13	RXXX-X, EXXX-X
72	21	RXXX-X
<u>Cast Iron Base Electrodes</u>		
81	15	RCI, RCI-A
82	15	RCI-B
<u>Steel Base Electrodes</u>		
83	15	ESi
<u>Nickel Base Electrodes</u>		
84	15	ENiFe-CI
85	15	ENiFe-CI-A
86	15	ENi-CI
87	15	ENi-CI-A
88	15	ENiCu-A, ENiCu-B

C4.3.2 Gas Metal Arc. Any change in the mode of transfer shall require requalification.

C4.3.3 Gas Tungsten Arc Welding. For this process, requalification shall be required by a change in polarity.

C4.4 Performance Qualification Tests and Specimens Required

C4.4.1 Groove Welds. The performance tests and specimens shall be the same as required for procedure qualification for soundness as given in C2.8. Qualification tests for welding operators shall be conducted in continuous grooves shown in Figure C6(B), (C), or (D).

C4.4.2 Fillet Welds. The performance tests and specimens required for qualification shall be as shown in Figure C11 for plate and Figure C8 for pipe.

C4.4.3 Limits of Qualified Positions — Groove Welds. Welders and welding operators who pass the required tests for groove welds in plate, in a specific test position, shall be qualified in the same position for groove and fillet welds on pipe of nominal size six inches or larger. In addition, welders and welding operators who pass the required tests for groove welds shall also be qualified to make fillet welds in all thicknesses and pipe diameters of any size within the limits of the essential variables.

C4.4.4 Limits of Qualified Positions — Fillet Welds. Welders who pass the required tests for fillet welds shall be qualified to make fillet welds only in the position tested and shall be qualified in all thicknesses of material, sizes of fillet welds, and diameters of pipe.

C4.5 Preparation of Specimens and Methods of Testing and Inspection. Preparation of the macroetch test specimens and the testing and inspection methods shall be the same as for the procedure qualification tests.

C4.6 Test Results Required. For acceptable qualification, the macroetch test results shall conform to the requirements of Appendix D, Table D2, Class I or Class II.

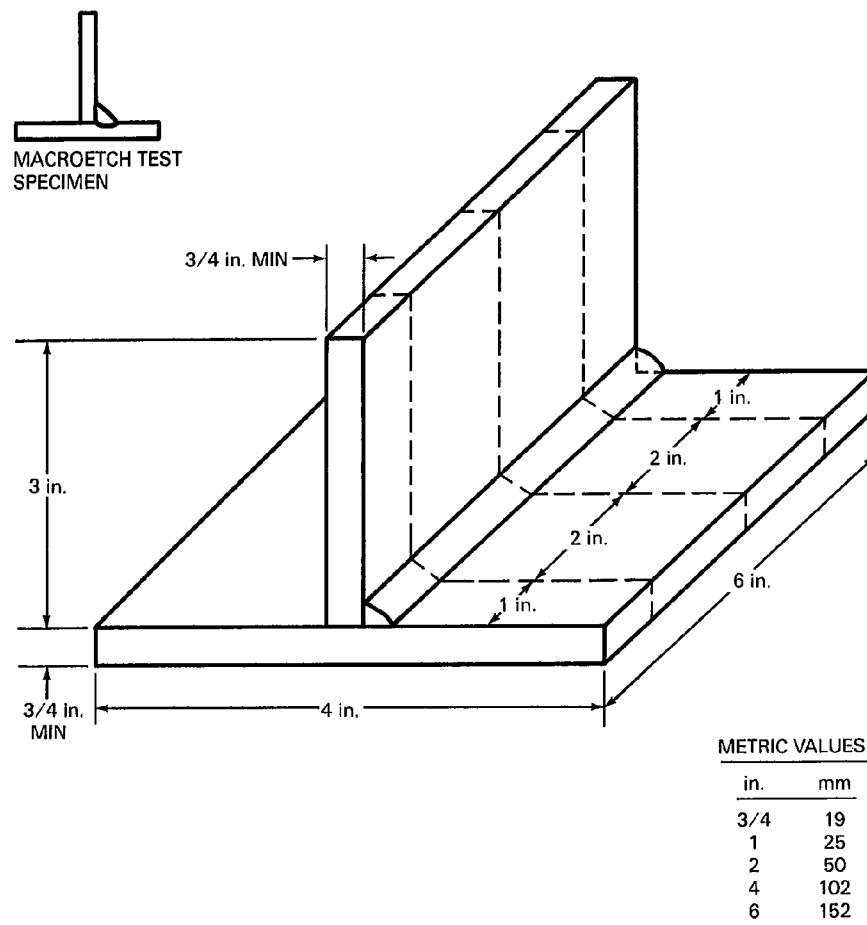


Figure C11 — Fillet Weld Soundness Test for Performance Qualification

SUGGESTED WELDING PROCEDURE SPECIFICATION (WPS)

Date _____		Identification _____	
Company name _____		Revision _____	
Supporting PQR no.(s) _____	Type - Manual ()	Semi-Automatic ()	
Welding process(es) _____	Machine ()	Automatic ()	
Backing: Yes () No ()			
Backing material (type) _____			
Material number _____	Group _____	To material number _____	Group _____
Material spec. type and grade _____		To material spec. type and grade _____	
Base metal thickness range: Groove _____		Fillet _____	
Deposited weld metal thickness range _____			
Filler metal F no. _____		A no. _____	
Spec. no. (AWS) _____		Flux tradename _____	
Electrode-flux (Class) _____		Type _____	
Consumable insert: Yes () No ()		Classifications _____	
		Shape _____	
Position(s) of joint _____		Size _____	
Welding progression: Up () Down ()		Ferrite number (when reqd.) _____	
PREHEAT:		GAS:	
Preheat temp., min _____		Shielding gas(es) _____	
Interpass temp., max _____		Percent composition _____	
(continuous or special heating, where applicable, should be recorded)		Flow rate _____	
		Root shielding gas _____	
POSTWELD HEAT TREATMENT:		Trailing gas composition _____	
Temperature range _____		Trailing gas flow rate _____	
Time range _____			
Tungsten electrode, type and size _____			
Mode of metal transfer for GMAW: Short-circuiting () Globular () Spray ()			
Electrode wire feed speed range: _____			
Stringer bead ()		Weave bead ()	
		Peening: Yes () No ()	
Oscillation _____			
Standoff distance _____			
Multiple () or single electrode ()			
Other _____			

Filler metal					Current		
Weld layer(s)	Process	Class	Dia.	Type & polarity	Amp range	Volt range	Travel speed range
							e.g., Remarks, comments, hot wire addition, technique, torch angle, etc.

Form C5

Approved for Production by _____

Employer

Note: Those items that are not applicable should be marked N.A.

SUGGESTED PROCEDURE QUALIFICATION RECORD (PQR)

Page 1 of 2

WPS no. used for test _____ Welding process(es) _____
 Company _____ Equipment type and model (sw) _____
 Weld Class Qualified _____

JOINT DESIGN USED (C2.2.4)**WELD INCREMENT SEQUENCE**

Single () Double weld ()

Backing material _____

Root opening _____ Root face dimension _____

Groove angle _____ Radius (J-U) _____

Back gouging: Yes () No () Method _____

BASE METALS (C2.2.2)

Material spec. _____ To _____

Type or grade _____ To _____

Material no. _____ To material no. _____

Group no. _____ To group no. _____

Thickness _____

Diameter (pipe) _____

Surfacing: Material _____ Thickness _____

Chemical composition _____

Other _____

FILLER METALS (C2.2.3)

Weld metal analysis A no. _____

Filler metal F no. _____

AWS specification _____

AWS classification _____

Flux class _____ Flux brand _____

Consumable insert: Spec. _____ Class. _____

Supplemental filler metal spec. _____ Class. _____

Non-classified filler metals _____

Consumable guide (ESW) Yes () No ()

Supplemental deoxidant (EBW) _____

POSITION (C2.2.5)

Position of groove _____ Fillet _____

Vertical progression: Up () Down ()

PREHEAT (C2.2.6)

Preheat temp., actual min _____

Interpass temp., actual max _____

POSTWELD HEAT TREATMENT (C2.2.7)

Temp. _____

Time _____

Other _____

GAS (C2.3.3)

Gas type(s) _____

Gas mixture percentage _____

Flow rate _____

Root shielding gas _____ Flow rate _____

EBW vacuum () Absolute pressure ()

ELECTRICAL CHARACTERISTICS (C2.3)

Electrode extension _____

Standoff distance _____

Transfer mode (GMAW) _____

Electrode diameter tungsten _____

Type tungsten electrode _____

Current: AC () DCEP () DCEN () Pulsed ()

Heat input _____

EBW: beam focus current _____ Pulse freq. _____

Filament type _____ Shape _____ Size _____

Other _____

TECHNIQUE (C2.3)

Oscillation frequency _____ Weave width _____

Dwell time _____

String or weave bead _____ Weave width _____

Multi-pass or single pass (per side) _____

Number of electrodes _____

Peening _____

Electrode spacing _____

Arc timing (SW) _____ Lift ()

PAW: Conventional () Key hole ()

Interpass cleaning: _____

Pass no.	Filler metal size	Amps	Volts	Travel speed (ipm)	Filler metal wire (ipm)	Slope induction	Special notes (process, etc.)

Note: Those items that are not applicable should be marked N.A.

Form C6

TENSILE TEST SPECIMENS: SUGGESTED PROCEDURE QUALIFICATION RECORD

PQR No. _____

Type: _____ Tensile specimen size: _____

Groove () Reinforcing bar () Stud welds ()

Tensile test results: (Minimum required UTS _____ psi)

Specimen no.	Width, in.	Thickness, in.	Area, in. ²	Max load lbs	UTS, psi	Type failure and location

GUIDED BEND TEST SPECIMENS - SPECIMEN SIZE: _____

Type	Result	Type	Result

MACRO-EXAMINATION RESULTS:

Reinforcing bar () Stud ()
1. _____ 4. _____
2. _____ 5. _____
3. _____

SHEAR TEST RESULTS - FILLETS:

1. _____ 3. _____
2. _____ 4. _____

IMPACT TEST SPECIMENS

Type: _____ Size: _____

Test temperature: _____

Specimen location: WM = weld metal; BM = base metal; HAZ = heat affected zone

Test results:

Welding position	Specimen location	Energy absorbed (ft.-lbs.)	Ductile fracture area (percent)	Lateral expansion (mils)

IF APPLICABLE**RESULTS**

Hardness tests: () Values _____ Acceptable () Unacceptable ()
Visual () Acceptable () Unacceptable ()
Torque () psi Acceptable () Unacceptable ()
Proof test () Method _____ Acceptable () Unacceptable ()
Chemical analysis () Acceptable () Unacceptable ()
Non-destructive exam () Process _____ Acceptable () Unacceptable ()
Other _____ Acceptable () Unacceptable ()
Mechanical Testing by (Company) _____ Lab No. _____

We certify that the statements in this Record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of the American Welding Society Guide for Welding Iron Castings, (AWS D11.2).

Qualifier: _____

Date: _____

Form C6

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SUGGESTED PERFORMANCE QUALIFICATION TEST RECORD

Name _____ Identification _____ Welder () Operator ()
 Social security number: _____ Qualified to WPS no. _____
 Process(es) _____ Manual () Semi-Automatic () Automatic () Machine ()
 Test base metal specification _____ To _____
 Material number _____ To _____
 Fuel gas (OFW) _____ Weld Class Qualified _____
 AWS filler metal classification _____ F no. _____
 Backing: Yes () No () Double () or Single side ()
 Current: AC () DC () Short-circuiting arc (GMAW) Yes () No ()
 Consumable insert: Yes () No ()
 Root shielding: Yes () No ()

TEST WELDMENT	POSITION TESTED	WELDMENT THICKNESS (T)
GROOVE:		
Pipe	1G () 2G () 5G () 6G () 6GR ()	Diameter(s) _____ (T) _____
Plate	1G () 2G () 3G () 4G ()	(T) _____
Rebar	1G () 2G () 3G () 4G ()	Bar size _____ Butt () Spliced butt ()
FILLET:		
Pipe ()	1F () 2F () 3F () 4F () 5F ()	Diameter _____ (T) _____
Plate ()	1F () 2F () 3F () 4F ()	(T) _____
Other (describe) _____		

Test results:	Remarks
Visual test results	N/A () Pass () Fail ()
Bend test results	N/A () Pass () Fail ()
Macro test results	N/A () Pass () Fail ()
Tension test	N/A () Pass () Fail ()
Radiographic test results	N/A () Pass () Fail ()
Penetrant test	N/A () Pass () Fail ()

QUALIFIED FOR:**PROCESSES**

GROOVE:	THICKNESS
Pipe 1G () 2G () 5G () 6G () 6GR ()	(T) Min _____ Max _____ Dia _____
Plate 1G () 2G () 3G () 4G ()	(T) Min _____ Max _____
Rebar 1G () 2G () 3G () 4G ()	Bar size _____ Min _____ Max _____
FILLET:	
Pipe 1F () 2F () 4F () 5F ()	(T) Min _____ Max _____
Plate 1F () 2F () 3F () 4F ()	(T) Min _____ Max _____
Rebar 1F () 2F () 3F () 4F ()	Bar size _____ Min _____ Max _____

Weld cladding () Position(s) _____ T Min _____ Max _____ Clad Min _____
 Consumable insert () Backing type ()
 Vertical Up () Down ()
 Single side () Double side () No backing ()
 Short-circuiting arc () Spray arc () Pulsed arc ()
 Reinforcing bar - butt () or Spliced butt ()

The above named person is qualified for the welding process(es) used in this test within the limits of essential variables including materials and filler metal variables of the AWS Guide for Welding Iron Castings (AWS D11.2).

Date tested _____ Signed by _____ Qualifier _____
 Form C7

Appendix D

Recommended System for Classification of Welds in Iron Castings, and Associated Quality Levels

(This appendix is not a part of ANSI/AWS D11.2, *Guide for Welding Iron Castings*, but is included for information purposes only.)

D1. Classification of Welds in Iron Castings

Welds in iron castings are divided into three classifications according to the location of the repair, the type of weld or joint, and the type of cast iron:

Class I. Class I welds are in the most critical areas of the casting. They are major repair welds or complete joint penetration welds in ductile or white heart malleable iron castings where the minimum specified base metal tensile strength is required. Ductility requirements should be as agreed upon between the purchaser and supplier.

Class II. Class II welds are identical to Class I welds, except that the base metal is gray iron. Since this type of cast iron has practically no ductility, no requirements for ductility in the welded area are specified. Strength of the welded area must be 80 percent of the minimum specified base metal strength or as agreed upon between the purchaser and supplier.

Class III. Class III welds are the same type of welds in the same material as described for Class I and II weldments; however, they are located in noncritical areas, so weld strength and ductility are not specified.

D2. Test Requirements

Inspection methods are assigned, based on their sensitivity and the class of weld to be examined. Testing required for each class is given in Table D1.

D2.1 Acceptance Criteria for Radiographic Tests. The following weld defects shown by radiography shall be unacceptable:

- (1) Any cracks or linear indications
- (2) Any elongated slag inclusions over 1/4 in. (6.4 mm) for weld thicknesses to 1/2 in. (12.7 mm) and over 1/2 in. for weld thicknesses over 1/2 in.
- (3) Any group of slag inclusions per 6 in. (152 mm) of weld length that have a cumulative length greater than:
 - (a) 1/2 in. (12.7 mm) for weld thicknesses to 1/2 in.
 - (b) 1 in. (25.4 mm) for weld thicknesses 1/2 in. or greater
- (4) Any rounded indications exceeding 1/8 in. (3.2 mm) in diameter
- (5) Any group of rounded indications with diameters 1/32 in. (0.8 mm) or greater, when the sum of their diameters exceeds 1/4 in. (6.4 mm) per square inch (645 mm²)

Table D1
Weld Quality Control Requirements
for Welds in Iron Castings

Weld Class	Visual Inspection	Magnetic Particle or Liquid Penetrant Tests ¹		Radiography ²
I	Yes	Yes		Yes
II	Yes	Yes		Yes
III	Yes	Yes		No

1. Acceptance criteria per Table D2.

2. Acceptance criteria per D2.1.

Table D2
Acceptance Criteria for Magnetic Particle,
Dye Penetrant, and Visual Tests

Weld Class	Linear Discontinuities ¹	Undercut ²	Rounded Discontinuities	Weld Surface Appearance
I, II	None Allowed	None Allowed	Rounded discontinuities with any dimensions exceeding 1/16 in. (1.6 mm) not permitted. The sum of discontinuities with diameters 1/16 in. (1.6 mm) or less not to exceed: (1) 1/4 in. (6.4 mm) per inch (25.4 mm) (2) 1/2 in. (12.7 mm) per 12 in. (305 mm) of weld lengths. Four or more discontinuities in a line separated by 1/16 in. (1.6 mm) or less not permitted.	Reinforcement ground or machined flush, with no irregularities
III	One linear discontinuity 1/8 in. (3.2 mm) maximum length	1/32 in. (0.8 mm) maximum	Rounded discontinuity with any dimension exceeding 1/8 in. (3.2 mm) not permitted.	Rough, irregular welds, and excessive reinforcement ground smooth.

1. Indications (cracks, lack of fusion, etc.) with length greater than three times the width and major dimensions greater than 1/16 in. (1.6 mm).

2. A maximum depth of 1/16 in. (1.6 mm) is allowed to remove undercut by grinding.

RECORD OF DOCUMENTATION OF WELD REPAIRS

File No. _____ Date: _____
Welding Procedure Specification No. _____
Procedure Qualification Record No. _____
Welder's Name: _____ Clock No. _____ Stamp No. _____
Welder Performance Qualification Records No. _____

CASTING DESCRIPTION

Part Name: _____ Part No. _____
Type of Iron _____ Gray _____ Ductile _____ Malleable _____ Other _____
Grade of Iron: _____ Specification: _____ M-No. _____
Producing Foundry: _____

REPAIR DESCRIPTION

Description and location of defect (use back of form for sketch): _____

Size of excavation: _____ depth _____ area _____ wall thickness _____

WELDING PROCEDURE

Process: _____ Welding Position: _____
Filler Metal: _____ Diameter: _____
Type Current: _____ Polarity: _____ Amperage: _____
Shielding gas: _____ Wire feed speed: _____
Electrode extension: _____ Voltage: _____
Preheat temperature: _____ Travel speed: _____
Interpass temperature: _____ Flux: _____
Postweld heat treatment: _____

Special techniques; other details: _____

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INSPECTIONPrior to welding: ☐ VT ☐ PT ☐ MT ☐ RT ☐ Other

Results: _____

During Welding: _____

After welding: ☐ VT ☐ PT ☐ MT ☐ RT ☐ Other

Results: _____

APPROVALS

Affiliation

Name and Title

Date

SKETCHES

Appendix E

ASME Code Cases*

(This appendix is not a part of ANSI/AWS D11.2, *Guide for Welding Iron Castings*, but is included for information purposes only.)

Two cases cited in the ASME *Boiler and Pressure Vessel Code* which are related to this guide are the following:

E1. Case 1867

This ruling allows repair welding on "projections and/or appendages" of certain gray cast iron boilers and boiler parts during manufacture.

Details for the allowable scope of the repairs, qualification of welding procedures and welders, inspection of the repairs, and the documentation required are carefully described in the Case.

E2. Case 1939

This ruling allows the use of SA-395, Class 60-40-18 welded ferritic ductile cast iron in welded construction for Section VIII, Division 1 of the ASME Code.

Design considerations and details of welding and inspection requirements are carefully described in the Case.

*Available from the American Society for Mechanical Engineers, 345 East 47th St., New York, NY 10017.

Appendix F

Safety and Health

(This appendix is not a part of ANSI/AWS D11.2, *Guide for Welding Iron Castings*, but is included for information purposes only.)

The following pages present copies of eleven short articles (Fact Sheets) on Safety and Health topics which appeared in the *Welding Journal* during the period from August 1982 through January 1984. Each article is followed by a list of reference material from which further detailed information may be obtained.

FACT SHEET NO. 1 — FUMES AND GASES

Many welding, cutting and allied processes produce fumes and gases which may be harmful to health. Fumes are solid particles which originate from welding consumables, the base metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. You — the reader — should acquaint yourself with the effects of these fumes and gases. The amount and composition of these fumes and gases depend upon the composition of the filler metal and base material, welding process, current level, arc length and other factors.

The possible effects of over-exposure range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever. The possibility of more serious health effects exists when especially toxic materials are involved. In confined spaces, gases might displace breathing air and cause asphyxiation.

Keep your head out of the fumes. Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from your breathing zone and general area. In some cases, natural air movement will provide enough ventilation. Where ventilation may be questionable, air sampling should be used to determine if corrective measures should be applied.

Refer to the following sources for more detailed information on fumes and gases produced by the various welding processes:

1. The permissible exposure limits required by OSHA can be found at CFR Title 29, Chapter XVII, Part 1910. The OSHA General Industry Standards are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
2. The recommended threshold limit values for these fumes and gases may be found in *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment* published by the American Conference of Governmental Industrial Hygienists (ACGIH), 6500 Glenway Avenue, Building D-5, Cincinnati, OH 45211.
3. The results of an AWS-funded study are available in the report entitled *Fumes and Gases in the Welding Environment* available from the American Welding Society, P.O. Box 351040, Miami, FL 33135.

Source: August 1982 *Welding Journal*

FACT SHEET NO. 2 — RADIATION

Welding, cutting and allied operations may produce radiant energy (radiation) harmful to health. You should acquaint yourself with the effects of this radiant energy.

Radiant energy may be ionizing (such as x-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, depending on the radiant energy's wavelength and intensity, if excessive exposure occurs.

Ionizing Radiation

Ionizing radiation is produced by the electron beam welding process. It is ordinarily controlled within acceptable limits by use of suitable shielding enclosing the welding area.

Nonionizing Radiation

The intensity and wavelengths of nonionizing radiant energy produced depend on many factors such as the process, welding parameters, electrode and base metal composition, fluxes, and any coating or plating on the base material.

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful effects caused by nonionizing radiant energy from welding include the following measures.

1. Do not look at welding arc except through welding filter plates which meet the requirements of ANSI Z87.1 *Practice for Occupational and Educational Eye and Face Protection*, published by American National Standards Institute, 1430 Broadway, New York, NY 10018. Note: Transparent welding curtains are not intended as welding filter plates, but rather are intended to protect passersby from incidental exposure.
2. Protect exposed skin with adequate gloves and clothing as specified in ANSI Z49.1 *Safety in Welding and Cutting*, published by American Welding Society, P.O. Box 351040, Miami, FL 33135.
3. Beware of reflections from welding arcs, and protect all persons from intense reflections. Note: Paints using pigments of substantially zinc oxide or titanium dioxide have a low reflectance for ultraviolet radiation.
4. Avoid exposing passersby to welding operations by use of screens, curtains, or adequate distance from aisles, walkways, etc.
5. Safety glasses with UV protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

Ionizing Information Sources Include:

1. AWS F2.1-78, *Recommended Safe Practices for Electron Beam Welding and Cutting*, available from American Welding Society, P.O. Box 351040, Miami, FL 33135.
2. Manufacturer's Product Information Literature.

Nonionizing Information Sources Include:

1. J. F. Hinrichs, "Project Committee on Radiation — Summary Report", *Welding Journal*, January 1978.
2. Nonionizing Radiation Protection Special Study No. 42-0053-77, *Evaluation of the Potential Retina Hazards from Actinic Ultraviolet Radiation Generated by Electric Welding and Cutting Arcs* available from the National Technical Information Service, Springfield, Virginia. ADA-033768.

FACT SHEET NO. 2 — RADIATION**(Continued)**

3. Nonionizing Radiation Protection Special Study No. 42-0312-77, *Evaluation of the Potential Retina Hazards from Optical Radiation Generated by Electric Welding and Cutting Arc* available from the National Technical Information Service, Springfield, Virginia. ADA-043023.

4. C. E. Moss and W. E. Murray, "Optical Radiation Levels Produced in Gas Welding, Torch Brazing and Oxygen Cutting," *Welding Journal*, September 1979.

5. "Optical Radiation Levels Produced by Air-Carbon Arc Cutting Processes", *Welding Journal*, March 1980.

6. *Safe Use of Lasers*, Z136.1, published by ANSI — 1430 Broadway, New York, NY 10018.

7. ANSI Z49.1, *Safety in Welding and Cutting*, Z49.1 published by American Welding Society, P.O. Box 351040, Miami, FL 33135.

8. ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*, published by American National Standards Institute, 1430 Broadway, New York, NY 10018.

9. C. E. Moss, "Optional Radiation Transmission Levels Through Transparent Welding Curtains," *Welding Journal*, March 1979.

Source: January 1983 *Welding Journal*

FACT SHEET NO. 3 — NOISE

Excessive noise is a known health hazard. Exposure to excessive noise can cause a loss of hearing. The loss of hearing can be either full or partial, and temporary or permanent. In welding, cutting, and allied operations, noise may result from the process, the power source, or other equipment. Air-carbon arc and plasma arc are examples of processes which are frequently noisy. Engines of engine-driven generators may also be quite noisy.

Excessive noise adversely affects hearing capability. This adverse effect in hearing capability may be temporary threshold shift from which the ears may recover if removed from the noise source. However, if a person is exposed to this same noise level for a longer time, then the loss of hearing may become permanent. The time required to develop permanent hearing loss depends upon factors such as individual susceptibility, noise level, and exposure duration. In addition, there is evidence that excessive noise affects other bodily functions and behavior.

A direct method to protect against excessive noise is to reduce the intensity of the source. Another method is to shield the source, but this has limitations. The acoustical characteristics of a room will also affect the level of noise. When engineering control methods fail to reduce the noise, personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective.

The permissible noise exposure limits can be found in CFR Title 29, Chapter XVII, Part 1910. This is available from the U.S. Government Printing Office, Washington, D.C. 20402. Additional information may be found in *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment* published by the American Conference of Governmental Industrial Hygienists, 6500 Glenway Avenue., Bldg. D-5, Cincinnati, OH 45211.

A recommended method for measuring noise emitted by arc welding processes may be found in ANSI F6.1-78, *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes* published by American Welding Society, P.O. Box 351040, Miami, FL 33135.

Source: August 1982 *Welding Journal*

FACT SHEET NO. 4 — CHROMIUM AND NICKEL IN WELDING FUME

Compounds of chromium, including hexavalent chromium, and of nickel may be found in fume from welding processes. The specific compounds and concentrations will vary with the composition of the base metals, the welding materials used, and the welding processes. Immediate effects of overexposure to welding fumes containing chromium and nickel are similar to the effects produced by fume from other metals. The fumes can cause symptoms such as nausea, headaches, and dizziness. Some persons may develop a sensitivity to chromium or nickel which can result in dermatitis or skin rash.

Chronic (long term) effects of exposure to chromium and nickel in welding fume are unknown. However, the National Institute for Occupational Safety and Health (NIOSH) has concluded that some forms of hexavalent chromium and nickel and their inorganic compounds should be considered occupational carcinogens. These conclusions were published in NIOSH Criteria Documents 76-129 and 77-164 listed below. The conclusions were based on data from the chromate producing industry and from nickel ore-refining processes. No determination has yet been made concerning the health effects on welders or users of chromium- or nickel-containing alloys. Nevertheless, consideration must be given to the NIOSH conclusions.

To protect against the effect of overexposure to chromium and nickel in welding fume, do not breathe fumes and gases. Keep your head out of the fumes. Use enough ventilation or exhaust at the arc or both to keep fumes and gases from your breathing zone and general area. In some cases, natural air movement will provide enough ventilation. Where ventilation may be questionable, air sampling should be used to determine if corrective measures should be applied.

Refer to the following sources for more detailed information on welding fumes which may contain chromium and nickel compounds.

1. NIOSH publication No. 76-129, *Criteria for a Recommended Standard-Occupational Exposure to Chromium (VI)*. This is available from: National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226.
2. NIOSH publication No. 77-164, *Criteria for a Recommended Standard-Occupational Exposure to Inorganic Nickel*. This is available from: National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226.
3. AWS report, *Fumes and Gases in the Welding Environment*, available from: American Welding Society, P.O. Box 351040, Miami, FL 33135
4. American Conference of Governmental Industrial Hygienists publication *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, available from the American Conference of Governmental Industrial Hygienists (ACGIH), 6500 Glenway Ave., Bldg. D-5, Cincinnati, OH 45211.
5. OSHA Standard 29 CFR 1910, Section 1910.1000, available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

The following references include the specific precautionary methods which can be used to protect against exposure to fumes and gases:

1. ANSI Z49.1, *Safety in Welding and Cutting*, available from American National Standards Institute, 1430 Broadway, New York, NY 10018.
2. NIOSH publication No. 78-138, *Safety and Health in Arc Welding and Gas Welding and Cutting*, available from National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226. This is also available from the U.S. Government Printing Office.
3. OSHA Standard 29 CFR 1910, Section 1910.252, available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Source: November 1982 *Welding Journal*

FACT SHEET NO. 5 — ELECTRICAL HAZARDS

Electric shock can kill. However, it can be avoided. Do not touch live electrical parts. Read and understand the manufacturer's instructions and recommended safe practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

Ground all electrical equipment and the workpiece. The work lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece. Do not mistake the work lead for a ground connection.

Use the correct cable size, since sustained overloading will cause cable failure and result in possible electric shock or fire hazard. Make sure all electrical connections are tight, clean and dry. Poor connections can overheat and even melt. Further, they can produce dangerous arcs and sparks. Do not allow water, grease, or dirt to accumulate on plugs, sockets or electrical units. Moisture can conduct electricity. To prevent shock, keep the work area, equipment, and clothing dry at all times. Wear dry gloves, rubber soled shoes, or stand on a dry board or insulated platform.

Keep cables and connectors in good condition. Improper or worn electrical connections may set up conditions that could cause electrical shock or short circuits. Do not use worn, damaged or bare cables. Avoid open circuit voltage.

When several welders are working with arcs of different polarities, or when a number of alternating current machines are being used, the open circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

In case of electric shock, turn off the power. If the rescuer must resort to pulling the victim from the live contact, use nonconducting materials. If the victim is not breathing, administer cardiopulmonary resuscitation (CPR) as soon as contact with the electrical source is broken. Call a physician and continue CPR until breathing has been restored, or until a physician has arrived. Treat electrical burns as thermal burns; that is, apply clean, cold (iced) compresses. Prevent contamination and cover with a clean, dry dressing. Call a physician.

Follow recognized safety standards such as ANSI Z49.1, *Safety in Welding and Cutting*, available from the American Welding Society, P.O. Box 351040, Miami, FL 33135. Also follow the National Electrical Code NFPA 70, available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

Source: December 1982 *Welding Journal*

FACT SHEET NO. 6 — FIRE PREVENTION

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Many of the fires associated with welding, cutting, and allied processes have been caused by sparks which can travel up to 35 feet in a horizontal direction from the work area. Sparks can pass through or become lodged in cracks, clothing, pipe holes, and other small openings in floors or partitions. (Note: Sparks and molten metal can travel greater distances when falling.)

Typical combustible materials commonly involved in fires are floors, partitions, roofs, and building contents such as wood, paper, clothing, plastics, chemicals and flammable liquids and gases. Outdoors, the combustible materials involved are dry leaves, grass and brush. Explosions have occurred where welding or cutting have been performed in spaces containing flammable gases, vapors, liquids or dusts.

Remove any combustible material from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, protect combustibles with a cover of fire resistant material. Remove or make safe all combustible materials for a radius of 35 feet around the work area. All open doorways, windows, cracks and other openings should be covered or blocked with fire resistant material. If possible, enclose the work area with portable fire resistant screens. Protect combustible walls, ceilings, etc. from sparks and heat with fire resistant covers. If work is to be performed on a metal wall, ceiling, etc. prevent ignition of combustibles on the other side by moving the combustibles to a safe location. If this cannot be done, designate someone to serve as a fire watch, equipped with a fire extinguisher during the welding operation and for one-half hour after welding is completed. Welding or cutting should not be performed on material having a combustible coating or combustible internal structure, as in walls or ceilings, without an approved method for eliminating the hazard. Do not dispose of hot slag in containers holding combustible material. Keep fire extinguisher nearby. Make a thorough examination for evidence of fire. Remember that easily visible smoke or flame may not be present for some time after the fire has started.

Overloading and improper sizing can cause overheating of electrical equipment. Be sure all electrical equipment and wiring is installed properly with recommended circuit protection.

Be sure the work cable is connected to the work as close to the welding area as practical. Work cables connected to the building framework or other locations some distance from the welding area increase the possibility of the welding current passing through lifting chains, crane cables or other alternate circuits. This can create fire hazards or overheat lifting chains or cables until they fail.

Do not weld or cut in atmospheres containing dangerously reactive or flammable gases, vapors, liquids, or dust. Do not apply heat to a container that has held an unknown substance or a combustible material whose contents when heated can produce flammable or explosive vapors. Heat should not be applied to a workpiece covered by an unknown substance or whose coating can produce flammable, toxic or reactive vapors when heated. Adequate procedures should be developed and proper equipment used to do the job safely. Provide adequate ventilation in work area to prevent accumulation of flammable gases, vapors or dusts. Clean and purge containers before applying heat.

Closed containers, including castings, should be vented before preheating, welding or cutting. Venting will prevent the buildup of pressure and possible explosion due to the heating and the resultant expansion of gases.

FACT SHEET NO. 6 — FIRE PREVENTION**(Continued)**

Refer to the following sources for more detailed information on fire hazards from welding and cutting operations:

1. ANSI Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, P.O. Box 351040, Miami, FL 33135.
2. NFPA Standard 51B, *Cutting and Welding Processes*, National Fire Protection Association, Batterymarch, Quincy, MA 02269.
3. Code of Federal Regulations, Title 29, Labor, Chapter XVII, Part 1910, OSHA General Industry Standards available from the U.S. Government Printing Office, Washington, DC 20402.
4. AWS F4.1, *Recommended Safe Practices for the Preparation for Welding and Cutting Containers that Have Held Hazardous Substances*, American Welding Society, P.O. Box 351040, Miami, FL 33135.

Source: August 1983 *Welding Journal*

FACT SHEET NO. 7 — BURN PROTECTION

Molten metal, sparks, slag, and hot work surfaces are produced by the welding, cutting, and allied processes. These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire resistant material. Do not wear pant cuffs or have open pockets or other places on clothing that can catch and retain molten metal or sparks. Wear high top shoes or leather leggings and fire resistant gloves. Pant legs should be worn over the outside of high top boots. Use helmets or hand shields that provide protection for the face, neck, and ears, and wear a head covering to protect the head. In addition, appropriate eye protection should be used. When welding overhead or in confined spaces, wear ear plugs to prevent weld spatter from entering the ear canal and goggles or equivalent to give added eye protection. Keep clothing free of grease and oil. Do not carry combustible materials in pockets. If any combustible substance has been spilled on clothing, change to clean fire resistant clothing before working with open arcs or flame. Use aprons, cape-sleeves, leggings, and shoulder covers and bibs designed for welding service. Where usually heavy welding or cutting is involved, sheet metal shields should be used for extra protection. Mechanization of highly hazardous processes or jobs should be considered.

Other personnel in the work area should be protected by the use of noncombustible screens or by the use of appropriate protection as described in the previous paragraph. Before leaving a work area, mark hot work pieces to alert other persons of this hazard. Do not attempt to repair or disconnect electrical equipment under load. Disconnecting under load produces arcing of the contacts and may cause burns and/or shocks. (Note: Burns can be caused by touching hot equipment such as electrode holders, tips and nozzles. Therefore, insulated gloves should be worn when these items are handled unless an adequate cooling period has been allowed before touching.)

Refer to the following sources for more detailed information on personal protection:

1. ANSI Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, P.O. Box 351040, Miami, FL 33135.
2. *Code of Federal Regulations*, Title 29 Labor, Chapter XVII, Part 1910, OSHA General Industry Standards available from the U.S. Government Printing Office, Washington, DC 20402.
3. ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*, American National Standards Institute, 1430 Broadway, New York, NY 10018.
4. ANSI Z41.1, *Safety — Toe Footwear*, American National Standards Institute, 1430 Broadway, New York, NY 10018.

Source: September 1983 *Welding Journal*

FACT SHEET NO. 8 — MECHANICAL HAZARDS

Welding operations involve the use of mechanical equipment. The use of, or the proximity of, mechanical equipment can present hazards to the welder. Know and understand the proper and safe way to use all equipment. This knowledge includes portable power tools such as grinders, chippers, and power drills. Use the appropriate guards and personal protective equipment. Know and understand the safe limits and proper use of cranes, positioners, and other material handling equipment. Be aware of other operations in your area which can affect your safety. Do not permit unsafe acts by others. Other examples of safety considerations include the following:

1. Be aware of grinding wheel speed limitations.
2. Don't grind on the side of the wheel.
3. Foresee results of unexpected occurrences such as tools getting away, binding, grinding wheel breakage, and tools coming loose. Any tool that has become jammed or otherwise overstressed should be checked for damage before reuse. Foresee the reactive force from tools.
4. Wear proper hand protection. Watch out for sharp objects, pinch points, and moving objects.
5. Use face shields, safety glasses and goggles as appropriate.
6. Always wear safety glasses or goggles when using compressed air for cleaning procedures. Use only approved safety nozzles when compressed air is employed for cleaning.
7. Avoid wearing items that can be caught in machinery such as rings, necklaces, bracelets, long hair, loose clothing, etc.
8. Be sure that all tool guards are in place.
9. Use the right tool for the job.
10. Keep a firm grip on tools to assure they will not get away.
11. Do not overload or force a tool beyond its expected capabilities.
12. Stand aside from a new wheel when starting until it has been up to speed and then wait the recommended time. Any abnormality should be corrected before further use.
13. Get the feel of a tool before working in difficult places or applying force.
14. Be aware of others around you and make sure they cannot be harmed.
15. Watch out for the acts of others.
16. Be aware of the concept of zero energy. This means balance weights should be at the bottom of their travel, and spring pressure should be released in a safe manner. Be aware of zero energy concept in hydraulic systems and air systems. Be aware that when unbolting a component what will happen when the bolts are loosened or removed.
17. Follow lock-out procedures. Intermittent or bypassed interlocks create a definite hazard which requires special care and concern.

For additional information on the safe operation and guarding of mechanical equipment, refer to the manufactures' safe operating procedures for the equipment being used and the following publications:

1. ANSI Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, P.O. Box 351040, Miami, FL 33135.
2. NIOSH publication No. 78-138, *Safety and Health in Arc Welding and Gas Welding and Cutting*, Department of Health and Human Services, National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226.
3. *Code of Federal Regulations*, Title 29 Labor, Chapter XVII, Part 1910, OSHA General Industry Standards available from the U.S. Government Printing Office, Washington, D.C. 20402.
4. ANSI Z244.1, *Safety Requirements for the Lockout/Tagout of Energy Sources*, available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

FACT SHEET NO. 9 — TRIPPING AND FALLING

Trips and falls are a frequent cause of occupational injury and can result in serious injury or death. Welding, cutting and heating can take place in a variety of locations. Therefore, welders are exposed to the same tripping and falling hazards as those in other occupations. Proper precautions should be observed. Be alert to the conditions in the work area. Good housekeeping is essential to minimize tripping and falling. Actions to prevent falls include the use of safety belts and harnesses that are tied off, secured ladder, guardrails, proper scaffolding, and nets. Scaffolds and other climbing and elevating equipment must be installed and used properly. Do not carry items which obstruct your view. Proper protective wear, such as skid resistant soles on shoes, should be used when conditions warrant. Electrical equipment should be grounded and other precautions taken to prevent shock. Shock can cause a fall due to involuntary movements.

An alert, professional approach needs to be taken at all times. Do not tolerate horseplay, tossing tools to each other, bumping someone in a precarious position, or other distractions such as shouting when there is no reason to shout. All these acts can contribute to tripping and falling.

For further information on tripping and falling protection, refer to the following publications:

1. NIOSH publication No. 78-138, *Safety and Health in Arc Welding and Gas Welding and Cutting*, Department of Health and Human Service, National Institute of Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226.
2. *Code of Federal Regulations*, Title 29, Labor, Chapter XVII, Part 1910, General Industry Standards, OSHA, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
3. ANSI Z49.1, *Safety in Welding and Cutting*, available from the American Welding Society, P.O. 351040, Miami, FL 33135.

Source: December 1983 *Welding Journal*

FACT SHEET NO. 10 — FALLING OBJECTS

Welding, cutting and heating operations are often performed in areas where falling objects may be present. Falling objects may seriously injure or kill. A safety net or equivalent placed below overhead work is recommended. Protect yourself and others by being aware of situations which might cause objects to fall from structures. Use toe boards with guardrails. Cover floor and wall openings. When working under overhead activities ensure that others are following safe work practices. Use a warning system to notify others of overhead work. Be certain that material being welded or cut is secured from falling. Wear approved head and foot protection. Remember, a welding hood or goggles restricts vision and may prevent taking the action necessary to avoid falling objects.

For further information on safe practices, refer to the following publications:

1. ANSI Z49.1, *Safety in Welding and Cutting*, available from the American Welding Society, P.O. Box 351040, Miami, FL 33135.
2. NIOSH publication No. 78-138, *Safety and Health in Arc Welding and Gas Welding and Cutting*, Department of Health and Human Services, National Institute for Occupational Safety and Health, 4676 Columbus Parkway, Cincinnati, OH 45226.
3. *Code of Federal Regulations*, Title 29, Labor, Chapter XVII, Part 1910, General Industry Standards, OSHA, which are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Source: January 1984 *Welding Journal*

FACT SHEET NO. 11 — CONFINED SPACES

Welding, cutting and heating operations can take place in a variety of locations. Some of these locations may be considered "confined spaces" having characteristics such as:

- (a) limited space, entry or exit, and/or
- (b) unfavorable ventilation which could contain or trap hazardous air contaminants and/or prevent replenishment of safe breathing air.

Typical confined spaces include small rooms, storage tanks, compartments of ships, process vessels, pits, silos, vats, degreasers, reactor vessels, boilers, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines. They can also include even the unventilated corner of a room. Death and serious injury have resulted from welding operations in confined spaces due to fire, explosions, asphyxiation, and exposure to hazardous air contaminants.

1. Open all covers and secure them from closing.
2. Test the atmosphere of the confined space to assure
 - (a) The oxygen content is suitable for breathing.
 - (b) The atmosphere is not combustible or reactive.
 - (c) The atmosphere is not toxic.

Note: Special equipment and training is required to perform the above testing.

3. Isolate lines by capping or double valving and venting, if feasible. Make sure the vent is free of any obstruction and the valves do not leak.
4. Lock out all systems not required during welding, cutting, or heating.
5. Provide means for readily turning off power, gas, and other supplies from outside the confined space.

Verify that personnel designated by the responsible management person have begun the following actions to protect the occupants of a confined space and consulted the list of references for detailed information on implementation.

1. Ventilate and continually monitor the space to assure safe conditions.
 - (a) Make safe or remove any hazardous materials or materials which may become hazardous when heated or exposed to an arc.
 - (b) Continuously ventilate the space to assure that fumes and gases do not exceed safe exposure limits. These limits may be found in references #2 and #5. Use NIOSH/MSHA approved breathing apparatus when proper ventilation cannot be provided, or when the material being welded or heated has such toxicity as to require this type of apparatus either by code, instruction or good practice.
2. Keep nonessential equipment to a minimum. Do not permit required equipment to impede exit or rescue efforts. Locate as much of the required equipment as possible outside the confined space.
3. Do not occupy a confined space unless someone, properly equipped and trained for rescue, is outside the confined space and in continuous communication with the occupants.
4. Provide means for turning off power, gases, and fuel from inside the confined space, if feasible, especially if outside turn-off means is not provided, feasible, or certain.

Refer to the following sources for more detailed information on confined welding space work:

1. NIOSH Publication No. 80-106, *Criteria for a Recommended Standard — Working in Confined Spaces*, Department of Health and Human Services, 4676 Columbia Parkway, Cincinnati, OH 45226.
2. *Code of Federal Regulations*, Title 29 Labor, Chapter XVII, Part 1910, General Industry Standards, OSHA. Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

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3. *Modern Safety and Health Technology*, De Reamer, Russel, John Wiley & Sons, New York, NY.
4. *Safety Requirements for Working in Tanks and Other Confined Spaces*, American National Standards Institute Standard Z117-1-1977, ANSI — 1430 Broadway, New York, New York 10018.
5. *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Room Environment*, American Conference of Governmental Industrial Hygienists, 6500 Glenway Avenue, Bldg. D-5, Cincinnati, OH 45211.
6. ANSI Z86.1, *Commodity Specification for Air*, Compressed Gas Association, 1235 Jefferson Davis Highway, Arlington, Virginia.
7. ANSI Z49.1, *Safety in Welding and Cutting*, American Welding Society, P.O. Box 351040, Miami, FL 33135.