

THE TOOL STEEL GUIDE

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MACOR INNOVATIVE TECHNOLOGIES

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PREFACE

Almost everything we use in our daily lives that is man-made came into existence by using some kind of a tool or die. Most likely, that tool or die in turn was made from a type of tool steel.

A good tool must meet at least four important requirements:

1. It must be made from the proper steel
2. It must have been properly designed
3. It must have been properly manufactured
4. It must have been properly heat treated

If any one of these requirements is lacking, the tool will not perform properly.

It is the purpose of this booklet to present a practical understanding of Tool Steels without being too technically detailed. The following grades will be considered. (A.I.S.I. designation in parenthesis.)

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INTRODUCTION

For many years an air of mystery has surrounded the selection, heat treatment and use of tool steels. Started by the secretiveness of early makers, it has been fostered somewhat by the never ending introduction of new grades.

In working with the diverse and special requirements of tool steels, metallurgists understand the reasons for so many different analyses. This situation is not unlike that of the chemist, who appreciates the infinite number of chemical compositions possible and the practical value of innumerable compounds.

Occasionally shop men and engineers, whose technical training in metal working has been devoted to other phases, do rub elbows with tool steels. For them, we present this simple approach to the understanding of tool steels. Familiarity with the nine basic types of tool steels will help to successfully handle the numerous grades, which are modifications within these types.

The nine basic types to be discussed are listed on page 6, with Crucible grades grouped under each for ease of discussion. These grades are representative of the many which

are required to serve both regular and special applications. The order of presentation in this booklet will start with the simplest type (least amount of alloys), the Water Hardening Carbon Tool Steels. Progressively, those types with increasing amounts of alloying elements will be discussed.

Before considering specific grades, two thoughts should always be associated with tool steel:

First, the term "tool steel" denotes a special quality. It is generally understood that all tool steels are electric furnace melted. Careful processing and conditioning are practiced during the many mill operations from ingot to finished product. Extreme care is exercised in each heating operation. Rigid physical and chemical standards are maintained to uphold this distinct level of quality.

Secondly, actual job experience will dictate the final selection of a tool steel. This not only encompasses the nature of the steel itself, but also includes other factors. Some of these are available heat treating facilities, the behavior of the steel while being shaped into a tool, and whether long or short production runs are planned.

Each grade has outstanding properties which will best serve the requirements of an

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PROPERTIES OF TOOL STEELS

Water Hardening Carbon Tool Steels

	C	Mn	Si	Analyses			AISI
				Cr	V		
LaBelle Cold Header Die	.95	.25	.20	—	—		W1
Black Diamond	1.05*	.25	.20	—	—		W1
Sanderson Extra	1.05*	.25	.20	—	—		W1
Alva Extra	.95	.25	.20	—	.20		W2
Sanderson Special	1.10*	.30	.50	.25	—		W4

* Typical carbon unless otherwise specified.

individual job. The manner in which the types are classified as well as distinction among grades within each type signifies the variety of traits in tool steels.

There is no one tool steel which can be superior in all respects. Analysis of the job will at first result in the selection of one of the nine basic types. Further examination will indicate the need for specific qualities in the tool steel. It then follows that a particular grade which has the best balance of properties to match the job will be the final choice.

Following the next section on Properties of Tool Steels, a general summary on selecting steels for various applications is presented.

Carbon Tool Steels have carbon as the principal control element, generally in the range .85-1.15%. When hardened, the surface becomes intensely hard providing good wear

qualities. Tools made from Carbon Tool Steels can be sharpened to a keen edge with a high finish. Some special steels are made with the carbon content as low as .60% or as high as 1.40%.

The significant characteristic of Carbon Tool Steels is that varied hardening results from heat treatment. This is better described as a 'base' and 'bore' effect.

The case is a uniformly hard, outer area which is file hard in the As-Quenched condition. The degree of hardness is in the range of Rockwell C65-67.

The core hardens to a lesser degree—about Rockwell C40-45. This provides support for the hard case. The relationship of case and core is illustrated in Figures 1 and 2.

While all the Carbon Tool Steels react to hardening in much the same manner, slight variations in analysis and melting practice will bring about variations in the depth of hardening or case depth. Thus, these steels are graded as shallow, medium, medium deep, and deep hardening. The relative depth of hardness penetration (case) for three of these five grades is shown in Table I.

Note: Alva Extra is a shallow hardening steel because of its vanadium content. Sanderson Special hardens deeper because of its .25% chromium addition.

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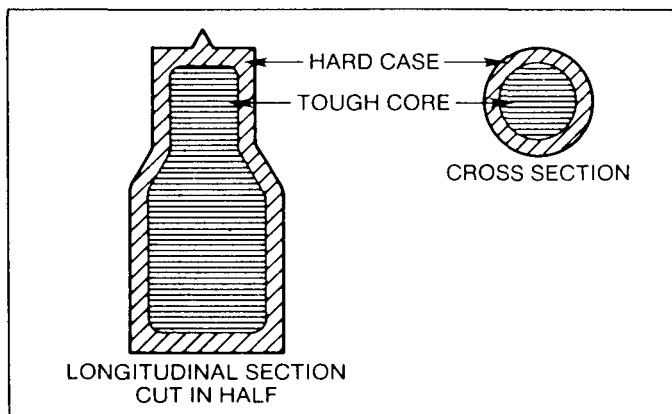


Figure 1. Cross section of case-hardened punch

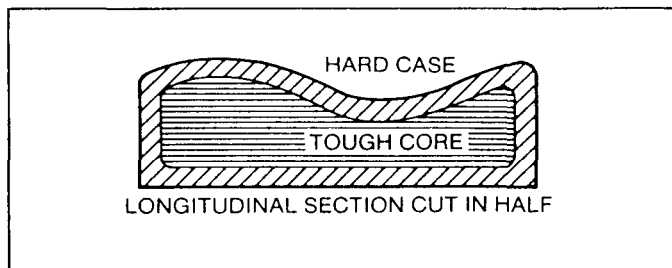


Figure 2. Cross section of carbon tool steel die

TABLE I-DEPTH OF HARDNESS PENETRATION

(in 64ths of an inch)

	Alva Extra (Shallow Hardening)		Sanderson Extra (Medium Hardening)		Sanderson Special (Deep Hardening)	
	1450 F	1550 F	1450 F	1550 F	1450 F	1550 F
1/2" Dia.	All grades harden all the way through					
3/4",Dia.	6	8	7	9	15	24
1" Dia.	5.5	7.5	6.5	8.5	12	18
1 1/2" Dia.	5.5	7	6	8	11	15
2" Dia.	5	6	5.5	7.5	10.5	12
2 1/2" Dia.	5	6	5	7	10	12
3" Dia.	5	6	5	7	10	11

Case Rockwell C65-67

Core Rockwell C40-45

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It can readily be seen that Carbon Tool Steels have an outstanding characteristic in the "case-core" effect. The shallow hardening steel is of vital importance to assure the presence of the tough core in small sections. As the size increases, it is advisable to go from the shallow hardening to the medium or deep hardening steels to develop a substantial case.

In selecting Carbon Steels, it is well to remember that there is a limit to the amount of grinding or sharpening which can be done. If the hard case is ground away, the cutting or wear-resisting qualities are lost. Actually, this seldom occurs in practice due to the small amount of metal removed.

The elasticity required to successfully stand up under repeated stresses makes Carbon Tool Steels useful as blacksmith tools, cold chisels, hand punches, cold header dies, jeweler die blocks, and cold forming tools. The intensely hard case which permits sharpening to a keen edge makes them valuable for tools such as knives, razors, shears, and wood chisels.

Oil Hardening Tool Steels

	C	Mn	Si	Cr	Analysis			AISI
					W	Mo	Ni	
Ketos	.90	1.35	.35	.50	.50	—	—	01
Halgraph	1.50	.75	1.00	—	—	.25	—	06
Champaloy	.75	.70	.25	.80	—	.30	1.50	L6

These steels require a fast quench to obtain maximum hardness. Therefore, they are quenched in water or a water solution such as brine. A tendency to distort results with drastic quenching. Dimensional changes in tools and dies can take place. Also, cracking may occur where sharp corners exist or thin and heavy sections adjoin. When design changes cannot be made, an Oil Hardening Steel should be used.

The addition of substantial amounts of manganese and other alloys permits these steels to be hardened in oil. There is no "case-core" condition and they will harden all the way through even in relative large sections, (up to 2 1/2 inch rd).

Ketos is by far the most frequently used oil hardening steel. Figure 3 shows sample designs which have been safely hardened in oil without excessive distortion or cracking.

Halgraph contains free graphite which gives it exceptional free machining properties and increased wear resistance.

Champaloy is a very tough oil hardening tool steel because of its additional nickel content. It is a fine grained steel with very desirable shock resistance properties.

Ketos and Halgraph are primarily used for punches, blanking dies, coining dies, drawing dies, gauges and similar applications.

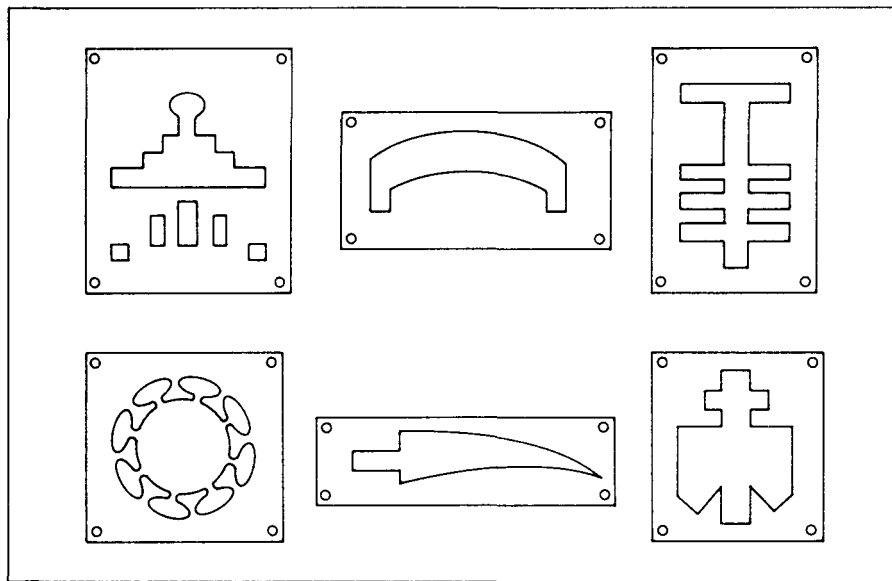


Fig. 3. Designs of dies with square corners and sharp angles which require an oil hardening steel for safe harden-

Champaloy is a general purpose oil hardening steel recommended for applications where greater toughness is required, such as in shear blades, collets, cams, pinions, rachets and sundry machine tool parts.

Because Oil Hardening Steels harden deeper than Water Hardening Steels, more grinding and resharpening is permitted.

Extreme strength to resist shock is required for a number of tool applications. With tool steels, the toughness value of a particular grade can be enhanced to some extent by lowering the carbon content.

Such a change, however, brings about a lower degree of hardness. To offset this loss, effective amounts of one or more of the following elements have been added—manganese, silicon, chromium, molybdenum, or tungsten. These elements also induce strength to absorb repeated stresses.

LaBelle Silicon #2 contains 1.90 silicon. In addition to promoting hardenability, silicon provides resistance to impact and battering at a relatively high hardness. This grade will harden either in oil or in water. Simple shapes and large sections are usually water quenched. Complicated shapes and smaller sections may be oil quenched. It is frequently used for cold cutters, mauls, screw drivers, concrete break-

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Shock Resisting Tool Steels

	Analyses							AISI
	C	Mn	Si	Cr	V	W	Mo	
Atha Pneu	.55	.25	.25	1.25	.20	2.75	—	S1
LaBelle Silicon #2	.60	.85	1.90	.25	.20	—	.30	S5
LaBelle HT	.43	1.35	2.25	1.35	.30	—	.40	S7
Crucible S7	.50	.70	.25	3.25	—	—	1.50	S7

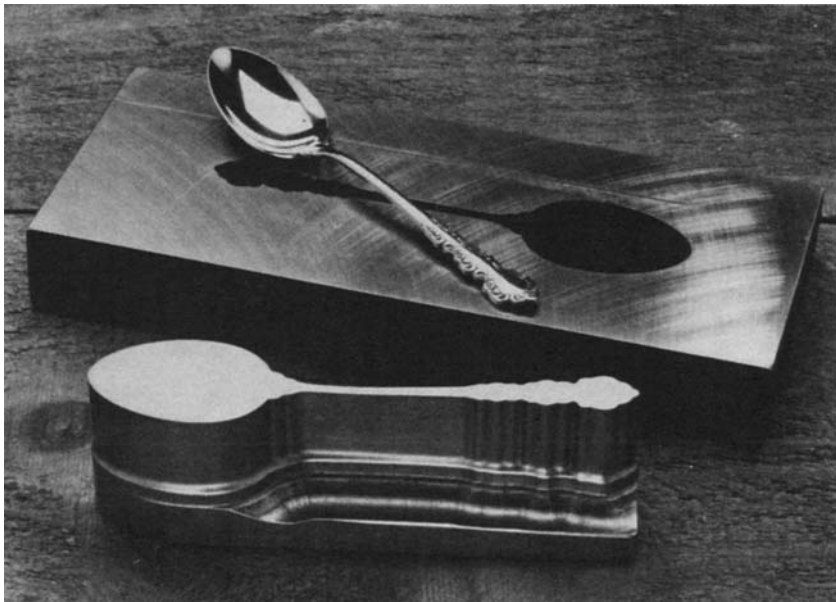
ers, shear blades, and hand chisels.

LaBelle HT is lower in carbon and higher in silicon than *LaBelle Silicon #2*. Because of its lower carbon content, this steel will harden to a lower hardness, 56 RC, which results in superior toughness and shock resistance. Typical applications are shear blades, rivet sets, cold coining dies, cold header punches and knock-out pins. Sections up to 4" thick will harden through when oil quenched.

Crucible S7 is a low chrome-moly steel with very high shock resistance and excellent grindability. Typical applications are punches, blanking dies, gripper dies, cold forming dies, and shears. It is very stable in heat treatment. Sections up to 2V2" thick can be air quenched. Larger sections should be oil quenched to obtain the desired hardness.

(Note: larger section oil quenched are not that stable in heat treatment)

Figure 4. Tough
Airkool (A2)
steel is used in a
punch and die
set to produce



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Air Hardening Tool Steels

	Analyses						AISI
	C	Mn	Si	Cr	V	Mo	
Airkool	1.00	.70	.30	5.25	.30	1.15	A2
CSM 6	.70	2.00	.30	1.00	—	1.35	A6
Airdi 150	1.55	.35	.45	11.50	.90	.80	D2
HYCC	2.25	.35	.50	11.50	.20	.80	D4

Atha Pneu with 2.75% tungsten and 1.25% chromium has accentuated wear resistance and cutting qualities. While these elements induce red hardness properties to a degree, the outstanding high transverse strength under repeated shock establishes this steel as a shock resisting type. *Atha Pneu* is quenched in oil for hardening. It is most useful as hot bolt header dies, shear blades, chipping chisels, forming dies, swaging dies, and rivet busters.

Knowing that the Oil Hardening Steels represent a pronounced improvement over the Water Hardening Types with regard to distortion and, size change, it follows that Air Hardening Steels would be even better. The slower cooling in the hardening phase results in less intense strains with less distortion. These steels are also more resistant to abrasion than the Oil Hardening Types.

In general, the most important elements in making these steels capable of hardening are

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chromium and molybdenum. By uniting with the carbon they produce hard carbides which provide high wear resistance. This is essential because these steels are used primarily for blanking and forming dies, rolls, cams, gauges, and similar long run applications. The higher alloy content requires that the hardening temperature be raised. Vanadium is introduced to prevent grain coarsening and to increase wear resistance by forming additional hard carbides.

Airkool is extremely tough with excellent properties to minimize distortion. It is a deep hardening steel used to replace the Oil Hardening Type when greater tool or die life is required for long production runs.

CSM 6 contains the least amount of alloy of the four grades listed in this group. It is used where a hardness of Rc 58 to Rc 61 is required and the stability of an air hardening grade is required.

Hot Work Steels

	C	Mn	Si	Cr	Analyses				Co	AISI
					V	W	Mo			
Halcomb 218	.40	.40	1.00	5.00	.55	—	1.35	—	H11	
Chro-Mow	.35	.35	1.05	5.00	.35	1.25	1.35	—	H12	
Nu-Die V	.40	.40	1.10	5.00	1.10	—	1.35	—	H13	
Nu-Die XL	.40	.35	1.00	5.20	.95	—	1.30	—	H13	
Halcomb 425	.40	.30	.30	4.25	2.10	4.25	.40	4.25	H19	
Peerless A	.30	.30	.30	3.35	.25	9.00	—	—	H21	

Mold Steels For Plastics

					Analyses		V	AISI
	C	Mn	Si	Cr	Ni	Mo		
CSM 2	30	.80	.50	1.65	—	.40	—	P20
CSM 6	70	2.00	.30	1.00	—	1.35	—	A6
Crucible S7	50	.70	.25	3.25	—	1.50	—	S7
CSM 21 0.02	—	—	15.00	4.75	—	3.50	Cu	—
CSM 414 03	1.00	1.00	12.50	2.00	—	—	—	T414
CSM 420 30	.80	.50	13.00	—	—	—	—	T420
Nu-Die V 40	.40	.40	1.10	5.00	—	1.35	1.10	H13
Crucible Holder Block	50	1.25	—	.65	—	.18	.08	Sulfur

Both Airdi 150 and HYCC contain greater amounts of carbon and chromium carbides than in CSM 6 or Airkool. Consequently these grades are used when there is a need for more abrasion resistance. The 2.25% carbon grade, HYCC, is used where abrasive wear is extreme. Airkool is used where toughness requirements are needed most. Airdi 150 is intermediate in both respects between these two.

Hot Work Steels, as the name implies, are used in operations where the temperature of the material being worked is above 1000 F. Actually, the tools and dies themselves become hot, reaching temperatures ranging from 600 F to 1200 F. Typical applications are shell forging dies, hot extrusion mandrels and hot shearing blades. Tool steels for plastic molds and die casting dies are covered in the next two sections.

The principal requirement of these tool steels is to maintain a high hardness or resistance to softening in their operating temperature range. Chromium, tungsten, and molybdenum are all effective in promoting this property. They are also important in developing the necessary resistance to abrasion. As stated earlier, these elements induce deep hardening characteristics permitting some of these steels to be air quenched.

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Toughness to withstand high pressures or intermittent shock is always a requirement of Hot Work Steels. For this reason the carbon content is in a range lower than any of the other types of steels being discussed. However, carbon is present in sufficient quantity to give reasonable hardness. Silicon is also useful in promoting toughness.

In referring to Hot Work Steels, it is common practice to class them either as chromium types or tungsten types. This depends on

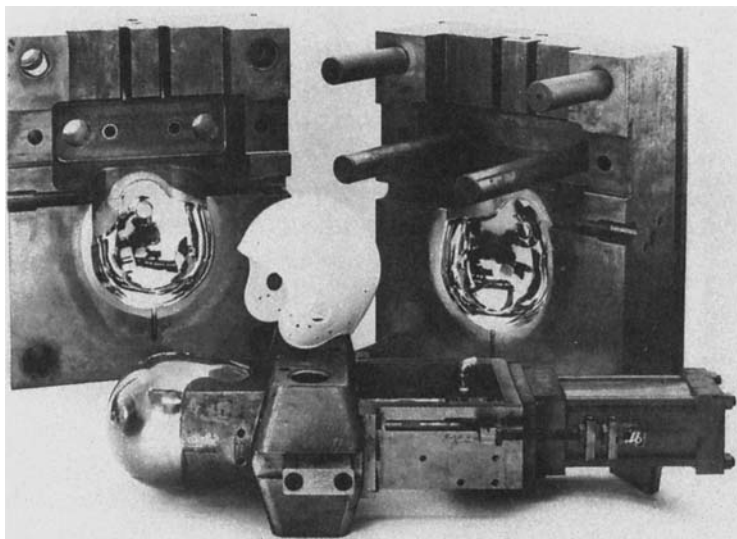


Figure 5. Crucible's CSM 2 is a prehardened AISI P20 plastic mold steel

which of these two elements predominates. *Halcomb 218*, *Nu-Die V* and *Nu-Die XL* are in the chromium group; *Peerless A*, *Chro-Mow* and *Halcomb 425* are in the tungsten group.

The chromium grades offer more resistance to repeated stresses. They will better resist heat checking from rapid temperature changes where liquid coolants are used.

The tungsten grades offer even greater resistance to repeated stresses. They are essentially semi-high speed steels with lower carbon content and possess greater toughness than the High Speed Steels. Tungsten grades are usually used when the tools approach a dull red heat in operation. Liquid coolants should be avoided for tools or dies of the tungsten types.

There are unique requirements for tool steels used in plastic molding. First, almost all plastic molding requires a superior polished or mirror finish. This means the steel must be sound and possess a high degree of micro-cleanliness.

In addition to soundness and polishability, mold steels for plastics should have a uniform structure to assure good machinability and dimensional stability in heat treatment. Good weldability is also helpful where high maintenance is anticipated.

CSM 2 (P20) is the most popular and versatile mold steel for plastics. It is used for all sizes of machine-cut molds. It is most frequently used in the pre-hardened condition of about 300 Brinell (Rockwell C 32), where no heat treatment is necessary. This eliminates the finish machining and grinding operations which are often necessary after heat treatment has created dimensional changes.

The mold can be easily nitrided after finishing if mold wear is a problem, as when molding reinforced plastics. It can also be chrome plated or nickel plated for wear resistance against corrosive materials (PVC), or rusting because of sweating.

Specific areas of steel tooling for plastics can be flame hardened if brinelling, peening or wear is a localized problem.

Molds for plastics may be carburized where surface hardness over 55 Rc is required. The core hardness will be about 45 Rc. The case depth can be easily controlled and may vary from .030" deep for the smaller molds to .065" deep for the very large molds. Carburized molds of P-20 steel show the best of the physical properties one may want in a plastic mold—wear resistance, toughness, and polishability. P-20 steel is available in forgings weighing up to 75,000 pounds. For injection

molding, this steel type is almost always used in the prehardened condition of 300 Brinell. For compression molding, the mold must be carburized.

CSM 6 (A6) is designed for use in plastic molding where high strength, good wear resistance and toughness are needed. It can be air hardened from relatively low hardening temperatures, resulting in lower residual stress levels and less chance of distortion.

Crucible S7 (S7) is recommended for molds requiring very high shock resistance as well as the strength and wear resistance of steels for automatic molding operations. Its high hardness capability (Rc 58) gives it excellent polishability making it suitable for clear plastics of all kinds.

Crucible CSM 21 is the newest addition to the Crucible tool steel line. The machinability of CSM 21 is excellent in comparison to other prehardened mold steels, and its' high corrosion resistance makes it the top choice for use with vinyl base and other corrosive resins and abrasive fillers. CSM 21 is normally supplied in the Solution Treated condition about BHN 302 (Rc 32) in sections suitable for small to medium size molds. It may be age hardened to about BHN 377 (Rc 40) through a low temperature cycle (975 °F).

CSM 414 is a prehardened stainless steel designed primarily for use in molding corrosives such as vinyl based plastics. It is used primarily for injection molding and is ideal where rusting of molds is a problem during service or storage. Because the steel is already hardened (300 Brinell), there are no distortion problems normally encountered during heat treatment. It is readily machinable and takes an excellent polish,

CSM 420 is furnished in the annealed condition primarily for use in molding of corrosive plastics. It can be hardened to 50 Rc and used for injection, compression, and transfer molding. In the annealed condition, *CSM 420* can be readily machined. It has excellent dimensional stability during heat treatment and takes a mirror finish. Most molds can be satisfactorily hardened by air quenching. This will minimize distortion or cracking.

Nu-Die V (H13) is furnished in the annealed condition and must be heat treated after the mold is machined. *Nu-Die V* hardens to a maximum of Rc 54 and is one of the toughest mold steels for plastics. It can be used for injection, compression and transfer molding requiring intermediate hardness. Should abrasive and excessive wear be a problem, the mold can easily be gas nitrided to a surface hardness of 65-70 Rc.

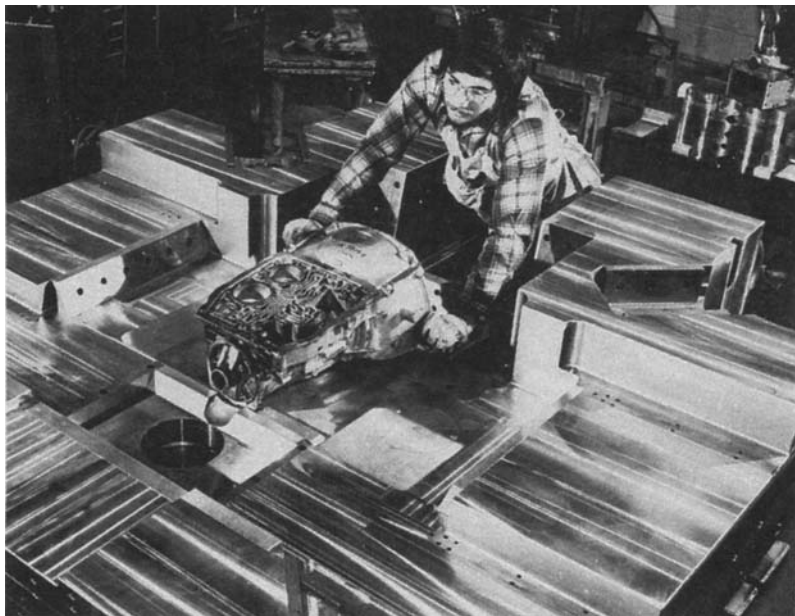


Figure 6. Automotive transmission is produced in die casting of Nu-Die V(AISI H13)

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Die Casting Die Steels

	Analyses								
	C	Mn	Si	Cr	Ni	Mo	V	W	AISI
CSM 2	30	.80	.50	1.65	—	.40	—	—	P20
Nu-Die V	40	.40	1.10	5.00	—	1.35	1.10	—	H13
Nu-Die XL	40	.35	1.00	5.20	—	1.30	.95	—	H13
Peerless A	30	.30	.30	3.35	—	—	.25	9.00	H21

Crucible Holder Block steel is an alloy steel which is usually used in the prehardened condition (300 Brinell) for mold tool holders, shoes, or bases. It is also used for injection molding of large, non-cosmetic parts where a high polish is not necessary.

The die casting process consists of forcing molten metal, under pressure, into a steel die. After the metal has solidified, the solid casting will be ejected. The metals being cast are: zinc alloys, aluminum alloys, brass alloys or other non-ferrous metals. Ferrous alloys have also been successfully cast.

For *zinc alloys*, which are liquid after heating above 750 F, *CSM 2* prehardened to 300 BHN is normally used for the dies. Millions of castings have been produced from just one set of dies. For longer production runs, and dies which are kept in production for many years, *Nu-Die V* is used. Because the dies are harder, usually 50 Rc, they wear longer and also resist heat checking in use.

Figure 7. Drills, hobs, end mills, taps, formtools and milling cutters are typical cutting tools made from high speed steels



For *aluminum alloys*, *Nu-Die V* is almost always used for the dies. Here the temperatures may go up to 1250-1300 F. The continuous expansion and contraction of the die surface, in contact with the hot metal, eventually causes random small cracks or heat checks. This is one of the more serious problems with all die casting dies.

Crucible's premium quality Nu-Die XL is certified to the exacting standards of the Die Casting Research Foundation and the widely accepted Chrysler specification. The improved properties of Nu-Die XL are designed to extend die life and increase long-run part productivity.

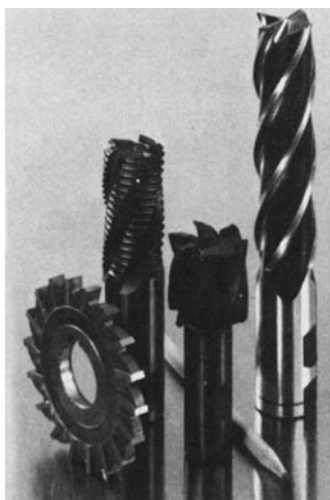


Figure 8. Performance of milling cutters and both roughing and finishing end mills is improved when the tools are made of Crucible Particle Metallurgy high speed steel

High Speed Tool Steels

	Analyses									
	C	MN	S	Si	Cr	V	W	Mo	Co	AISI
REX TMO	0.83	0.30	—	0.35	3.75	1.15	1.70	8.50	—	M1
REX M2(S)	0.85	0.30	(0.10)	0.30	4.15	1.95	6.40	5.00	—	M2
REX M2(S)HC	1.00	0.30	(0.12)	0.30	4.15	1.95	6.40	5.00	—	M2
CPM REX										
M2HCHS	1.00	0.80	0.27	0.30	4.15	1.95	6.40	5.00	—	M2
REX M3(S)-1	1.05	0.30	(0.12)	0.30	4.00	2.40	6.25	6.00	—	M3
REX M3(S)-2	1.20	0.30	(0.10)	0.30	4.00	3.00	6.25	6.00	—	M3
CPM REX										
M3HCHS	1.30	0.80	0.27	0.55	4.00	3.00	6.25	6.00	—	M3
CPM REX										
M4 (HS)	1.35	0.30	0.07(.22)	0.30	4.25	4.00	5.75	4.50	—	M4
REX M7	1.00	0.30	—	0.40	3.75	1.75	8.75	2.00	—	M7
REX VM	0.98	0.30	—	0.30	4.00	1.95	0.70	8.00	—	M10
REX M33	0.93	0.30	—	0.40	3.75	1.25	1.75	9.15	8.00	M33

High Speed Tool Steels Continued

	Analyses									
	C	MN	S	Si	Cr	V	W	Mo	Co	AISI
CPM REX										
M35HCHS	1.00	0.80	0.27	0.30	4.15	2.00	6.00	5.00	5.00	M35
REX 49	1.10	0.45	—	0.30	4.25	2.00	6.50	4.00	5.00	M41
REX M42 and										
CPM REX M42.	1.10	0.30	—	0.40	3.75	1.15	1.50	9.50	8.00	M42
CPM REX										
45 (HS)	1.30	0.40(.70)	0.03(.22)	0.55	4.05	3.05	6.25	5.00	8.25	—
CPM REX										
76 (HS)	1.50	0.30	0.07(.22)	0.30	3.75	3.10	10.00	5.25	9.00	M48
CPM REX 25	1.80	0.30	0.07	0.35	3.75	4.00	5.00	12.50	6.50	— M61
PM REX 20	1.30	0.35	0.07	0.35	3.75	2.00	6.25	10.50	—	M62
REX AA	0.75	0.30	—	0.30	4.00	1.05	18.00	—	—	T1
REX AAA	0.75	0.30	—	0.30	4.00	1.15	18.00	0.75	5.00	T4
REX 95	0.80	0.30	—	0.30	4.00	2.00	14.00	0.75	5.00	T8
CPM REX										
T-15 (HS)	1.55	0.30	0.07(.22)	0.30	4.00	5.00	12.25	—	5.00	T15

With *brass* or copper die casting, heat checking occurs to a much greater extent. *Peerless A*, containing considerable tungsten, is normally used to alleviate this problem.

Wherever heat checking is concerned, many factors other than selecting the proper die steel will affect the tool's life. Heat treatment, hardness, design, operating temperatures of the dies, maintenance, and more can all add or subtract from the life of a die. To minimize heat checking, see page 101.

High Speed Steels are high-alloy, vanadium bearing steels designed to cut other materials efficiently at high speeds, despite the extreme heat generated at the tool's cutting edge. This heat can reach 1000 F and more depending on cutting conditions, coolants used and other operational factors.

To provide good cutting tool performance, a High Speed Steel must have three basic characteristics:

First, the capacity for heat treatment to high room temperature hardness—Rc 63 to Rc 68 or higher. *High hardness* is necessary for good wear resistance.

Second, the capacity for maintaining high hardness at elevated temperatures. This is called *red hardness*. Because they are High

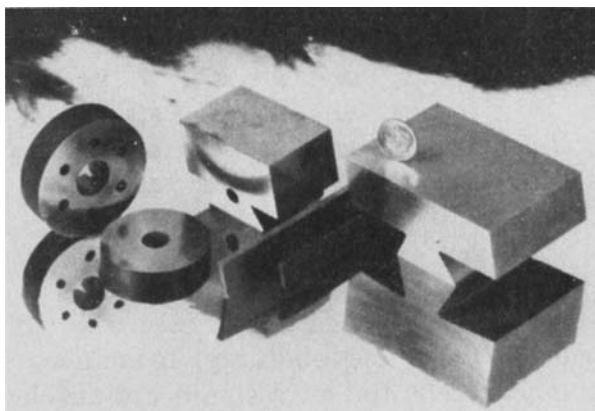


Figure 9. CPM REX 1'15 circular and dovetail form tool blanks and cut-off blades

Speed Steels, they are subject to considerable heat where the cutting edge meets the work piece chip interface. Red hardness is essential.

Third, High Speed Steels must have enough *impact toughness* to handle interrupted cut tooling applications. They are notably tougher than carbide materials.

Naturally, in addition to these three basic characteristics, High Speed Steel must be capable of being fabricated, hot worked, machined, ground, and whatever is necessary to manufacture a given cutting tool.

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Special CPM Alloys

	Analyses							
	C	Mn	Si	Cr	V	Mo	S	AISI
CPM9V	1.78	.50	.90	5.25	9.00	1.30	—	—
CPM 10V	2.45	.50	.90	5.25	9.75	1.30	.07	A11
CPM T440V	2.30	.50	.50	17.50	6.0	0.50	—	—

CPM High Speed Tool Steels

Production of High Speed Steels by CPM (Crucible Particle Metallurgy) techniques is the most recent and most significant development in the field of cutting tools since the introduction of cemented carbides.

The CPM process involves the production of fine particles of steel, which are screened and then compacted by hot isostatic pressure into cylindrical ingots. These ingots are further hot worked into round, flat and square bars.

The grades that result offer premium characteristics for both the manufacturers of cutting tools and their users. The more uniform distribution and the finer particle size of carbides in CPM steels are especially evident in comparisons with larger diameter bars of conventionally produced High Speed Steel, where carbide segregation is more of a problem. Thus, while the benefits pertain to cutters of

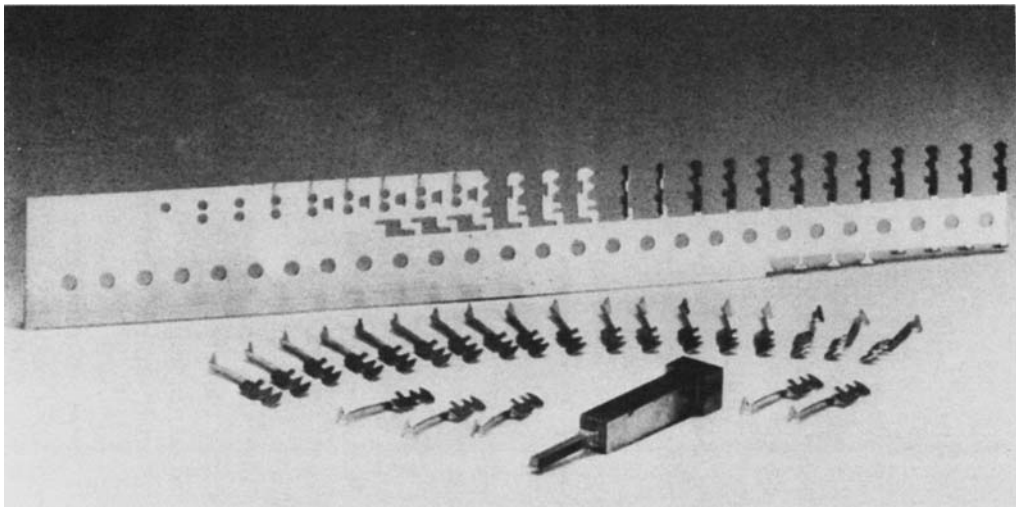


Figure 10. Special alloy CPM 10V, is used to make the punch in the progressive die producing brass parts

all dimensions, they are more pronounced in larger tools.

The three principal benefits of CPM High Speed Steels are:

First, improved grindability with no reduction in wear resistance of the tool. This means a reduced grinding-wheel wear per unit of High Speed Steels removed that varies from a factor of about 1.5:1 to nearly 5:1 in various grades. (See chart below.) The grinding can be done more quickly, with less danger of damage to the cutter, and it leaves an edge that produces a smoother finish on the work piece.

Second, the increased toughness of CPM Steels not only provides greater resistance to breakage (particularly valuable in intermittent-cut operations), but it also allows a tool to be hardened by 0.5 to 1.0 points higher on the Rockwell C scale without sacrificing toughness. Both longer tool life and higher cutting speeds can be realized.

Third, the greater uniformity of CPM Steels increases the degree of predictability for scheduling tool changes. This factor is particularly advantageous when, say, end mills are used in multi-spindle machines, where a single cutter failure affects several spindles and usually requires changing all cutters (including some that may have a lot of life left) for the

sake of prudence.

A final advantage of the CPM process is that it permits the practical production of High Speed Steels with higher alloy content than can be made by conventional techniques. REX 20, REX 25 and REX 76 are examples.

These grades represent significant progress in the development of steels with unique characteristics. REX 76 has the highest attainable red hardness of any high speed steel. CPM REX 20 equals or Outperforms M42 and REX 25 matches T15 performance, yet both are free of cobalt in their analysis. Dependence on that strategically vital and costly element is thus eliminated.

Continuing CPM research is leading to new alloys which cannot be efficiently made by conventional melting methods. These alloys each have unique characteristics making them highly beneficial as the raw material for a variety of both cold and hot work tooling.

CPM 9V is a tool steel uniting a tough hot work base analysis with added carbon and vanadium. This provides the steel with an excellent combination of toughness, wear resistance, and heat check resistance. Thus, CPM 9V meets problem areas requiring a tool steel with a high level of all three properties.

CPM 10V also derives its exceptional prop-

erties from added carbon and vanadium. High wear resistance, good toughness and cost effectiveness make CPM 10V an excellent candidate to replace carbide and other highly wear resistant materials in tooling or other applications where breakage or chipping is a problem.

CPM T440V, similar to T440C stainless steel, has been enriched with highly wear-resistant vanadium carbide particles. With the resultant characteristics of both stainless and tool steel, it is suited for corrosion-resistant application requiring unusually high wear resistance, and cold work tooling uses requiring corrosion resistance.

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SELECTION OF TOOL STEELS

The first step in the selection of any tool steel is to closely examine what the tool will be expected to do. The properties required in a high speed drill are far different from those required in an impact tool. In order to simplify this step, we may break most forming or tooling applications into six major categories.

1. Cutting
2. Shearing and Blanking
3. Forming
4. Drawing and Extrusion
5. Rolling
6. Miscellaneous

1. Cutting operations involve the forming of the work material by the removal of chips. Typical examples are single point tool bits, twist drills and end mills.

2. Shearing and Blanking operations involve the separation of material by a shearing operation. A typical example would be a punch and die which may punch a round blank from a sheet of steel. When the piece of material is cut to length by a shear or cut in half, the operation is called shearing. When a punch generates a round blank from a piece of material and that blank is the item desired, the operation is called blanking. When the

punch generates a hole in the sheet of material and the sheet with the hole is the desired item, it is called piercing.

3. Forming operations involve the shaping of the work material so that it conforms to the shape of the tool. Typical examples would be the molding of plastic into buckets, baskets, spoons or any variety of products. Another example may be the forging of a bar of steel into a crankshaft for a car. The examples can be quite extensive. Within this category of forming we may have at least six subcategories:

- a. Press Forming
- b. Forging
- c. Heading
- d. Coining
- e. Hobbing
- f. Die Casting and Plastic Molding

All of these operations involve the work material assuming the shape of the tool doing the work.

4. Drawing and extrusion involves the movement of the work material around the tool or through the tool so that it assumes the shape of the tool. Typical examples are the aluminum framework on storm windows or a bar of cold drawn steel.

5. Rolling involves the imparting of final material shape by the means of rolls. Round bars are rolled to shape from square billets. Flat sheets may be rolled from thicker blooms. The guard rails along the highway may be roll formed to shape from flat sheet. We may break this category into at least three subcategories:

- a. Plate and bar rolling
- b. Thread rolling
- c. Roll Forming

6. The last category is that of miscellaneous tooling applications. We might list in this area:

- a. Hammering
- b. Filing
- c. Scraping
- d. Spinning
- e. Gauging

It can be easily appreciated that a wide range of properties are required for the many ways in which materials may be formed. A high speed drill would need to have good wear resistance, good resistance to the softening effects of frictional heat and good grindability. An impact tool would require high toughness. A plastic mold needs good machinability and good polishability.

When we examine the many characteristics required for the various operations, we come up with two separate groups of properties. One may be called "inherent material performance characteristics" and the other "material characteristics which affect the manufacture of the tool."

Primary Properties

Inherent material performance characteristics are those which pertain directly to the properties the steel possesses to perform the intended forming operation. These may also be called the primary tool steel properties. There are three primary tool steel properties:

1. Wear Resistance
2. Toughness
3. Heat Resistance

These properties are self explanatory.

Some people question where the hardness of the tool enters into the tool steel properties. Hardness of the tool steel is very important. Without hardness, the tool steel would not be able to withstand the tremendous loads placed upon the tool. This resistance to deformation is extremely important, and a direct relationship exists between hardness and resistance to deformation. The graph in Figure 11 shows this general relationship. Naturally variations

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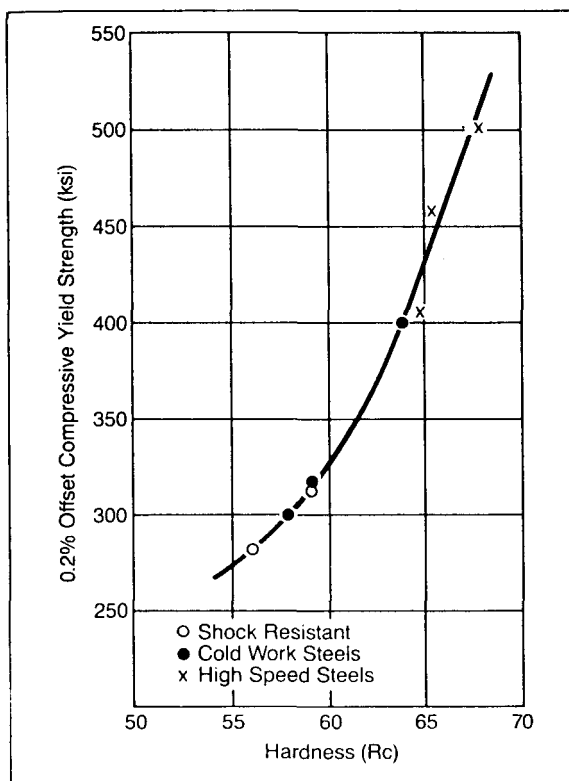


Figure 11. Relationship of steel hardness and its resistance to deformation

in grade and heat treated condition will cause variation from this relationship; and design values should not be scaled from the graph.

However, hardness is a property developed

in heat treatment rather than an inherent property. It may be viewed as a means of fine tuning the primary properties to the job at hand.

Secondary Properties

Material characteristics which effect the manufacture of the tool can be called secondary tool steel properties. They include a great number of characteristics which influence the ability to make a tool. Some of these are:

1. Machinability
2. Grindability
3. Polishability
4. Safety in Heat Treatment
5. Distortion in Heat Treatment
6. Heat Treating Range
7. Availability
8. Price

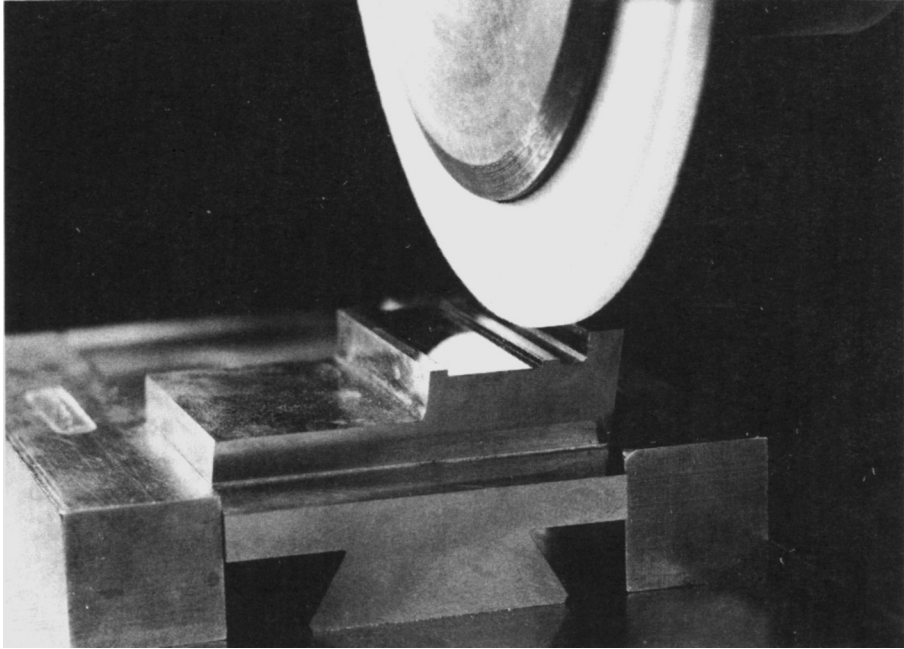


Figure 12.
A good
grindability
ratio is
achieved
when the
volume of
steel
removed is
high and
the volume
of wheel
worn is low

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TABLE II				
Forming Operation	Conditions	Primary Requirements	Secondary Requirements	AISI
Cutting		Wear Resistance Heat Resistance	Grindability	M2
Shearing and Blanking	Cold Light	Wear Resistance	Low Distortion	D2
	Cold Heavy	Wear Resistance Toughness	Safety in Hardening	S5
	Hot Light	Wear Resistance Heat Resistance	Safety in Hardening	S7
	Hot Heavy	Heat Resistance Toughness	Safety in Hardening	H13
Forming	Cold	Wear Resistance Toughness	Machinability Polishability	D2
	Hot	Heat Resistance Toughness	Machinability	H13
Drawing		Wear Resistance	Polishability Low Distortion	D2
Extruding	Cold	Wear Resistance	Low Distortion	M2
	Hot	Heat Resistance Toughness	Low Distortion	H13
Rolling	Cold	Wear Resistance	Polishability	D2
	Hot	Heat Resistance Toughness		H13

Table II (above) lists the various forming operations along with the primary properties and the secondary properties of each. When an operation only requires one primary property, a grade of steel may be chosen which has that primary attribute. However, when the tool requires all three primary properties, a lower than desired level will have to be accepted. Table II is intended only as a guide in examining applications and is considered too general to be universally applied. The typical AISI grade is included to give one an idea of the type of steel which may be typical for those general applications.

TABLE III - Primary Tool Steel Properties

Nominal Chemistry - %											Typical Hardness	Secondary Tool Steel Properties								
AISI	C	Mn	Si	Ni	Cr	V	W	Mo	Co	Rc		----- Wear Resistance	----- Red Hardness	----- Toughness	Machinability	Grindability	Polishability	Depth of Hardening	Distortion	Availability
W1	1.00									63	-----	-----		10	10	9	1	1	8	10
W2	1.00									63	-----	-----		10	10	9	1	1	5	10
O1	.90	1.00			.50		.50			61	-----	-----		7	9	9	6	7	10	10
O6	1.45	.80	1.00					25		61	-----	-----		8	10	6	6	7	5	10
L6	.70			1.50	.75					59	-----	-----		6.5	9	9	6	6	7	10
S1	.50				1.50		2.50			55	-----	-----		6.5	8	8	6	6	4	9
S5	.55	.80	2.00					40		55	-----	-----		7	9	9	5	6	10	10
S7	.50				3.25			1.40		55	-----	-----		7.5	8	10	7	6	3	10
A2	1.00				5.00			1.00		61	-----	-----		5	7	8	9	10	10	9
A8	.55				5.00		1.25	1.25		58	-----	-----		6	8	8	9	10	3	9
D2	1.50				12.00	1.00		1.00		61	-----	-----		3.5	3.5	6	10	10	10	8
D4	2.25				12.00			1.00		61	-----	-----		3	3	5.5	10	9	3	8
D7	2.35				12.00	4.00		1.00		62	-----	-----		2	1	5	10	8	2	5
H11	.35				5.00	.40		1.50		47	-----	-----		7	9	10	10	9	7	10
H12	.35				5.00	.40	1.50	1.50		47	-----	-----		7	9	10	10	9	6	9
H13	.35				5.00	1.00		1.50		47	-----	-----		7	8.5	10	10	9	10	9
H19	.40				4.25	2.00	4.25		4.25	47	-----	-----		6	6.5	8	8	8	2	6
H21	.35				3.50	.50	9.00			47	-----	-----		5.5	7	8	8	8	7	5
P20	.35				1.70			40		31	-----	-----		8.5	10	10	6	7	10	10
420	.35				13.00					50	-----	-----		6.5	8	10	8	8	8	10
440C	1.00	1.00	1.00		17.00			.75		58	-----	-----		3.5	4	8	7	7	9	8
A11	2.45		.90		5.25	9.75		1.30		61	-----	-----		4	3.5	7	10	10	5	1
T1	.75				4.00	1.00	18.00			65	-----	-----		4	3	5	9	8	3	1
T15	1.50				4.00	5.00	12.00		5.00	66	-----	-----		2	5	5	9	8	5	1
M2	.85				4.00	2.00	6.00	5.00		65	-----	-----		4	4	6	9	8	10	4
M4	1.30				4.00	4.00	5.50	4.50		65	-----	-----		3.5	1	4	9	8	5	2
M42	1.10				3.75	1.15	1.50	9.50	8.00	67	-----	-----		3.5	2	3	9	8	8	1

Low number means that property is poor.
High number means that property is good.

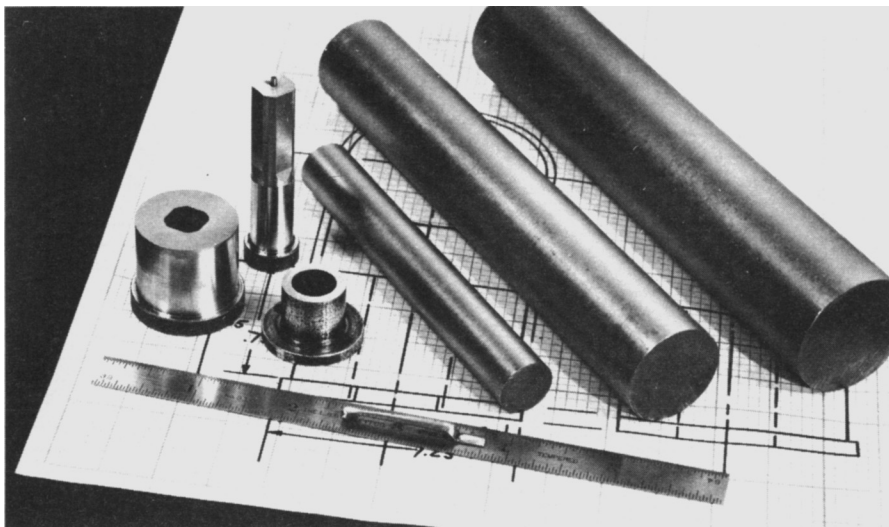


Figure 13. Blanking punches made of cold work steel must be wear-resistant and tough

Compromise Required in Steel Selection

In examining the characteristics of tool steels it becomes apparent that some compromising is required. As the alloy content of a tool steel is changed to provide greater wear resistance and greater heat resistance, the toughness decreases. If the alloy is adjusted to provide increased toughness, the wear resistance and heat resistance are decreased. In addition the secondary properties will change. Higher alloy materials may be more difficult to machine and harder to grind. The challenge of tool steel selection is to get an optimum blend of both the primary properties and the secondary properties and match these to the requirements of the job.

It is important to consider both primary properties and secondary properties in this matching process. If a punch is being manufactured which has an intended life of 100 holes, it would be wasteful to make it out of a tool steel designed to provide the properties to go 10,000 holes. The added alloy would cause more difficulty in manufacture of the tool, more difficulty in heat treatment and of course be higher in cost. Remember to consider the desired life of the tool in any selection consideration.

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In order to properly match the various tool steels to the material forming operations at hand, it is important to know how one tool steel compares with the others. This type of information is given in Table III. Included in this table is the standard AISI (American Iron and Steel Institute) classification and the nominal chemistry of the grades under consideration.

For the comprehensive table of various types of tools and the corresponding AISI grades which are generally recommended for each, please refer to the Crucible Tool and High Speed Steel Selector. This publication is available on request through Crucible Specialty Metals offices. It also contains basic technical information and heat treating information on Crucible's tool and high speed steels.

In using the Selector, the reader should recognize that the listed grades are intended as a starting point. Fine tuning of both grade selection and hardness involves a close examination of the problems encountered with tools which have been used or the problems you expect to encounter in a particular application. In addition, communications with the steel supplier, the tool builder and the heat treater are essential.

Steel Selection Example

If you are stamping 3/8" thick steel using A2 as your punch material but constantly encounter an edge chipping problem even if the hardness is dropped, one could conclude that increased toughness might correct the situation. In looking at Table II it would appear that grades L6, A8, S1, S5, and S7 all have both increased toughness and the hardness required to do the job. In examining the secondary properties you may decide upon S7 due to its greater safety in hardening and lower distortion characteristics. Of course this change involves a compromise in that S7 does not have the wear resistance of A2. One might also see that grades like A8 have better toughness than A2, but are more difficult to obtain. Grades like H11, H12, H13, and H21 might be considered, but they are typically used at much lower hardness levels.

It can be concluded from this example that there is no one right grade to be universally used in an application. Each and every application has its own primary requirements and its own secondary requirements. In many cases more than one grade will provide the needed proper properties for the job, and in some cases no grade will do the job!

In addition to the tool steels covered by

this section, there are many other types of materials which may be used in the construction of a tool. Materials such as the maraging steels, steel bonded carbides, copper beryllium and high temperature alloys cannot be overlooked as possible solutions to tooling problems.

So far we have been discussing the reasoning approach to tool steel selection. It is natural for tool steel users to consider a new grade when they encounter problems with a particular tool. The steel is tangible and may be seen and picked up. It may be examined. However, it is vital that the user realize that a tool's performance is based upon all of the circumstances surrounding its use. For example, when a tool fails one should ask:

1. Has the tool been designed properly?
2. Was the tool heat treated properly?
3. Was the tool used properly?
4. Was the tool maintained properly?

These are only a few of the questions one should examine before switching to a different tool steel.

When a proper match has been made between the requirements involved in forming the work material and what the tool steel has to offer, optimum tool life will result. It is the

goal of the tool steel selection process to obtain a grade of steel which will result in the lowest cost per piece of product produced, or as an alternative, the fewest problems in the production of a particular item. In any event, the tool steel user must realize that no tool will last forever.

Disclaimer of Liability

The material contained in this section is intended for general information only and should not be used in relation to any specific application without independent study and determination of its applicability and suitability for the intended application. Anyone making use of this material or relying thereon assumes all risk and liability arising therefrom.

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HEAT TREATMENT OF TOOL STEELS

The heat treatment of tool steels is an operation designed to bring out each steel's optimum physical properties for its intended use. No tool or die is better than its heat treatment. Therefore, it is important to do the best possible job for maximum tool performance. Don't try to cut corners and never rush a heat treatment. Performance statistics show that improper heat treatment is the most frequent cause of premature failure of tools and dies.

The heat treater is not being temperamental when he says one job will take longer than another. Actual differences exist in the correct procedure for the various types and grades of tool steels. As a rule, the more alloy in a tool steel, the longer it will take to harden the steel properly. Generally speaking, it is also true that the hardening temperature will be higher.

When discussing the heat treatment of tool steels, the basic concept is hardening followed by tempering.

Hardening consists of heating to a prescribed temperature to condition the steel for quenching, and then cooling at a predetermined rate usually to just above or near room temperature.

Tempering is a reheating after hardening to an intermediate temperature below the range for hardening and then cooling to room temperature. The primary purpose is to toughen the steel. This relieves the stresses set up in hardening and conditions the changed structure which has been developed.

The pattern for heat treating all tool steel types is the same. There are three stages: heating, quenching and tempering. Frequently, heating is done in two steps: a preheat and a high heat. In discussing these stages, it is most important to consider design and mass. Both are key factors in establishing proper procedures. Specifically, these two factors will influence the important relationship of time and temperature.

Decarburization

Before talking about the individual steps, it is appropriate to explain decarburization. It has always been the principal bugaboo which the heat treater must face.

Of all the elements that are used, carbon remains the prime ingredient in tool steel. Unfortunately, reactions between steel surfaces and heating atmospheres above 1300 F may cause a loss of carbon. This loss actually results in a two-toned steel with a lower car-

bon outside area covering the desired inner composition. Should this happen, an inferior working surface is produced with poor tool life. Some tool steels have a greater tendency to decarburize than others and, as a rule, those with higher carbon content will be more susceptible to decarburization.

Preheat

Preheating is the first step of the hardening procedure. It serves a number of purposes including minimizing decarburization, avoiding heavy scaling and relieving cold work stresses. In production hardening, it may lower costs. More uniform heating also results because equalization in temperature is gained. Thus, the temperature differential existing between the surface and center of the work is less in the high heat furnace.

The temperature of the preheat will vary depending on the type of steel, but is generally above 1000 F and seldom over 1600 F.

High hardening temperature requirements, and large or irregular tool sections, indicate the need for preheating. In many instances, it is not necessary to preheat water hardening, oil hardening, and the shock resisting steels unless the sections are large. If unusually large or complicated sections are

encountered, it may be wise to employ two pre-heating stages.

High Heat

The high heat cycle is the most important one. At this point, the final conditioning of the steel prior to quenching is accomplished. Not only is the temperature important, but the time must also be carefully watched. Excessive time or temperature will cause grain coarsening and decarburization. There is a reasonable leeway for control of both conditions. Low temperatures or short times bring about inadequate solution of carbides or nonuniform structural conditions.

Frequently, a "soak" at the high heat temperature is specified. This means that the steel must be held at the high heat temperature for a certain period of time. There are two reasons for this: first, it assures the entire section being thoroughly heated; second, the more highly alloyed steels, particularly the air hardening and hot work steels, are somewhat sluggish in responding to heat treatment and require time for uniform conditioning.

Quench

When the high heat cycle is complete, the work is quenched. The actual hardening of the

steel takes place during the quench. The change progresses as the temperature decreases within a range of 700 F to 400 F on down below 150 F where the reaction is sufficiently complete from a practical viewpoint.

Various compositions require different cooling rates to assure full hardness. The decision to use a particular quenching medium is based on its ability to remove heat at the rate required by the particular steel and the mass of the section. The ideal medium would reduce the temperature quickly at first and then more slowly to accommodate the stresses from hardening which develop in the lower temperature range.

Temper

Tempering follows the quench. While this step is the simplest and easiest to perform, its importance is by no means minor. Again, we have a time-temperature relationship which requires exact control of both.

Control of the time between the quench and tempering is most vital. Since hardening takes place gradually at the end of the quench cycle, tempering too soon interrupts proper cooling and puts a stop to further hardening. Also, in large sections where a decided temperature gradient exists, cracking may occur.

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On the other hand, if the work is permitted to lay around at room temperature, the stresses from hardening continue to build up to a point where rupture may occur. These conditions show the need for care in timing at this stage. The long standing rule is to begin tempering as soon as the work can be held with the bare hands, 125/150 F. This is still a good guide.

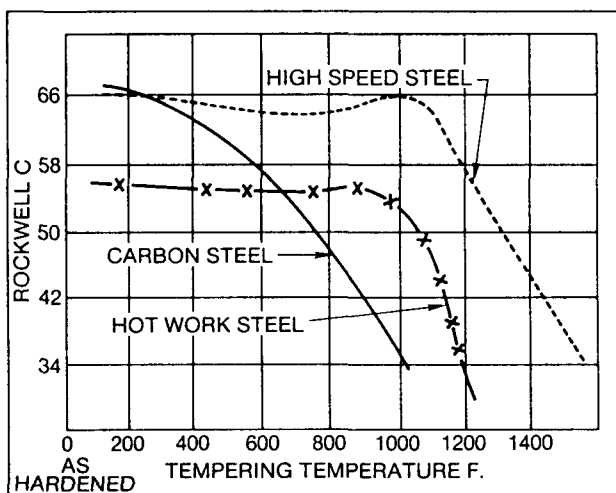


Figure 14. Hardness versus tempering temperature for three grades representative of carbon, hot work and high speed

The usual range for tempering spreads from 300 to 1200 F depending on the grade and the hardness desired. The time should be a minimum of one hour and may extend as long as six hours in some cases. The response to tempering is slow, requiring a full measure of time for completeness. For the higher alloyed steels, which generally are hardened from temperatures above 1700 F, double tempering is essential to achieve the full benefit from this treatment. Figure 14 shows the general effects on hardness after tempering three grades representative of the types shown.

Water Hardening

Quenching with water is most appropriate for the case-core Carbon Tool Steels. These steels are generally hardened from a range of 1420 F to 1475 F. To obtain a deeper case, temperatures as high as 1550 F are sometimes used. It is generally not advisable to go higher than this because excessive grain coarsening causes a loss of fatigue strength.

Because of the low alloy content and their rapid response to heat treatment, it is usually not necessary to preheat these steels. However, it is advisable to preheat large tools to provide more uniform heating and to reduce the time in the higher temperature furnace.

A critical part of the hardening of these steels is the quenching operation. Water quenching is drastic and will reduce the temperature of the tool or die in a matter of seconds.

There are two attendant dangers in water quenching: one is a tendency for the steel to crack; the other is soft spots which may develop if the proper technique is not used.

Tempering should follow quenching immediately to minimize the danger of cracking. If a tempering furnace is not readily available, the tool should be placed in boiling water without delay.

When quenching carbon tool steels, either in water or brine, the work should be agitated and remain submerged until all vibration stops. This is a signal that the most violent changes within the steel have ended. As soon as the work can be touched with the bare hands, it should be removed. The belief that the tool or die must be stone cold to get full hardness is erroneous. Such a practice invites cracking.

Soft spots cause a break in the uniformity of the hardened surface. As weak links in a strong chain, they spell failure. They develop in two ways—either the surface temperature is lowered just prior to quenching or areas on

the surface become insulated from the quenching medium.

Premature splashing or contact with tongs or fixture parts will cause the surface temperature to drop in localized points. Steam or air bubbles, dirt, scale, or oil in the quenching bath, are all sources of insulation. These insulators prevent the water or brine from contacting the area while the temperature is still high enough to bring about full hardness.

Good housekeeping to keep the quenching medium clean and the use of common sense in understanding what is taking place keeps the hardening of these steels practical for a wide variety of uses.

Where maximum hardness is desired, the lowest safe tempering temperature is that of boiling water. Except for work such as burnishing rolls, this low temperature is not usually applied. For general tool and die work, the normal tempering temperature is within 350 F to 400 F. For those tools subject to impact, such as chisels and rivet busters, temperatures between 550 F to 600 F are used.

Oil Hardening

The Oil Hardening Steels are hardened in much the same manner as the Carbon Tool Steels except oil is used as the quenching medium. The normal hardening range is

slightly higher, usually 1450 F to 1550 F. Preheating at 1200 F to 1250 F is recommended for large or intricate sections.

For quenching, warm thin oil should be used to bring the temperature below 150 F or until the work can be held in the bare hands. Where minimum size change is desired, the parts may be removed from the oil just under the flash point (about 400 F) and allowed to cool in air below 150 F.

Tempering should be done immediately. If there must be a delay, the use of boiling water is recommended. The usual hardness required is Rockwell C58-62. This can be obtained by tempering within the range of 350 F to 500 F for a minimum of two hours. Sections over two inches thick should be tempered a minimum of one hour per inch.

Air Hardening

This group of steels hardens in air by cooling from a temperature range of 1750 F to 1850 F. Preheating within a range of 1450 F to 1500 F is common practice. The usual hardness, obtained by tempering at 400 F to 600 F, is Rockwell C58-62.

Because of the high temperatures used in hardening, these steels should be heated in atmosphere controlled, muffle-type, vacuum furnaces, or salt baths, to avoid decarburiza-

tion and pitting. If such furnaces are not available, the work should be wrapped in stainless foil or packed in an inert material such as clean, dry, cast-iron chips or a commercial neutral packing compound.

To gain maximum hardness, air hardened types are sometimes quenched in oil. When this is done, the high heat temperature is dropped to the lower range of 1750 F to 1800 F. To avoid excess scaling, air hardening tools are sometimes flash quenched in oil to about 1000 F to 1200 F and then cooled in air.

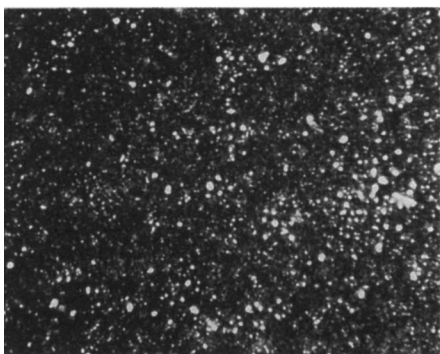
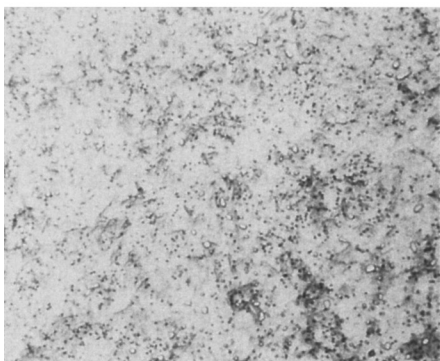
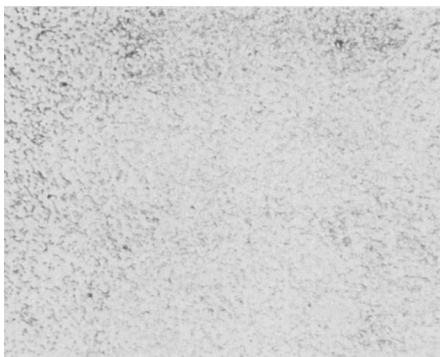
Adequate space should be allowed to afford a uniform movement of air around the parts being cooled. Although it is not good practice

Figure 15. These photomicrographs illustrate the microstructural changes which occur during heat treatment of an oil hardening tool steel.

Figure 15(a) shows the annealed structure consisting of spheroidal carbides in a ferrite matrix. Hardness is BHN 179.

Figure 15(b) shows the microstructure after austenitizing at 1475°F and quenching in oil. The microstructure consists of carbides in a matrix of light etching untempered martensite. Hardness is BC 65.

Figure 15(c) shows the microstructure after tempering at 500°F. Due to the tempering reactions, the matrix now etches



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to use forced air, a mild flow from an electric fan is often used to speed up the cooling action.

Shock Resisting

As a group these steels are not associated with a distinctive quenching medium, since LaBelle Silicon No. 2 may be hardened in either oil or water while Atha Pneu is an oil hardening grade. Crucible S7 can be air hardened.

Crucible S7 and Labelle Silicon No. 2 are both more susceptible to decarburization than the others. Therefore, it is desirable to use an atmosphere controlled furnace, salt bath or a vacuum furnace.

Hot Work (Including Mold and Die Steels)

Since this group is comprised of both Chromium and Tungsten Hot Work Steels, it is expedient to show the usual hardening cycles.

	Chromium	Tungsten
Preheat	1400/1500 F	1500/1550 F
High Heat	To 1900 F	2150/2250 F
Quench	Air Cool below 150 F	Interrupted Oil Quench to 1000 F, then Air Cool below 150 F
Temper	1050 F	1100 F
Rockwell C	45-50	45-50

Double tempering of these types is essential and triple tempering is recommended for increased performance. In double tempering, the steel is heated to the desired temperature, held for the required time, allowed to cool to room temperature, and then reheated and cooled through the same cycle. The tempering temperature used should be higher than that which the tool is expected to reach during the actual operation.

The surface of the hot work steels needs protection during heat treatment either by atmosphere control or pack hardening as described on page 78.

High Speed

These steels require high temperatures for hardening. The molybdenum types are usually hardened from a range of 2150 F to 2250 F, the tungsten types as a rule from 2250 F to 2350 F, when heat treated in an atmosphere controlled furnace. When salt baths are used, the temperature is lowered 25-35 F. Both types should be preheated within the range of 1450 F to 1550 F. In high production units, savings may be realized if a double preheat such as 1200 F and then 1550 F is used.

There are two predominant directions to take in heat treating High Speed Steels. One

aim is to develop maximum red hardness and resistance to abrasion. In such cases, the ideal practice is to heat the steel to the high side of the range and quench in oil. This procedure allows the maximum solution of alloy carbides to take place without excessive grain coarsening or the development of a duplex grain size. With this technique, hardness values of Rockwell C65 or better are consistently obtained, but toughness (the ability of the cutting edge to withstand operating stresses without chipping) is sacrificed to a degree. However, this treatment is practical for single point tools and inserts where the cutting edges are well supported.

The other aim in heat treating High Speed Steels could be to accent toughness in order to prevent the early failure of tools by chipping. To achieve this condition, lower hardening temperatures are recommended in conjunction with salt bath quenching or air cooling. Temperatures as much as 100 F to 200 F lower than normal are often used. Hardening in this manner will result in hardness values of Rockwell C62-64 for small multiple point tools, such as drills, end mills, taps, and hacksaw blades, requiring accentuated toughness. Other tools such as punches, where shock is

pronounced, are also under hardened in this way to as low as Rockwell C58-62.

Generally, High Speed Steel is quenched in a liquid bath, either salt or oil. To minimize distortion, air cooling is sometimes used. Water should not be used because its fast action invariably results in cracking even in small sections.

Liquid salt bath quenching is quite common where the complete installation for hardening consists of a battery of salt bath furnaces. The piece being hardened is quenched into a bath operating at about 1050 F. An important point to consider is the control of heat being absorbed in the quenching bath to prevent the temperature from exceeding 1150 F. After the temperature of the piece has equalized throughout, the piece is removed from the bath and cooled in air to about 150 F and immediately tempered.

Oil quenching is more effective and should be used when maximum hardness is the aim. The piece is either quenched directly into oil at about 150 F or the "interrupted" quench is used. The latter is the best and preferred procedure. To accomplish this, the work is plunged into the oil until the color disappears from the surface. Then the tool is removed and held

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in the air until the color reappears on the surface. It is usually necessary to repeat this a number of times, depending on the size of the work, until the color becomes a uniform dark red. The tool is then allowed to finish cooling in air.

As in the case of Hot Work Steels, most High Speed Steels should be double tempered. Some of the more highly alloyed High Speed Steels may even require 3 or 4 tempering treatments.



Figure 16. Molten salt is commonly used to heat and to quench high speed steel tools

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CPM Steels

CPM *High Speed Steels* can be heat treated the same as conventional high speed steels. If desired, the soaking times may be decreased by one third since the smaller carbides go into solution more rapidly than for conventional steels.

CPM *Tool Steels* are characterized by high vanadium contents. Since these carbides are the last to go into solution, a thorough soak at the high heat temperature is required. Since this group of steels is comprised of three different types, it is expedient to show typical hardening cycles.

	CPM 9V	CPM 10V	CPM 440V
Preheat	1500/1550F	1500/1550F	1550/1600F
High Heat	1950F	2050F	1950F
Soak	20-30 minutes	15-30 minutes	20 minutes
Quench	Salt, interrupted oil or air cool to 125/150F	Salt, interrupted oil or air cool to 125/150F	Oil or air cool to 125/150F
Temper	1100F, 2 + 2 hr.	1000F, 2 + 2 hr.	400F, 2 + 2 hrs.
Hardness	Rc 48/50	Rc 60/62	Rc 57/59

Surface protection during hardening is required for these steels because of the high heat temperatures required.

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HEAT TREATING RECOMMENDATIONS

The previously described heat treating procedures are “general” since they apply to a number of individual steels in a family grouping. Precise temperature ranges for each grade have not been shown. To use these procedures requires a certain amount of heat treating “know-how.” Like so many other skills, there just isn’t any published manual which covers the practical “tricks of the trade.” In the absence of such a manual, several recommendations are offered as a guide for each heat treater to establish his own “bible” as a supplement to his every day experience.

Records

The recording of data pertaining to the heat treating of specific tools is commonly practiced. Actually, the recorded notes represent an interpretation of metallurgical science.

One of the primary values of individual notes is that the information relates to the equipment at hand. There are also many other values: practical results to compare with laboratory reports; ready reference for repeat jobs which only occur at long intervals; and a his-

tory of the job to correlate with field performance. In this latter respect, good notes serve as useful evidence to determine the reasons for unusual performance, either good or bad.

In addition to this personal record, the heat treater's library should include data sheets of tool steels, booklets and reprints of articles, as well as bulletins relating to heat treating equipment and supplies.

Inspection of Incoming Material

Usually tool steel ready for heat treatment will be in the annealed condition with the mill surface removed. Of course the steel in one way or another will have been formed into a particular shape.

A look at the tool or die will often tell the condition of the material to indicate whether or not a successful hardening operation can be accomplished, and certainly the work should be clearly marked with the brand name or symbol of the tool steel type. Such things as sharp corners, variation in thickness, shiny streaks from cold working, original bar surface, excessive burning from grinding or tool marks all tell a story. As experience is accumulated, the ability to detect grade mix-up or improper hardness as revealed by a machined surface will prevent many tool failures.

If inspection of the material in any way suggests a cause for hardening difficulty, a careful review should be made. Hardness may require checking, or a spark test to identify the material may be necessary. Frequently, such faulty results as hardening cracks, low hardness, size change, coarse grain and distortion are traced to conditions which existed prior to hardening. It's not only spoilage of expensive tools which is involved, but production may be delayed because of a lack of tools.

Preparation

While the work is being inspected, plans for outlining the heat treating cycles can be made. Some cycles are long, and close timing for the best use of a variety of heat treating equipment requires good planning. With tool steels, no part of the operation should be left to chance, nor should the heat treater get himself into a dilemma for want of preparation. In some cases, it may be worthwhile to make a "dry run" to assure the best results.

In addition to arranging fixtures, tongs and other handling equipment, it is sometimes necessary to pack the work for protection against furnace atmospheres. Cast iron chips are commonly used for this purpose. This is an excellent material for the job, but trouble can

occur if the chips are not properly conditioned. They are first cleaned free of dirt and oil, and then burned or "spent" to remove the carbon. This makes them inert. It is important that all packing mediums be kept dry. Otherwise, decarburization and scaling will result.

In preparing a pack, the work is wrapped in heavy wrapping paper before being placed in the box. The paper chars and prevents the chips from sticking to the work. The layer of chips lining the box should be 1 1/2" to 2" thick. There are also several commercial compounds for this purpose. The important feature is to be sure that they are inert.

Another good method for heating small dies and tools without letting air come in contact with the surface is to wrap them in stainless foil, or put the tools into stainless steel envelopes which are then tightly closed. Small shops have learned to heat treat their own tools or dies very successfully in this manner. The stainless sheet is about .004" thick and can be handled easily.

Testing

To check results of hardening, the heat treater should be familiar with several practical test procedures. File test, Rockwell hardness testing, and sandblasting to check soft

spots are quick methods for obtaining indications of the response to heat treatment.

It is not always possible to make a hardness test on the material itself. For this reason, the use of pilot samples for test purposes is highly recommended. Not only can hardness tests be made, but the samples can be broken for visual inspection of the grain size or the sample may be used for examination under a microscope.

The file hardness test is used to determine if the heat treated product is "file hard". The best time to use this test is after hardening, but before tempering. The reason for this is that this test is specifically associated with "full hardness", and tempering usually softens the steel.

When file testing, a firm pressure on the flat (not the edge) of the test file is required with a slow forward stroke. In most cases, a shallow skin (tenths of thousands) will be present on the work. The file will quickly bite through this skin and then slide over the hard area beneath. If the work is not "full hard" or decarburization is present, the file will drag and remove appreciable amounts of metal.

The test file is a standard product made specifically for this purpose. A good description of the file test is given in the ASM Metals

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Handbook. If much filing is done on hard steel, the test file quickly loses its sensitivity and usefulness because of wearing and dulling of file teeth.

The Rockwell Hardness Tester (Figure 17), is universally used for testing hardened tool

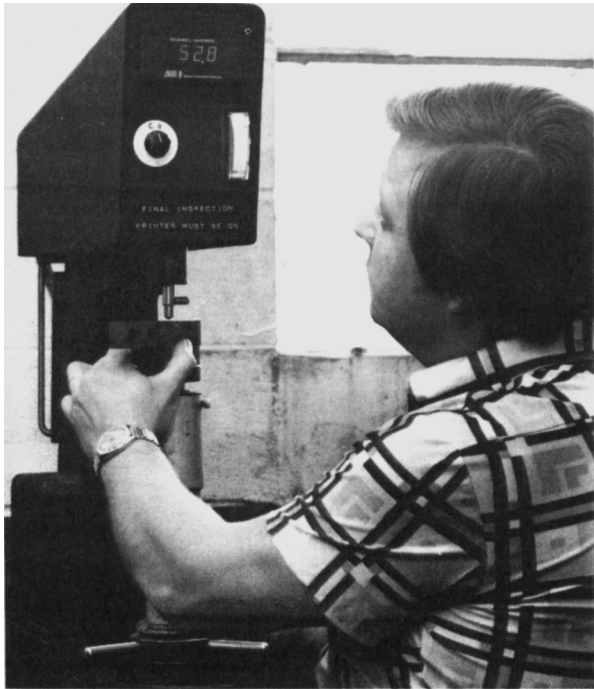


Figure 17. Rockwell hardness tester determines the hardness of heat treated tool

steels. The most important fact to remember is that the hardness values, in themselves, are not positive indications but are relative. When compared with technical reports and data from previous field experience, they will indicate if the aims of heat treatment have been realized.

Sandblasting permits surface inspection for soft spots. This is especially useful with Carbon Tool Steels to determine the effectiveness of the quench.

Areas which are soft will be dull because the abrasive will have penetrated the surface more than in the hard areas. Variations of the finish due to differences in hardness are readily distinguished. This inspection is also useful in determining the presence of tight scale.

Heating Equipment

Furnace equipment for heating tool steels includes salt baths, atmosphere controlled furnaces, muffle-type furnaces, and vacuum furnaces. At one time, salt baths were considered a cure-all to avoid decarburization, carburization, pitting, and poor surface conditions in general. The idea existed that no change in the surface was possible because there was no contact between the work and a gaseous atmosphere. This proved to be an erroneous concep-

tion because oxides in the bath itself can attack the steel.

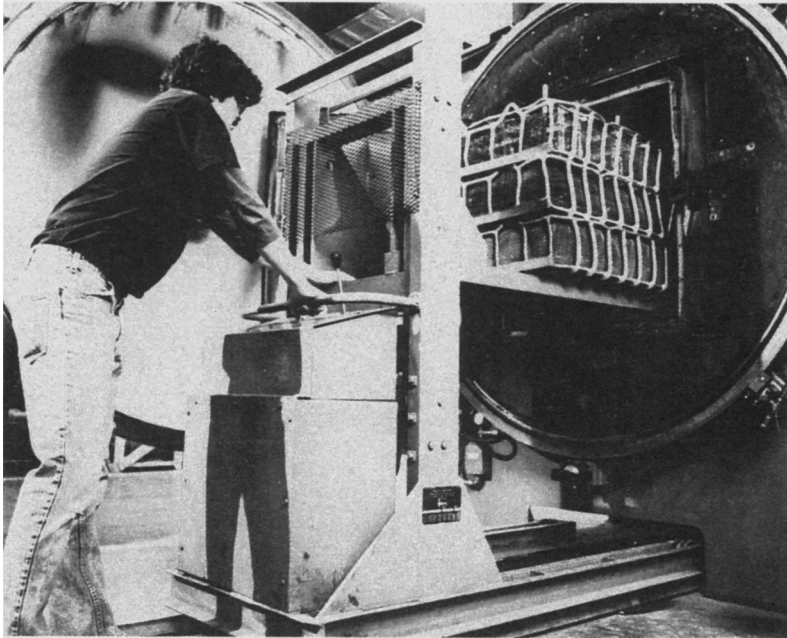
On the other hand, salt baths definitely represent a means of positive control as far as the surface is concerned. To be effective, however, close attention must be paid to the maintenance of the neutral condition of the salt. Desludging, additions of fresh salt, the use of graphite rods, and other rectifiers must be used on a regular schedule to keep the bath clean.

Each type of heating medium has its particular advantages and disadvantages, but to get clean work without surface attack requires religious control under all conditions. An important consideration in selecting a type of furnace concerns the requirements to properly fixture or support the work.

Heating in a vacuum furnace is the best method of protecting the tool or die surface during heat treatment. Vacuum heat treating produces tools with a bright surface free of decarburization or carburization. Of course, even with this advantage, things can go wrong if the vacuum is not properly maintained, if the furnace leaks, or if moisture is present in the inert gas used to quench.

Flame hardening and induction heating, although well known, are seldom used with

Figure 18.
Vacuum heat
treatment pro-
duces tools
with no surface
carburization or
decarburization



tool steels. With these methods, positive control of temperature is not possible, and the fast rates of heating result in undesirable temperature differentials within the work. In some special cases, they may be used with small sections.

Martempering, austempering, carburizing and nitriding are other heat treating processes used in connection with tool steels. Because of their rather special applications, they are not detailed in this booklet.

When Tools or Dies Won't Harden

Generally, unsatisfactory hardening of tools or dies can be traced to one of the following causes:

1. Failure to heat to a high enough temperature
2. Failure to quench fast enough
3. Decarburization—soft skin
4. The presence of residual austenite resulting from heating to an excessively high temperature
5. Mixing of steel grades

Size Change or Distortion During Hardening

During the heat treatment of a tool or die, dimensional variations take place. They are of

two types: namely, size change and shape change.

Size changes are caused by a change in the structure of the steel as it changes from its annealed structure to its hardened condition. Because of a different arrangement of the atoms, the steel is not as dense in the hardened condition, which causes it to grow in volume. Nothing can prevent this change. However, because size or volume changes are predictable for a given type of steel, allowances can usually be made by the tool or die maker.

Shape changes, usually referred to as distortions, are caused by stresses generated during the making of a tool or die, by such operations as machining or grinding. Heating too fast to the hardening temperature also causes stresses. The geometry (design) of the work can also cause distortion.

Stresses caused by the machining of a die can be relieved by a stress relieving treatment. This is done after roughing out and prior to finishing. The die is heated to about 1200-1300 F and then cooled to room temperature. The tool or die can then be finished allowing for the normal dimensional changes anticipated during heat treatment.

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Shape distortion can also occur if tools are not supported properly while being heated. For complex or intricately designed tools and dies, “step heating” and uniform quenching will minimize any distortion.

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AVOIDING TOOL OR DIE FAILURE

It can be factually stated that a tool or die will fail or break when the forces applied to it have become greater than the strength of the steel. For example, if the ultimate strength of a steel is 300,000 PSI, a load or stress of 301,000 PSI will cause it to break.

There are two major kinds of stresses which influence the performance of a tool or die:

1. Stresses which are put into the tool or die while it is being made, such as machining stresses or heat treating stresses
2. Stresses which are put into the tool or die while it is in operation

There are four factors which will determine the success of a new tool or die:

1. Tool design
2. Grade of steel selected
3. Heat treatment
4. Surface finishing (machining, grinding, etc.)

Not only must the tool or die be manufactured properly, it must also be operated under proper conditions. To begin with, it must be well and evenly supported. It must run at the correct temperature, and it must be preheated if required.

Good Design

Avoid sharp corners. Frequently, early failures occur because of excessive stresses which are concentrated in a sharp corner. Failures can be avoided by providing a radius, if possible. Fillets should be used where radii are not permissible. In both cases, the stresses are redistributed over a larger area. Figure 19.

Don't position holes near the edges. Holes should always be located so that the section thickness between the hole and the edge is larger than the hole diameter. The walls of the hole should be smooth. Tool marks are also stress raisers.

Do give the end of a blind hole a generous radius. It should not end with a sharp point.

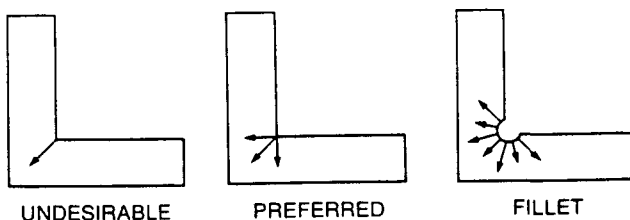


Figure 19. Distribution of stresses in a die corner

Furthermore, it is good practice to pack the holes to prevent cracking during liquid quenching.

Don't underdesign. Many tools and dies fail simply because they are skimpy—not enough steel. Thinner sections deflect more than thicker sections under a given load and will soon fail by fatigue. Making the tool harder or switching to another steel will not make any appreciable difference. The amount of deflection can only be reduced by making the section larger.

Avoid deep stamp markings. Many tools, well designed otherwise, have been ruined because of sharp or deep letter stampings. Letters should be rounded and never too deep. If possible, other means of identification should be used.

Avoid irregular water lines. Sharp recesses are created and cooling liquid cannot flow freely. Figure 20.

In summarizing good design of steel tools, it must be restated that sharp corners are the most frequent cause of early tool or die failure. Always try to provide a radius, however small, or at worst a fillet. The table below clearly shows the effects of sharp corners on the impact strength (toughness) of Nu-Die V heat treated to 47 Rc.

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TABLE IV

Radius at Base of Notch Inches	Izod Impact Strength ft. lbs.
.002	4
.010	7
.020	16
.040	19
.080	22
.125	27
notch free	240+

Selecting the Proper Type of Tool Steel

See pages 43—58.

Proper Heat Treatment

See pages 76—88.

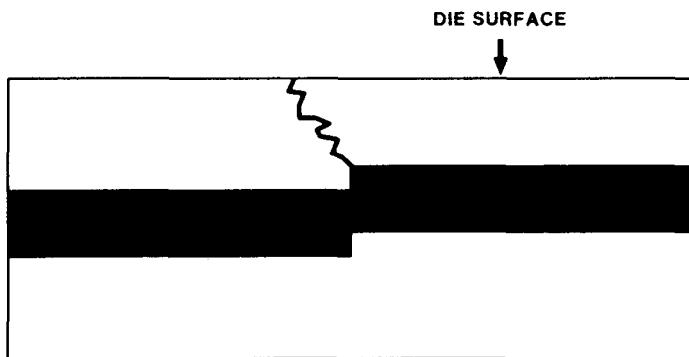


Figure 20 Cooling lines must meet

Finishing of Steel Tools and Dies

Grinding Stresses

During the making of a tool or die, stock is being removed by various methods such as milling, planing, EDM, and grinding. Grinding is usually the last operation, but often receives little attention until trouble occurs. After heat treatment, tools and dies are being fitted and it is often necessary to correct distortion which may have occurred during the heat treatment. This fitting or finishing operation is usually done by grinding.

Tools are also ground to produce a cutting edge as in cutting tools, shear blades, or blanking dies.

The most common mistakes in grinding are:

1. Removing too much metal too fast
2. Using the wrong grinding wheel
(awheel too hard or too fine)
3. Grinding with a loaded or dull wheel
4. Using an improper coolant or using the coolant improperly

Any of the above mistakes can cause the surface of the tool to be heated above its hardening temperature causing a rehardened layer of steel. Under less drastic conditions, the tool

surface may be heated to a temperature that will cause over-tempering. Thus, a soft layer of steel will be produced on the surface.

Both of these described conditions are very detrimental and will cause a drastic drop in tool performance.

By far, the greatest harm to the surface of a tool is done by the inevitable stresses which are produced during improper grinding. Under certain conditions, grinding can be so abrasive that cracks and grinding checks become visible on the surface. When this happens, the stresses produced during grinding have actually exceeded the strength of the steel. The tool or die may be worthless.

Grinding stresses do not always show on the tool surface. During final grinding, stresses may weaken the core with no evidence showing on the harder surface. New tools and dies, seemingly perfect, fail or crack early in their operation because faulty grinding weakened them to near their breaking point.

Stress Relieve After Grinding

Fortunately, grinding stresses can be largely removed by heating the tool or die after grinding to below its tempering temperature and holding at that temperature for about one hour per inch of thickness, or a minimum of

two hours. As a rule, stress relieving should be done at 50 to 100 F lower than the tempering temperature to avoid softening the tool or reducing its original hardness.

EDM (Electric Discharge Machining)

Stresses

EDM is useful for cutting deep and narrow slots into hardened steel that would be a problem if attempted with conventional tools. However, like any other machining operation, EDM produces stresses on the tool surface.

EDM produces a layer of hardened steel on the surface called the "*white layer*", Figure 21. This white layer is very brittle and, if not removed or relieved of stress, has been the cause of heat checking, pitting or cracking. The white layer varies from a few tenths to several thousandths of an inch, depending on the rate of stock removal. This rate is controlled by the amperage and frequency used. A coarse finish from heavy stock removal results in a deep white layer. In contrast, a very fine finish obtained by light stock removal will show a very shallow white layer. Regardless of the depths of the layer, the surface of the tool or die is highly stressed and should be relieved.

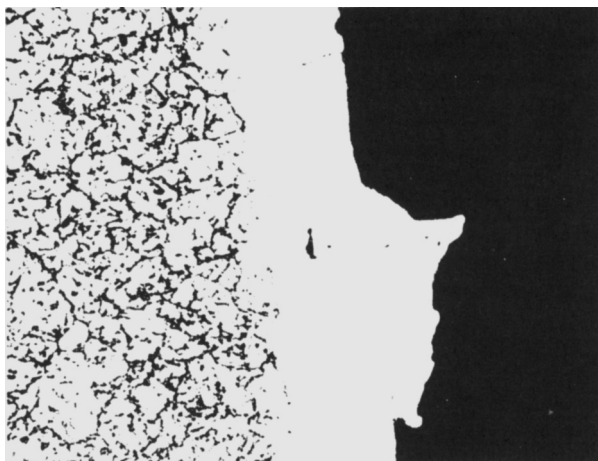


Figure 21 EDM re-hardened "White Layer" must be removed following electrical discharge machining

The following EDM stress relieve procedure has been recommended by AISI:

1. EDM finish with a high frequency. This will remove the effects of previous heavier cuts
2. Remove white layer (rehardened zone) by grinding or stoning
3. Heat to below steel's tempering temperature so hardness will not be lowered
4. If steps 1 and 2 cannot be done, step 3 will remove at least some of the stresses

Preheat Before Use

Cracking of molds occurs more often in molds which are run "cold." If the molder has a choice and molds can be run hotter, it will prolong mold life because the steel becomes tougher as it gets hotter. It is also recommended when using "hot" molds, to preheat the molds to the operating temperature to prevent thermal shock. Figure 22 clearly illustrates this point. It will be noted that by merely increasing the temperature of steel from

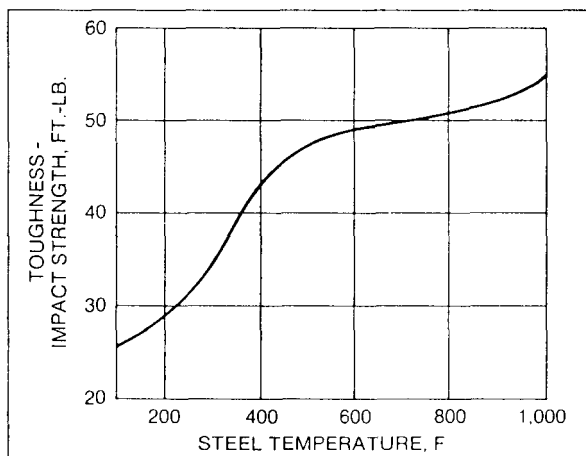


Figure 22. Hot tools run tougher

100 F to 400 F, we almost double its toughness. This is true for almost all steels.

At times, molds are run "cold" purposely when cooled with refrigerated water. Under such conditions, it is advisable to have cooling channels located not too close to the surface of the mold and also to use as low a hardness as permissible. Remember, the toughness of steel increases when the hardness decreases.

Operational Stresses

It has been stated that failures occur when the operational stresses, added to the unrelieved stresses already in the tool or die, exceed the inherent strength of the given steel.

Operational failures can be caused by:

1. Uneven loading or overloading
2. Excessive stress
3. Concentrated stress
4. Improper clearance or alignment
5. Improper maintenance

If a tool or die has no inherent (original) stresses, it should produce satisfactorily—provided it is used properly. Good tools and dies too often fail because they are not set up with care.

It is known that tools and dies flex while in operation. Excessive flexing causes failure by

fatigue. The tools crack. To minimize flexing, small tools or dies are seated into holders or pockets of larger pieces made from a tough alloy steel. If there is space between the tool and its holder, the tool will flex excessively and fail. See figure 23.

Poor shimming, causing uneven loading, may also cause fatigue failures. If shims are used to build up a pocket, they must touch the entire area between tool and holder. If empty spaces remain, only a small area will be subjected to the working forces. Cracking will result.

Shrink fitting often causes very large stresses to be concentrated on an insert. It has been reported that shrink fitted tool shave cracked in corners or sharp radii during the shrink fitting operation itself or shortly after the tool was in operation. Any shrink fitted tool assemblies should be stress relieved after fitting at a temperature low enough to avoid reducing the hardness of the working tool.

Misalignment and Improper Clearance are also operational causes of premature tool failures. When two hardened parts, such as a punch and its companion die, are allowed to touch each other in service, either one or both will break.

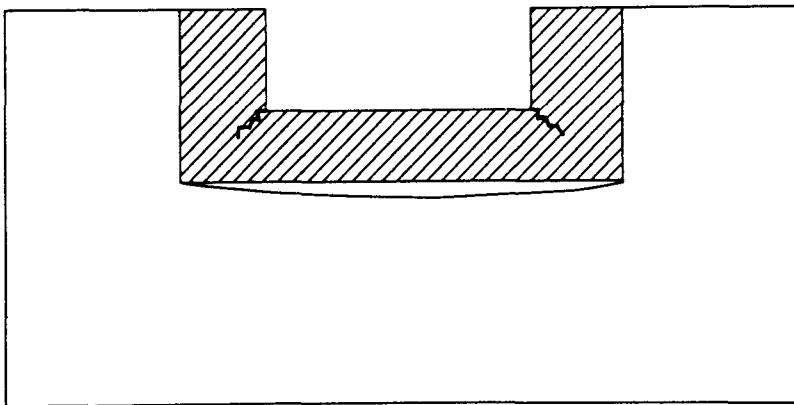


Figure 23. Improper seating or leaving an open space with poor shimming will cause excessive tool flexing and fatigue failure

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Shear blades must not touch each other during the shearing operation. They must have clearance. If not, they will chip at the cutting edges if fully hardened, or they will dull rapidly if too soft.

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TOOL MAINTENANCE

Proper tool maintenance is seldom done on time. It more often comes too late, when major repair work is necessary to restore the tool or die to its former production capability. Most failures of tools and dies do not occur suddenly. They gradually develop into major failures.

A tool or die wears down slowly. The first signs of wear usually show as very fine pits in areas subject to the greatest abrasive action. These pits become larger and larger until finally the entire surface disintegrates.

Heat checking is a common failure of hot work dies caused by the continuous expansion and contraction of the surface while it is heated and cooled during each production cycle. It is very similar to the phenomenon which occurs during wear. At first, very small pits occur. Soon, they orient themselves to form a spider web appearance. If not corrected, the surface will deteriorate beyond salvage.

Insipient *cracks* appear in sharp corners and radii of tools bearing these design characteristics. These cracks are very shallow at first, but get deeper and deeper as the tool or die flexes in operation.

Obviously, the proper time to repair tools and dies is when the first signs of failure

occur. The pits and shallow cracks may be removed by a moderate amount of stoning or grinding. After repair, tools and dies should be stress relieved, (see page 93) or the defects will reappear after a short time in operation. Remember, it was stresses which caused the failure signs to begin with. Therefore, it is essential that we not only repair what we see, but also eliminate any invisible stresses within the tool or die.

Welding

Expensive tools and dies can often be salvaged by welding at a fraction of the cost of a new replacement. When cracks, heat checks, and pits have become too deep to remove by stoning or grinding, welding may be the answer.

To do a reliable job, the welder must know the grade of steel from which the tool or die was made, its heat treatment, and its hardness. He will then select the proper welding rod and welding procedure. For most steel tools and dies, the TIG (tungsten inert gas) method of welding is recommended. To avoid cracking at or near the welded joint, certain procedures must be followed.

After the crack or defect has been completely removed, make sure there is no moisture or oxide present. Then proceed as follows:

1. Preheat the tool to about 100 F below its tempering temperature. Heating it to

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above the tempering temperature would draw the temper and soften the tool. The maximum preheating temperature should be 900 F.

2. Weld. Reheat the tool if the temperature drops 300 F below the preheating temperature before welding is completed.

3. After welding is completed, allow the tool to cool to hand-warm or at least to 200 F.

4. Relieve all inherent stresses by reheating the tool to the preheating temperature and hold one hour per inch of thickness of the tool, but a minimum of two hours.

5. Allow the tool to cool to room temperature.

It is extremely important to reheat welded tools to the preheating temperature after welding and then cooling to below 200 F because this treatment tempers the rehardened layer of steel next to the weldment and, most important, it relieves the stresses imparted to the welded zone. Figure 24 is a cross-section of a forging die made from H11 type steel. It shows the various zones of metal in the welded, heat-affected area.

Adjacent to the weld deposit is a layer of metal (the light-etching layer) which has been rehardened from the heat of the molten metal because it was heated above the hardening temperature of

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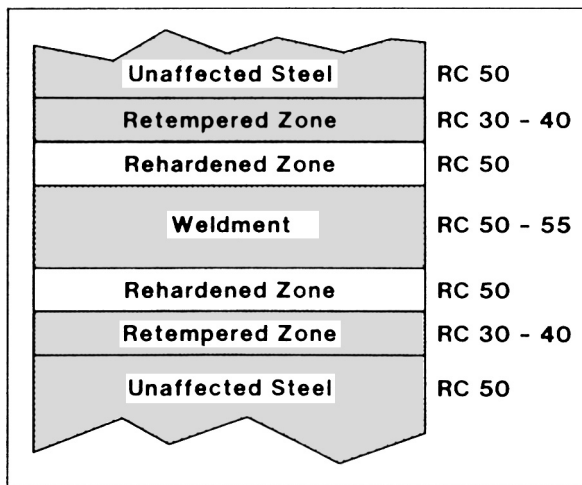


Figure 24. Hardness differences in welded zone

the steel. Next to this layer is a zone (dark etching) which has been overtempered from the heat of welding. This zone is somewhat lower in hardness than the original hardness of the tool.

With all the variations in hardness and structure, it is easily understood why a thermal treatment or stress relief after welding is so necessary. A close inspection of figure 25 will show two small cracks in the rehardened or light-etching zone. These were caused by

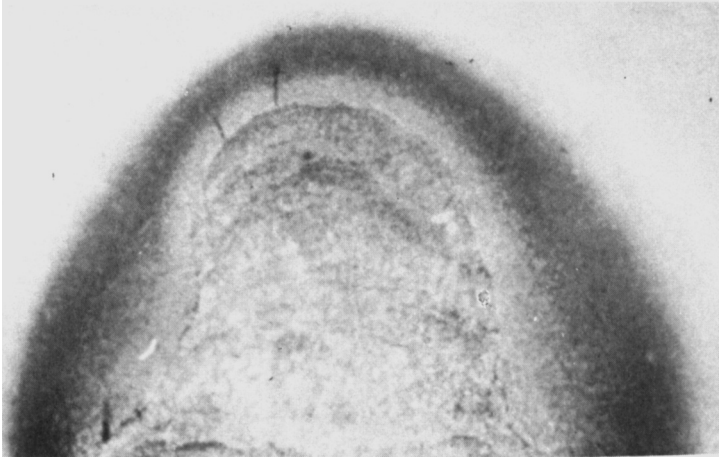
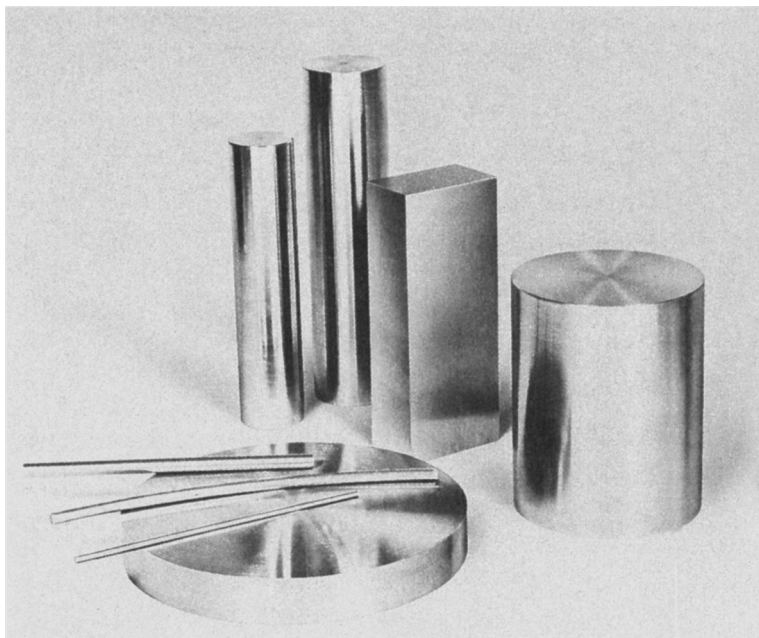


Figure 25. Internal cracks are the result of failure to reheat after welding during tool repair

neglecting to reheat the die after welding. This condition was henceforth prevented by incorporating a postheat treatment into the routine welding procedure of all tools and dies used in the shop.



A special thanks to
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The Nine Types of Tool Steels**Steel Properties on Page**

Water Hardening:		11
Shallow Hardening—Alva Extra	(W2)	
Medium Hardening—Sanderson Extra	(W1)	
Black Diamond	(W 1)	
LaBelle Cold Header Die	(W1)	
Deep Hardening —Sanderson Special	(W4)	
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Nu-Die® V	(H13)	
Nu-Die® XL	(H13)	
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Peerless A	(H21)	
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CSM 6	(A6)	
Crucible S7	(S7)	
CSM 21	—	
CSM 414	(T414L)	
CSM 420	(T420)	
Nu-Die® V	(H 13)	
Crucible Holder Block	—	

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Nu-Die® V (H13)

Nu-Die® XL (H13)

Peerless A (H21)

High Speed Steels:

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REX TMO® (M 1)

REX M2® (S) (M2)

REX® M2(S) HC (M2)

CPM® REX M2HCHS (M2)

CPM REX M2HS HC (M2)

REX M3(S)- 1 (M3-1)

REX M3(S)-2 (M3-2)

CPM REX M3HCHS (M3)

CPM REX M4 (HS) (M4)

REX M7 (M7)

REX VM (M 10)

REX M33 (M33)

CPM REX M35HCHS (M35)

CPM REX 45 (HS)

REX 49® (M41)

REX M42 and

CPM REX M42 (M42)

CPM REX 76® (HS) (M48)

CPM REX 25 (M61)

CPM REX 20 (M62)

REX AA (T1)

REX AAA (T4)

REX 95® (T8)

CPM REX T15(HS) (T15)

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