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Tool Steel Reference Guide

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AISI A2

Air Hardening Tool Steel

AISI A2 is an air-hardening tool steel containing 5 pct chromium. It replaces O1 when safer hardening, better dimensional stability, and increased wear-resistance are required. Use for dies, punches, and similar forming and blanking tools as recommended for Type O1, but where less distortion in heat-treatment or better wear-resistance is required.

Machinability - If properly annealed to Brinell 212 max, A2 has a machinability of 65, as compared with a 1-pct carbon tool steel, rated at 100.

Dimensional Stability - When air-quenchedfrom the proper hardening temperature, this grade generally expands 0.001 in./in. of cross-section.

Typical Analysis

Carbon 1.00	Molybdenum 1.10
Vanadium 0.25	Chromium 5.25
Silicon 0.60	Manganese 0.60

Annealing

A2 should always be annealed after forging. To prevent decarburization use a controlled-atmosphere furnace or pack in a sealed container using some inert material. To anneal for lowest hardness, heat slowly to 1650°F and hold at this temperature for about two hours per inch of greatest cross-section. Cool at a rate of 20 degrees per hour to 1150°F and reheat to 1350°F; hold three hours per inch of greatest cross-section; furnace cool at 20 degrees per hour to 1100°F; then furnace-cool to 900°F and air-cool. A hardness of Brinell 212 max will result from this treatment.

Hardening

To prevent decarburization, pack in some inert material; or the treatment can be carried out in a salt bath or controlled-atmosphere furnace. Preheat to 1200°F and hold at this temperature until thoroughly soaked. Heat to 1750 to 1800°F and hold for one hour per inch of greatest cross-section. Remove from the furnace and cool in air. Although A2 is primarily an air-hardening grade, flash oil-quenching is occasionally used on large sections; but tools must be removed from the oil when they reach 1000°F, and air-cooled to 1500°F. Temper immediately to minimize the possibility of cracking.

The fracture grain size and Rockwell C hardness of specimens 1in. square X 4 in. long, quenched in air and quenched in oil, after holding 1 hour at temperatures ranging from 1600 to 1900°F are:

	Still-Air Cooled		|		Oil-Quenched	
Quenching	**Fracture**	**Rockwell**	|	**Quenching**	**Fracture**	**Rockwell**
temp - °F	**grain size**	**C**	|	**temp - °F**	**grain size**	**C**
1600	7	48	|	1600	9-3/4	54
1650	9-1/2	54	|	1650	9-3/4	55
1700	9-3/4	59.5	|	1700	9-3/4	62
1750	9-3/4	64	|	1750	9-3/4	65
1775	10	64	|	1800	9-3/4	64
1800	10	64	|	1850	9-1/2	63.5
1850	9-1/2	63	|	1900	9-3/4	62
1900	9-1/4	62	|			

Tempering

After the pieces have cooled in the quench to about 150°F they should be tempered immediately. For most applications A2 should be tempered at 350 to 400°F. A minimum holding time of two hours per inch of greatest cross-section should be used.

The Rockwell C hardness obtained on specimens 1 in. square when quenched in air from 1775°F, and quenched in oil from 1750°F, and tempered at various temperatures, are as follows:

Rockwell C		
Tempering	**1775°F**	**1750°F**
temperature - °F	**Air-quench**	**Oil-quench**
None	64	65
300	62	62.5
400	60	61
500	56	57.5
600	56	56
700	56	56
800	56	56
900	56	56
1000	56	55
1100	50	50
1200	43	45
1300	34	34

These results on 1-in. diameter specimens may be used as a guide in tempering tools to desired hardness. However, tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

AISI A6

Air Hardening Die Steel

A6 is an air hardening, cold work die steel which exhibits less distortion during heat treatment than water or oil hardening steels and most high alloy, air hardening die steels. It is a fully air hardening steel, a 6 inch cube hardening to Rockwell C 60 in still air. In addition, A6 has the advantage of a low hardening temperature range, 1500'-1600F, usually available only in oil hardening steels.

The minimum distortion characteristic of A6 makes it particularly attractive for dies and punches in blanking and forming operations, for gages, or for other tools where close size tolerance is important.

Typical Analysis

Carbon .70	Chromium 1.00
Manganese 2.00	Molybdenum 1.35
Silicon .30	Sulfur .09

Annealing

A6 may be annealed in either a controlled atmospheric furnace or packed in spent pitch coke, spent cast iron chips, or in lime, fine dry ashes, sand, or ground mica with approximately 10 percent burned charcoal added. Heat to 1325- 1375°F and hold approximately 4 hours for each inch of thickness. Cool very slowly at a rate of 20' per hour to approximately 1000°F. Annealed hardness range is normally 235 to 245 Brinell.

Hardening

The hardening temperature range for A6 is from 1500'-1600°F. Tools with simple shapes may be heated directly to the hardening temperature from room temperature. A preheat of 1200-1250°F should be used for tools or intricate shapes. A furnace atmosphere for hardening should be slightly oxidizing. Cool in still air or an air blast.

Tempering

To obtain high hardness with minimum distortion, A6 should be tempered at temperatures between 300-400°F. Tempering time will vary with the size of the piece being hardened, but even the smallest tools should be tempered for a minimum of 1 hour. Reference to the hardening and tempering table will give approximate hardness obtained with various tempering temperatures.

Hardening	Air Cooled	Shepherd	Tempering	
Temp.	Hardness	Fracture	Temp.	Hardness
°F	Rockwell C	Rating	Rating	Rockwell C
1400	56	9	300	54
			400	54
			500	51.5
			600	51
			700	49
			800	47
			900	44
			1000	41
1450	60.5	9	300	60
			400	58.5
			500	57
			600	56
			700	54
			800	49.5
			900	47
			1000	43
1500	61.5	9	300	60.5
			400	59
			500	56
			600	55
			700	53
			800	50
			900	48
			1000	44
1550	62	9	300	60.5
			400	59
			500	56
			600	56
			700	54
			800	51
			900	48.5
			1000	45
1600	63	9	300	61
			400	59
			500	57
			600	56.5
			700	54.5
			800	52.5
			900	50
			1000	46
1650	60	8.5	300	57
			400	56
			500	56
			600	56
			700	55.5
			800	52.5
			900	51
			1000	46

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design.
Data on any particular piece of material may vary from those herein.

AISI D2

High Carbon/High Chrome Tool Steel

As the result of its special annealed structure, developed and tested over a period of several years, AISI Type D2 is the ideal grade for maximum production runs. Its machinability is superior to any of the similar types of tool steel. It also has excellent wear-resistance and deep hardening properties, and high compressive strength. Use D2 for applications requiring long runs and close tolerances. Use it for tools and dies for blanking, punching, forming, cold-extruding, and other operations requiring high compressive strength and excellent wear resistance.

Machinability - D2 has a machinability rating of 65, as compared with a rating of 100 for a 1 pct carbon tool steel.

Dimensional Stability - Tests on this grade normally show a slight amount of contraction after hardening with the part in the as-quenched condition or tempered below 900F. Tempering at approximately 925F usually eliminates this contraction and brings the part virtually back to its original size. D2 has the minimum distortion in heat-treatment as compared with other tool steels.

Typical Analysis

Carbon 1.55	Molybdenum 0.080
Chromium 12.00	Vanadium 0.090

Annealing

Use a controlled-atmospheric furnace or pack in some inert material in a sealed container to prevent decarburization. To anneal, heat slowly to approximately 1600°F to 1650°F and hold at temperature for 1-1/2 hours for each inch of greatest thickness. Cool slowly at a rate of 20 degrees per hour to 900°F, after which the steel may be allowed to cool down with the furnace. Resulting hardness will be Brinell 217 max.

Hardening

When heating for hardening, protect the steel by packing or wrapping in some inert material. When available, the use of a well-regulated salt bath, a controlled-atmospheric furnace, or a vacuum furnace is preferred. Preheat to 1200°F and hold at this temperature until thoroughly soaked.

Heat to 1850°F and hold at this temperature 1 hour for each inch of greatest cross section. The pieces may then be removed and cooled in still air to a temperature of 150°F and tempered immediately. Oil quenching is required on sections 6 in. and larger.

The fracture grain size and Rockwell C hardness of 1-in.-square specimens quenched in air after holding for one hour at various temperatures are indicated in the following chart.

Still Air-Cooled		
Quenching	Fracture	Rockwell
temperature - °F	grain size	C
1700	8-3/4	62
1750	9-1/4	64
1800	9-1/4	65
1850	9-1/2	65
1900	9-1/4	63

Tempering

Double tempering is always preferable with the second temper 50 degrees lower than the first. The type of tool and service requirements largely determine the tempering temperature. For most applications the tempering range is 900°F to 960°F. A minimum holding time of two hours for each inch of greatest cross section should be used.

To minimize the possibilities of cracking, temper immediately after hardening and heat slowly to desired tempering temperature.

In the as-quenched condition, D2 normally shows a slight amount of contraction in size. Tempering at 900°F or slightly higher usually neutralizes the original shrinkage produced in the quench and brings the part virtually back to its original size. If the first temper does not completely neutralize the shrinkage, then a second, or even a third temper may be used, each temper being raised 10 degrees over the previous temper. This produces a hardness in the range of Rockwell C 58 to 60.

After the shrinkage of the part has been neutralized, it is advisable to give the part a final temper to temper any newly formed martensite. This final temper should be done at 25°F to 50°F below the previous temper.

Various size specimens from several heats of steel were air quenched from 1850°F and tempered for a minimum of 2 hours per inch of cross section with the following results:

	1850°F
Tempering	**Air-Quenched**
Temperature - °F	**Rockwell C**
None	64
400	60
500	58
600	58
700	58
800	57
900*	
960	58/60
1000	56
1100	48
1200	40

These results may be used as a guide in tempering tools to desired hardness, keeping in mind that tempering below 900°F is not recommended. However, tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

AISI D3

High Carbon/High Chrome Tool Steel

D3 is a high carbon-high chromium steel developed for applications requiring high resistance to wear or to abrasion and for resistance to heavy pressure rather than to sudden shock. Because of these qualities and its non-deforming properties, D3 is unsurpassed for die work on long production runs. It is primarily an oil-hardening steel, and it hardens to a great depth. The production from a die after each grind is consistently uniform. While the impact strength is comparatively low, by proper adjustment of tool design and heat treatment, this steel has been used successfully for punches and dies on quite heavy material (up to 1/4 inch thick).

Among the more important applications of D3 are the following:

- Blanking, stamping, and cold forming dies and punches for long runs; lamination dies
- Bending, forming, and seaming rolls
- Cold trimmer dies or rolls
- Burnishing dies or rolls
- Plug gages
- Drawing dies for bars or wire
- Slitting cutters
- Lathe centers subject to severe wear

Typical Analysis

Carbon 2.20	Vanadium 1.00
Chromium 12.00	

Annealing

Pack annealing is preferable for D3. Heat slowly to 1600°F-1650°F and allow the charge to equalize at this temperature, then cool slowly in the furnace. In the fully annealed condition, D3 will have a Brinell hardness of 212-248.

Hardening

In general, pack hardening is recommended unless controlled atmospheric furnaces are available. Heat slowly and uniformly to 1750-1800°F. Hold 1 to 3 hours at temperature for tools of ordinary size, or until thoroughly heated through. If it is desired to heat in an open fire, preheat slowly to 1300-1400°F and raise to the hardening temperature. Quench in oil. The quenching oil should be slightly warm to the touch to insure proper fluidity.

Tempering

The usual tempering temperatures range from 300 to 500°F for tools working on medium to light gage material. Tools subject to shock, such as punches working on heavy stock, should be tempered at higher temperatures, 750 to 1000°F. It is desirable to temper in an electric furnace rather than in a molten bath or on a hot plate. The time should be approximately 1 hour at temperature for each inch of thickness. When tempering at 750- 1000°F, double tempering is recommended.

Mean Thermal Coefficient of Expansion

Temperature	**Coefficients**
Range °F	**in./in./°F**
70-200	6.74
70-300	6.74
70-400	6.82
70-500	6.87
70-600	6.98
70-700	6.98
70-800	7.19
70-900	7.29
70-1000	7.37
70-1100	7.43
70-1200	7.48
70-1300	7.52
70-1400	7.63

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Hardening and Tempering Series

Ground annealed bars 1 inch round by 2 inches long were preheated at 1200°F. The samples were transferred to an electric furnace with an atmosphere of about 10 percent CO, held for 30 minutes, and quenched in oil. They were then fractured and tested for hardness. Samples were tempered cumulatively for 1 hour at the indicated temperature.

The best hardening range for both open fire and pack hardening is 150-1800°F. Sections 1 inch thick and under will harden in air from 1850°F.

	Energy	
Tempering	**Absorbed**	**Hardness**
temperature - °F	**Ft-lbs.**	**Rockwell C**
As quenched	12	66.0
300	21	64.5
400	32	62.0
500	32	59.5
600	33	59.0
700	34	58.0
800	34	58.0
900	30	58.5
1000	29	55.5
1100	40	50.0
1200	53	43.0

AISI S1

Chrome-Tungsten Shock Resistant Steel

AISI S1 is a versatile chrome-tungsten shock-resisting tool steel. Its properties provide excellent service in both cold and hot work shock applications. In addition, it is widely used for master hobs.

It's low carbon content provides toughness and its combination of alloying elements provides the carbide formation necessary for abrasion resistance, the hardenability necessary for shock tools, and improved hot work characteristics.

For additional wear resistance, tools of SI may be carburized during pack hardening.

Uses - Heavy duty blanking and forming dies, punches, chisels, shear blades, slitter knives, cold striking dies, cold extrusion tools, coining dies, master hobs.

Hot work applications with operating temperatures under 1050F such as headers, piercers, forming tools, shear blades, and drop forge die inserts.

Machinabilty - In the annealed condition S1 has a machinability rating of 75 as compared with a rating of 100 for a 1pct carbon tool steel.

Dimensional Stability - When oil-hardened, S1 can be expected to expand approximately 0.002 in./in. of greatest cross section.

Typical Analysis

Carbon 0.500	Chromium 1.250
Chromium 0.750	Tungsten 2.250
Vanadium 0.200	Manganese 0.300

Annealing

S1 can be softened to proper structure for machining by heating slowly to 1450 to 1500°F, holding at temperature for at least one hour per inch of greatest thickness, and cooling slowly to 1000°F, after which it may be air- cooled. Hardness resulting from this treatment will be Brinell 212 max. To prevent decarburization, pack or pipe-anneal in sealed containers, using inert material or use a controlled atmosphere furnace.

Hardening

Preheat to 1200°F. Then heat to 1750°F for quenching and hold at temperature for a half-hour for each inch of greatest thickness. Tungsten chisel steels are susceptible to decarburization on hardening and, therefore, precautions should be taken to minimize surface deterioration. It is advisable to protect the surface by using vacuum heating, neutral salt bath or atmosphere furnaces. If these are not available, pack hardening in spent pitch coke or similar material should prove adequate.   Preheating at approximately 1200°F serves to minimize the subsequent time at hardening temperature, which also helps to reduce decarburization.

S1 is one of the most commonly used grades for master hob applications. Master hobs require a steel that has a very high toughness and at the same time a surface of almost file hardness. This can be achieved by carburizing and hardening from 1750°F. Use new carburizing compound to preserve the hob surface and to obtain maximum surface hardness. Aim for a case depth of .010 in. Avoid deep carburized cases (.015 or greater) which could cause brittle failures. Oil quenching can be conducted directly from the carburizing temperature. Temper at 350°F immediately after oil quenching. This carburizing treatment should result in a shallow file hard case of approximately HRC 61 and a tough core of approximately HRC 57.

Though primarily an oil-hardening grade, S1 can also be hardened by quenching In water from 1700°F, provided the section is not intricate. Water-quenching increases the hardness but likewise increases the amount of distortion.

The Rockwell C hardness and fracture grain-size of S1 specimens 1-in. square, quenched in oil after holding one hour at various temperatures, are as follows:

Oil Quench		
Quenching	**Fracture**	
Temperature - °F	**rating**	**Rockwell °C**
1550	9-1/2	56.5
1600	9-1/2	57.5
1650	9-1/2	58.5
1700	9-3/4	59.5
1750	9-3/4	61
1800	9	60
1850	7-3/4	59

Tempering - Next Page

Tempering

The tempering temperature of S1 varies with the intended use of the steel. For hot-work tools the range may be within 1000 to 1200°F, and for cold-work tools-the range may be between 300 and 500°F. Hold at temperature a minimum of one hour for each inch of thickness.

Specimens 1in. diameter by 5 in. long were quenched in oil from 1750°F and tempered at 100 degree intervals from 300 to 1200°F for one hour. Hardness results were as follows:

	1750°F
Tempering	**Oil-quench**
Temperature - °F	**Rockwell C**
None	61
300	57.5
400	56.5
500	54
600	53
700	52
800	50
900	48
1000	47
1100	47
1200	42

These results may be used as a guide in tempering tools to desired hardness. However, since 3/4-in. diameter specimens were used in this test, tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

AISI S5

Silicon-Manganese-Moly-Vanadium Shock Resistant Steel

S5 was developed primarily for shock-resisting parts in which a combination of great ductility with hardness is required. Carbon tool steels with hardness under Rockwell C-60 cannot compare in shock-resisting properties with the alloy grades. S5 is primarily an oil hardening tool steel; intricate parts made of S5 are usually oil quenched. S5 may be quenched in water with satisfactory results, but care should be taken if the part has drastic sectional changes or sharp corners.

Uses - Hand and pneumatic chipping chisels, shear blades, caulking tools, beading tools, punches and all types of severe or unusual service, involving drastic and repeated impact at room temperatures.

Machinability - When annealed to Brinell 229 max, S5 machines without great difficulty. Where 1pct. carbon tool steel has a rating of 100, S5 is given a rating of 65.

Dimensional Stability - Although S5 is not classified as a non-deforming tool steel, it will hold size and shape reasonably well during heat-treatment, if normal precautions are used in its application and treatment. Where freedom from distortion is of primary importance, the tools should always be oil quenched rather than water quenched. S5 can be expected to expand 0.002 in./in.(+).

Impact Properties - To determine S5's resistance to impact, a series of tests were made with unnotched Charpy specimens 0.250 x 0.375 x 2 in. long. The specimens were rough-turned oversized, heat-treated and finished by grinding down to the standard size. Samples were oil quenched from 1600F and tempered at 100-degree intervals from 300 to 1000F. Although, S5 showed impact values above 40 ft-lb without tempering, all hardened tools made of this grade should be tempered.

Typical Analysis

Carbon 0.600	Manganese 0.700
Silicon 1.850	Molybdenum 0.450
Vanadium 0.200	

Annealing

Pack-annealing in sealed containers using inert materials is preferable because of the tendency of this steel to decarburize; otherwise controlled atmospheric furnaces may be used. Heat it slowly to a temperature of 1450°F, and hold one hour for each inch of greatest thickness.

To obtain best machining properties, the steel should be cooled slowly to 1000°F. Careful annealing should result in a hardness of Brinell 229 max.

Hardening

S5 is primarily an oil hardening grade; however, it hardens satisfactorily by water quenching when the design is not too intricate. Hardening temperature for both oil and water quenching is 1600°F. Holding time at hardening heat should be just sufficient for uniformity of temperature; holding time should not exceed a half-hour per inch of thickness because of the danger of excessive decarburization. After quenching, temper immediately.

Fracture grain size a Rockwell C hardness of S5 specimens 3/4-in. diameter by 5 in. long, quenched in oil and quenched in water at various temperatures, were as follow:

Oil Quench

Quenching Temperature - °F	Fracture rating	Rockwell C
1450	8	49
1500	9-1/2	55
1550	9-1/2	61
1600	9-1/2	64
1650	9	63

Water Quench

Quenching Temperature - °F	Fracture rating	Rockwell C
1450	8	51
1500	9	59
1550	9-1/2	64
1600	9-1/2	65
1650	9-1/2	65

Tempering – Next Page

Tempering

Normal tempering procedure for S5 is to hold at temperature for at least two hours for each inch of greatest thickness. Tempering temperatures should be between 400 and 650°F, depending on the service desired. The resulting Rockwell C hardnesses for oil and water quenching and tempering from 300 to 1300°F by 100-degree intervals are as follows:

Tempering	1600°F	1600°F
Temperature	**Oil quench**	**Water quench**
°F	**Rockwell C**	**Rockwell C**
300	63	63
400	61	61
500	60.5	60
600	59	59
700	57.5	57.5
800	53	53.5
900	51	51
1000	49	48
1100	47	45
1200	40.5	40
1300	33.5	33

These results may be used as a guide in tempering tools to desired hardness. However, since 3/4-in.diameter specimens were used in this test, tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

AISI S7

AISI S7 - Chrome-Moly-Shock Resistant Steel

AISI S7 is a shock steel with exceptional impact properties - unnotched Charpy over 200 ft-lb at 400F temper. Since it hardens in air, it is safe and stable in heat treatment. But perhaps the most remarkable characteristic of S7 is its versatility. It is used widely for medium-run cold-work tools and dies, for plastic-molding dies, for shear blades, for medium hot-work dies, for master hobs, and for component parts of many products.

S7 has an unusual combination of properties, making it suitable for an extremely wide range of tool and die work - where shock-resistance, medium hot-work properties, or ease of machining and heat-treatment are most important.

It is recommended for both hot and cold shock applications such as rivet sets, chisels, punches, moil points, hot headers and gripper dies. S7 is also suited for short-run dies used in cold-forming, blanking, and bending. Other uses include: engraving dies, machined cavities for plastic-molding dies, die-casting dies, shear blades, and master hobs.

S7 is often chosen for hot-work jobs which involve shock. When tempered in the higher range, it is an excellent performer as a hot-work tool where the operating conditions do not cause the temperature of the tool to exceed 1000F.

Machinability - When annealed to Brinell 197 max, S7 is rated at 95, as compared to a rating of 100 for a 1.00 pct carbon tool steel.

Dimensional Stability - When quenched in air from the proper hardening temperature, S7 can be expected to expand no more than 0.001 in./in. of cross-section.

Typical Analysis

Carbon 0.500	Manganese 0.700
Silicon 0.250	Molybdenum 1.400
Vanadium 3.250	

Annealing

Anneal in a protective atmosphere. Heat rapidly to 1500 to 1550°F and hold at that temperature for one and one-half hours for each inch of greatest thickness. To obtain best machining properties, cool slowly to 1000°F, and then air-cool. This annealing procedure should produce a hardness of Brinell 197 max.

Hardening

In order to maintain the surface chemistry, S7 should be hardened in a controlled neutral environment. It should be recognized that packing in cast-iron chips could result in imparting a light, carburized case. Unless such a case is considered desirable for the end use, provision must be made for grinding it off after treatment.

S7 should be preheated at 1200 to 1300°F and raised to the hardening temperature of 1725°F, holding at temperature for one hour for each inch of greatest cross-section. Sections 2-1/2-in. or less should be quenched in still air. Upon reaching 150°F, the piece should be tempered without delay.

Sections over 2-1/2-in. and up to 6 in. should be oil-quenched until black (1000°F), then cooled in air. For massive sections larger than 6 in., it is advisable to oil-quench until the piece reaches 150°F; then temper immediately. (After oil-quenched sections have cooled to room temperature, temper again to insure complete transformation).

To determine the refinement produced by hardening, the fracture grain size and Rockwell C hardness of S7 specimens 1 in. round by 3 in. long were established. Still-air quench, air-blast quench, and oil-quench followed a preheat at 1300°F, and a quench from various temperatures. See accompanying tables.

Still-Air Quench

Quenching	Fracture	
Temperature - °F	rating	Rockwell C
1550	6-1/2	43.5
1600	7	48
1650	8	57
1700	9	60
1725	8-1/2	60
1750	8	60
1800	7	60

Air-Blast Quench

Quenching	Fracture	
Temperature - °F	rating	Rockwell C
1550	6-1/2	52.5
1600	7	57
1650	8-1/2	57.5
1700	9	58
1725	8-1/2	60
1750	8	60
1800	7-1/2	60
1850	7	61

Oil Quench

Quenching	Fracture	
Temperature - °F	rating	Rockwell C
1550	8	52
1600	8	54
1650	9	57.5
1700	9	61
1725	8-1/2	61
1750	8	61.5
1800	8	62
1950	7	62

Tempering

S7 is normally tempered one and one-half hours to two hours for each inch of greatest cross-section. The tempering temperature varies according to the intended use. For cold-working and similar applications, a tempering temperature of 400°F is recommended. For hot-work applications, a tempering temperature of 900 to 1000°F is suggested. Never temper at less than 400°F.

When interrupted oil-quench (to 1000°F) or full oil-quench (to 150°F) has been utilized in hardening, always temper immediately. Then, after cooling all the way down to room temperature, temper again to insure complete transformation.

Specimens 1 in. round by 3 in. long were air-hardened from 1725°F and tempered at various temperatures for 2 hours. Results are shown in the above table.

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those herein.

AISI 420

ESR Mold Quality Stainless Steel

AISI 420 ESR Is an air or oil hardening mold steel having superior internal steel cleanliness combined with good resistance to corrosion. It is suitable for mold applications and is capable of providing an excellent polished surface.

The manufacture of 420 ESR includes an additional refining step. High quality 420 steel type is remelted in a process called Electro-Slag-Refining or ESR. This remelting process provides a 420 type steel with the very low inclusion content required by mold makers who polish mold surfaces.

Typical Analysis

Carbon .30 - .40	Sulfur .030 Max
Manganese 1.00 Max	Silicon 1.00 Max
Phosphorus .030 Max	Chromium 12.00-14.00

Annealing

Atmosphere controlled furnaces should be used. Heat uniformly to 1550°F to 1650°F and hold at the annealing temperature for 1 hour per inch of cross section. The lower temperature limit is recommended for small sections and the upper temperature limit for large sections. Cool in the furnace at a rate not exceeding 30°F until 1100°F, after which a faster rate can be allowed.

Stress Relieving

Stresses developed from heavy machining cuts may be relieved by heating the steel to 1200°F to 1250°F and holding for 1 hour per inch of cross section (minimum 1hour) followed by an air cool.

Hardening

Preheat at 1400°F to 1450°F long enough to equalize the temperature. Then raise temperature to 1850°F to 1950°F and hold until uniformly heated through. Use high side of hardening range for thicker sections or where maximum corrosion resistance and strength are required.

Quenching

Quench in still air, dry air blast or warm oil. Warm oil is preferred because it provides maximum corrosion resistance. Once the part has cooled to 125°F, or when it can be handled with bare hands, temper it immediately.

Tempering

420 ESR is usually tempered in the range of 300°F to 400°F for maximum hardness and resistance to corrosion. A double temper is beneficial. Allow part to cool to room temperature before the second temper:

Tempering Temperature - °F	Rockwell C Hardness
As quenched	51-53
300	51-53
400	50-52
500	49-50
600	49-50
700	48-49
800	48-49

NOTE: The above table is intended to serve as a guide. Variation in analysis, size, heat treatment, etc. may result in slight deviations from the above.

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those herein.

AISI P20

Mold Steel

P20 is a chrome-moly tool steel made specifically to fill the requirements for the machined cavities and forces used In zinc die casting and plastic molding. It Is delivered fully quenched and tempered to approximately Brinell 300. Other hardness levels may be obtained through additional heat treatment.

P20 Is the standard mold steel for machine-cut plastic molds and zinc die casting dies.

P20 Is usually supplied in the prehardened condition, about 300 Brinell, for injection molds and zinc die casting dies. While in the prehardened condition, P20 can be nitrided for greater wear resistanoe. It can also be textured in the prehardened state.

P20 Is also available at an annealed hardness of about 200 Brinell. It can be hardened or carburized up to a higher hardness of 50/60 RC when used for compression or transfer work.

Prehardened P20 is used in cavities and cores of zinc die-casting dies, in plastic-molding dies, and in other mold parts which do not require high surface hardness or high temperature operation. When carburized, P20 is used for compression, transfer, and other types of molds requiring high surface hardness.

Machinablilty - In the prehardened condition, P20 has a machinability rating of 65 as compared with a rating of 100 for a 1 percent carbon tool steel.

Dimensional Stability - When quenched in oil from a hardening temperature of 1550F, this grade normally expands 0.003 in./in. However, as with all liquid quenching analyses, dimensional changes during heat treatment are greatly influenced by the size and shape of the piece. Strict observance of good heat treating practice is essential for minimum distortion.

Typical Analysis

Carbon 0.350	Manganese 0.800
Silicon 0.500	Molybdenum 0.450
Chromium 1.700	

Annealing

Heat the piece in a protective atmosphere (preferably a controlled atmosphere furnace) to between 1450 and 1500°F and hold for one hour per inch of greatest thickness. Maintaining atmosphere control, cool at a rate of 30°F per hour to 1000°F. Then air-cool to room temperature. The resulting hardness Is Brinell 207 max.

Hardening

Heat to the hardening temperature range of 1550 to 1650°F, using the high side for large pieces. Although not inherently subject to decarburization, wherever possible P20 should be hardened in an atmosphere controlled furnace. Hold at the hardening temperature for one hour per inch of greatest thickness. Quench in oil to 150°F and temper immediately.

Tempering

The tempering temperature varies with the size of the piece and the application. Following are results of tests performed on a 1 in. round specimen quenched in oil from 1555°F. For large sections, the mechanical properties may be somewhat lower requiring an adjustment in tempering temperature.

Tempering Temperature (°F)	Yield Strength at .2% offset (psi)	Tensile Strength (psi)	Elongation (%)	Reduction (%)	Hardness (Rockwell C)
300	197,000	284,000	11.0	35.0	54
400	215,000	276,500	11.5	36.6	53
500	216,000	262,500	11.5	40.4	52
600	213,000	254,500	12.0	43.7	50
700	207,000	242,000	12.0	46.3	48
800	197,000	224,500	12.0	47.4	46
900	187,000	207,500	13.5	50.8	44
1000	173,000	192,000	14.5	50.6	41
1050	159,500	180,000	16.5	54.1	38
1100	151,000	168,000	16.0	58.3	35
1150	130,000	144,500	17.5	59.3	30
1200	114,500	130,000	18.5	62.3	26

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design.
Data on any particular piece of material may vary from those herein.

AISI H13

Hot Work Steel

H13 combines good red hardness and abrasion resistance with the ability to resist heat checking. It is an AISI H13 hot work tool steel, the most widely used steel for aluminum and zinc die casting dies. It is also popular for extrusion press tooling because of its ability to withstand drastic cooling from high operating temperatures.

H13 is produced from vacuum degassed tool steel ingots. This manufacturing practice plus carefully controlled hot working provides optimum uniformity, consistent reponse to heat treatment, and long service life.

H13 Is an outstanding die steel for die casting aluminum and manganese. It is used for zinc in long production runs, and also employed successfully for slides and cores in tool assemblies.

H13 in the hardness ranges from 45/52 RC is an excellent steel for plastic molds. It takes a high polish, making it suitable for lens and dinner ware molds.

Consider using this grade of hot work tool steel for applications where drastic cooling is required during the operation, and where high red hardness and resistance to heat checking are important. This grade has found wide acceptance for die casting dies for zinc, white metal, aluminum and magnesium. It is also widely used for extrusion dies, trimmer dies, gripper dies, hot shear blades, casings, and other similar hot work applications.

Machinablllty - In the thoroughly annealed condition, H13 may be machined without difficufty. It has a rating of 75 as compared with a 1 % carbon tool steel, which has a rating of 100.

Dimensional Stability - When air quenched from the proper hardening temperature, H13 generally expands 0.001 in./in. of cross section.

Typical Analysis

Carbon 0.400	Chromium 5.250
Silicon 1.000	Molybdenum 1.250
Vanadium 1.050	Manganese 0.400

Annealing

H13 may be annealed by heating to 1600°F. Soak one hour per inch of greatest thickness, and furnace cool at 30 degrees per hour to 900°F. Then air cool. Proper annealing procedure includes packing in a sealed container, using a neutral inert material. Result, maximum Brinell hardness of 207.

Hardening

In a controlled atmosphere, preheat thoroughly at 1300 to 1400°F. Then heat to 1850°F and hold for an hour per inch of greatest cross section. Quench in still air and temper immediately. When maximum hardness is the primary requirement, H13 may be oil quenched, but keep in mind that when oil quenched, this grade is vulnerable to cracking and has the same distortional characteristics as an oil hardening tool steel.

Specimens 1 in. round by 3 in. long were pre-heated at 1350°F. They were then transferred to a high-heat furnace and air-quenched from various temperatures ranging from 1750 to 2000°F.

The hardness and fracture grain size of these specimens were as follows:

Quenching	Fracture	
Temperature - °F	**rating**	**Rockwell C**
1750	8-1/2	46
1800	8-3/4	52
1850	9	54
1900	9	54
1950	9	55
2000	8-1/2	56

Tempering – Next Page

Tempering

For hot work applications, H13 is used in the hardness range of HRC 38 to 48. The usual hardness range for die casting dies is HRC 44 to 48 requiring a temper at approximately 1100°F. For improved shock resistance, the steel is often tempered at temperatures approaching 1150°F, resulting in hardnesses of HRC 40 to 44. The steel should be held at the tempering temperature for at least two hours per inch of greatest cross section. All hot work steel should be tempered at a minimum of 50 degrees above the expected maximum operating temperature of the tool or die. Double tempering, with the second temper of 25 to 50 degrees lower than the first temper is always advisable, particularly where heat checking is a problem.

Hardness tests were made on 1-in. round specimens of H13 which were air quenched from 1850°F and tempered for two hours at various temperatures. The results below may be used as a tempering guide, keeping in mind that tools of heavy section or mass may be several points lower in hardness.

Tempering	
Temperature - °F	**Rockwell C**
400	54
500	53
600	53
700	53
800	53
900	54
1000	52
1100	46
1200	36

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those herein.

AISI M2

Molybdenum-Tungsten High Speed

M-2 Is the most widely used type of high-speed steel and, in general, can be used for the same applications as T-1 high speed. Its higher carbon content and balanced analysis produce properties applicable to all general-purpose high-speed uses.

M-2 tool steel is used in practically all applications specified for T-1 high speed. These applications include lathe tools, planer tolls, drills, taps, reamers, breaches, milling cutters, form cutters, wood knives, gear cutters, and end mills.

Machinability - Like all highly alloyed steels, M-2 machines with somewhat more difficulfy than the lower alloyed steels. It is rated at 65 as compared to a 1-pct carbon tool steel, which is rated at 100.

Typical Analysis

Carbon 0.830	Chromium 4.150
Molybdenum 5.000	Vanadium 1.900
Tungsten 6.350	

Annealing

Annealing should always follow forging, preferably in controlled-atmosphere furnaces. If these are not available, pack-anneal in sealed containers using the protective material of your choice. Heat to 1600°F, thoroughly soak, then cool in the furnace at about 30 degrees per hour to 900°F and air-cool. Proper annealing should result in a hardness of Brinell 241 max.

Hardening

Harden M-2 by preheating slowly to 1550°F and holding until thoroughly soaked. Heat rapidly to 2250 to 2275°F Generally, total heating time in the furnace varies from a few minutes to a maximum of 15 minutes, depending on the size of the tool. Oil quenching from the hardening temperature is preferred for developing full hardness, although air quenching or quenching in hot salt or lead may be done.

When the tools have reached a temperature of 150 to 200°F in the quench, temper immediately. Precautions should be taken to prevent decarburization on tools which cannot be ground after hardening. For this purpose non-oxidizing furnace atmosphere or salt baths may be used.

Hardening – Cont.

Specimens 1 in. square x 2 in. long were held at various temperatures for three minutes and quenched in oil and in air with the following results:

Quenching	Oil-Quenched		Air-Quenched	
Temperature	Fracture	Rockwell	Fracture	Rockwell
(°F)	rating	C	rating	C
2000	9-1/2	62	9-1/2	61.5
2050	9-1/2	63.5	9-1/2	61.5
2100	9-1/2	64	9-1/2	63
2150	9-3/4	65.5	9-3/4	65
2200	9-3/4	66	9-3/4	65.5
2225	9-3/4	66	9-3/4	65.5
2250	9-3/4	66	9-3/4	65.5
2275	9-1/4	66	9-1/2	65
2300	8-1/2	66	9	64.5
2325	8-1/2	66	8-1/2	64.5
2350	7	65.5	8	64
2400	6	66	6	62

The effect of different holding times at a quenching temperature of 2250°F on 1-in. square specimens is shown in the following table. All pieces were oil-quenched.

	2250°F Oil-Quenched	
Holding time	Fracture	Rockwell
Minutes	rating	C
1	9-1/2	60.5
2	9-3/4	65.5
3	9-3/4	66
4	9-1/4	66.5
5	9	66.5
6	8-3/4	66.5
7	8-1/4	64.5
10	8	64.5
12	7-3/4	64.5
14	7-1/2	66.5

Tempering

The best tempering range for M-2 is 1000 to 1050°F. This results in the best combination of cutting ability, hardness, strength, and toughness. Tools are tempered by heating to the above temperature and holding for two hours per inch of greatest thickness, then cooling all the way to room temperature. It is customary to use a double-tempering operation on high-speed tool steels. This is carried out by a second heating to a temperature 25 to 50 degrees .below the first tempering operation. Tempering at higher temperatures will increase the toughness of tools at the expense of hardness. Therefore, hot-work and shock-resisting tools are usually tempered within a range of 1100 to 1200°F.

Test specimens 1 in. round x 2-1/2 in. long of M-2 steels were hardened in oil and still air at a temperature of 2250°F. After hardening, specimens were tempered for two hours at temperatures ranging from 300 to 1400°F. Specimens were then tested for Rockwell hardness. Treatment given the specimens and the hardnesses obtained are shown In the table below.

These results on 1-in. round specimens may be used as a guide in tempering tools to desired hardness. However, tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

Tempering	**Oil-quenched**	**Air-quenched**
temperature - °F	**Rockwell C**	**Rockwell C**
300	65	65
400	64	63
500	63	62.5
600	62.5	62.5
700	63	62.5
800	63.5	63.5
850	63.5	63.5
900	65	64
950	66	65
1000	66	65.5
1050	66	63.5
1100	64.5	61.5
1150	62	60
1200	53.5	53
1300	43	39.5
1400	33.5	34

AISI O1

Oil Hardening Tool Steel

AISI 01 is one of the most well respected oil-hardening tool and die steels. It is easy to machine. Normal care in treatment gives good results in hardening and produces small dimensional changes. It has good abrasion-resistance, and sufficient toughness for normal tool-and-die applications. When it is essential to have a safer hardening tool-and-die steel, O1 is used for the majority of applications too sensitive for carbon tool steels.

Recommended applications include cold-forming, blanking and bending dies, forming rolls, broaches, knurling tools, and gages.

Machinability - Annealed to Brinell 202 max, O1 machines easily and approaches the machinability of straight-carbon water-hardening tool steel. Where a 1 pct carbon steel is rated at 100, O1 has a rating of 90.

Dimensional Stability - When quenched from the proper hardening temperature this grade normally expands .0015 in./in. plus. In many instances a slight scaling will occur during heat treatment which tends to counteract this expansion. Like all tool steels, hardening of 01 to insure minimum size change necessitates careful study of the die or tool and the furnace equipment used for heat treatment.

Typical Analysis

Carbon 0.90	Manganese 1.20
Tungsten 0.50	Chromium 0.50
Vanadium 0.20	

Annealing

The recommended annealing practice is to use controlled-atmosphere furnaces. If these are not available, pack-anneal in an inert material. For a quick annealing cycle to develop fair machining properties, heat slowly to 1375 to 1425°F. and cool slowly in the furnace. To develop the lowest hardness and best spheroidization for optimum machinability, heat slowly to 1450°F. and furnace cool at 20 degrees per hour to 900°F. The piece may then be removed from the furnace and cooled in air. Hardness after this cycle will be Brinell 202 max.

Hardening

If pack-hardening cannot be used or is not essential, a slight oxidizing atmosphere should be used in heating to the hardening temperature of 1450to 1475°F. This will give a minimum of decarburization and distortion. On large parts, pack-hardening and pre-heating at approximately 1200°F,with a thorough soaking before raising to the quenching temperature of 1475 to 1500°F, are recommended. Hold at the quenching temperature for one half hour per inch of greatest cross-section. Follow by quenching in oil to 150°F and temper immediately.

A series of oil-quenched samples were tested. Here are the resulting hardness and fracture ratings from different quenching temperatures:

Quenching	Fracture	Rockwell
temperature - °F	grain size	C
1400	9	60
1425	9	62
1450	9-1/2	63
1475	9-1/2	65
1500	9-1/2	65
1525	9-1/4	65
1550	9-1/4	65

Tempering

The tempering temperature generally employed may vary from 300 to 450°F, depending on size and properties required. For all general purposes tempering at 350°F is satisfactory. Temperatures above 450°F are rarely used on 01. The hardness levels produced by tempering above 450°F can also be produced in shock-resisting grades. Therefore, where greater toughness is required than 01 provides after tempering at 450°F, it is customary to change to a shock-resisting steel. Small tools should be held at the tempering temperature for at least one hour, and larger tools for two hours, per inch of greatest thickness. If a second temper is used, it should be 25 degrees lower than the first.

Tempering temperatures and resulting Rockwell hardness, based on 1-in. round samples oil-quenched from 1475 °F and tempered for two hours, are as follows:

Tempering	Rockwell
temperature - °F	C
None	65
300	63
350	62.5
400	62
450	61
500	60
600	57
700	53
800	50
900	47
1000	44
1100	39
1200	31
1300	22

These results on 1-in. diameter specimens may be used as a guide in tempering tools to desired hardness. However, tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those herein.

AISI O6

Graphitic Oil Hardening Tool Steel

O6 Graphitic is a medium alloy, 1.45 carbon, oil-hardening, tool steel. In the annealed conditions, about one-third of the carbon is present as graphitic carbon and the remainder as combined carbon in the form of carbides. In this condition, O6 is the most readily machinable of the oil-hardening tool steel grades.

Use O6 Graphitic for forming, shaping, and drawing dies, and for a great variety of cold-work dies calling for physical properties, wear resistance, and edge-holding similar to those of standard oil-hardening tool steels such as Type O1. Dies subject to galling and seizing can benefit from the non-galling, self-lubricating characteristics of O6 Graphitic.

Machinability - If properly annealed to Brinell 212 max, O6 has a machinability rating of 125, as compared with a 1 pct carbon tool steel, rated at 100.

Dimensional Stability - When oil quenched from the proper hardening temperature this grade normally exhibits an expansion of 0.001 5 in/in. plus.

Typical Analysis

Carbon	1.45	Manganese	0.80
Silicon	1.15	Molybdenum	0.25

Annealing

Heat uniformly to a temperature range of 1425 to 1450°F. Then cool slowly in the furnace to 1000°F and hold at this temperature approximately one hour per inch of greatest cross-section. Cool in air. The resulting hardness will be Brinell 217 max.

Hardening

Preheat thoroughly at approximately 1250°F, and then heat to the hardening temperature of 1450 to 1500°F. For small sections, the lower part of the hardening range should be used; larger sections require the higher temperatures. All sections should be equalized at the hardening temperature for one hour per inch of greatest cross-section before quenching in oil to 150°F. Temper immediately.

Tempering

For the majority of tooling work, tempering at 300 to 400°F is satisfactory. This will result in a hardness of approximately Rockwell C 61/62. Heat the tools to the tempering temperature and hold for approximately two hours per inch of greatest cross-section.

Heat-treatment, consisting of oil quenching 1-in.diameter round specimens from 1475°F and tempering at various temperatures, has produced the following results:

Temperature - °F	Rockwell C
As Quenched	65
300	62
400	61
500	60
600	58
700	54

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design.
Data on any particular piece of material may vary from those herein.

AISI L6

Oil Hardening Tool Steel

AISI L6 is in the general class of alloy, oil-hardening tool steels. Due to its lower carbon content, it has slightly better shock-resistance than more highly alloyed types and should be used where some wear-resistance can be sacrificed for increased toughness.

Use for general purpose tools and dies where greater toughness is required, but with some sacrifice of abrasion-resistance. The following are some of the applications:

- Forming rolls
- punches
- blanking and forming dies
- trimmer dies
- clutch parts
- pawls
- knuckle pins
- clutch pins
- shear blades
- spindles

Advantages - Oil hardening, low distortion in heat-treatment, good toughness at lower hardness levels, good wear-resistance at high hardness levels.

Machinability - When annealed to a maximum of Brinell 217, L6 machines with relative ease. It has a rating of 85, as compared with a 1 pct carbon tool steel, rated at 100.

Dimensional Stability - L6 has good safe-hardening and non-deforming properties characteristic of oil-hardening steels. Tools small enough in section to be air-hardened maintain their dimensions with movement of less than 0.0001 in./in. When properly oil quenched, expansion of 0.0015 in./in.
is expected.

Typical Analysis

Carbon	0.75	Manganese	0.75
Nickel	1.75	Molybdenum	0.35
Chromium	0.90		

Annealing

To anneal L6, heat to 1400°F and hold one hour per inch of greatest thickness. Cool at 20 degrees per hour to 900 and then air-cool. A maximum hardness of Brinell 217 will be obtained following this treatment. Because of its air-hardening ability, L6 should not be normalized.

Hardening

L6 should be preheated at 1200°F, soaked, then raised to a hardening temperature of 1500 to 1550°F and held for one hour per inch of greatest cross section. Quench in oil to a temperature of 1500°F, followed immediately by tempering. Tools made of L6 in sections less than 1 in. thickness are often air-quenched from 1500°F. Air quenching provides safer hardening of intricate sections. It also results in less distortion than oil quenching.

A series of specimens 1in. round by 5 in. long were hardened in an air-blast furnace and in oil. The hardening temperatures ranged from 1400 to1800°F at intervals indicated below. The hardened samples were fractured, given fracture ratings and tested for Rockwell hardness. Following are the results obtained:

	AIR-BLAST		OIL-QUENCH	
Quenching	**Fracture**	**Rockwell**	**Fracture**	**Rockwell**
temperature - °F	**rating**	**C**	**rating**	**C**
1400	9-3/4	61	9-3/4	63
1450	9-3/4	63	9-3/4	64
1500	9-1/2	63	9-3/4	64.5
1525	9-1/2	63	9-3/4	64.5
1550	8-3/4	63	9-1/4	64
1600	8-1/2	63	8-1/2	63
1650	8-1/4	63	7-1/2	63
1700	8	62.5	7-1/4	62
1750	8	62.5	7-1/4	61.5
1800	7	62	7	61

Tempering

L6 should be tempered at 400°F. However, where increased toughness is desired, at a sacrifice of some hardness, higher tempering temperatures are often used.

L6 does not become brittle, as many other die steels do, when tempered in the range of 450 to 800°F. A minimum holding time of one hour per inch of thickness should be used when tempering at 400°F.

To minimize the possibility of cracking, the steel should be tempered immediately after hardening and should be heated slowly to the desired tempering temperature.

For the tempering test of this grade, specimens 7/8 in. round by 2-1/2 in. long were hardened from 1500°F in air-blast furnace and from 1525°F in oil. The hardened specimens were tempered at temperatures ranging from 300 to 1000°F at 100-degree intervals.

Tempering – Cont.

The Rockwell C hardness results which were obtained are as follows:

Temperature - °F	Rockwell C	Rockwell C
No Draw	63	65
300	59.5	62
400	57.5	61
500	56.5	58
600	55	56
700	51	53
800	49	50
900	47.5	48
1000	43.5	46

These results may be used as a guide in tempering tools to the desired hardness. However, since specimens 7/8 in. in diameter were used in this test, it may be found that tools of heavy section or mass may be several points lower in Rockwell hardness for a given treatment.

AISI W2

Water Hardening Carbon Tool Steel

W2 tool steel depends primarily upon a comparatively high carbon content for its useful properties. For proper application, the correct carbon content must be selected. Standard carbon contents range from .070 to 1.30 per cent, generally in 0.10 per cent increments. Microscopic, macroscopic, and hardenability requirements are not specified for standard quality carbon tool steels but do apply for cold-heading die or special quality material.

This carbon range produces a tool steel having both maximum toughness and adequate wear-resistance for general-purpose blacksmithing tools such as chisels, moil points, etc.

In heat-treatment carbon tool steels develop high surface hardness with a relatively tough core. This characteristic makes them an excellent choice for a wide variety of uses. Carbon tool steeels are low in cost, easy to machine and simple to heat-treat.

For greater wear-resistance or safety in hardening, use an oil- or air-hardening grade.

Annealing

For best results, annealing should be carried out in controlled-atmospheric furnaces. Otherwise, use sealed pipes or containers with the parts protected by cast-iron chips, mica, charcoal, or a mixture of sand and a carbonaceous material, to prevent decarburizing the surface. Three types of annealing procedures based on the carbon content and size of the piece to be annealed are outlined below.

Normalize and Anneal - If carbon content is 1.10 or under and size is over 2 in., or if carbon content is over 1. and size is 2 in. or under.

Oil-Quench and Anneal - If carbon content is over 1.10 and size is over 2 in.

Anneal Only - If carbon content is 1.10 or under and size is 2 in. or under.

For normalizing and annealing or oil-quenching and annealing, the piece should be heated slowly and held at the proper temperature for at least one hour per inch of greatest thickness during both treatment operations. Where annealing is the only treatment, the part should be held at the proper temperature for at least one hour per inch of greatest thickness. After holding, the part should be cooled slowly. Temperatures for these operations are as follows:

	Normalizing	
	or Oil-Quenching	Annealing
Carbon Range	Temperature - °F	Temperature - °F
.70 to .090	1450-1525	1400-1450
.90 to 1.00	1475-1550	1375-1425
1.00 to 1.10	1500-1575	1375-1425
1.10 to 1.30	1500-1650	1375-1425

Hardening

Heat slowly and uniformly and hold at the quenching temperature at least one-half hour per inch of greatest thickness. Carbon grades can be quenched in water but brine-quenching is preferred because it results in more positive response to treatment and insures uniform surface hardness. When the section is light and maximum hardness is not desired, oil may be used as a quenching medium. For best results, the temperature of the quenching medium should be about 70°F. Quenching temperatures, depending upon the carbon content, are as follows:

	Quenching
Carbon Range	**Temperature-°F**
.70 to .90	1425-1475
.90 to 1.00	1425-1475
1.00 to 1.10	1400-1450
1.10 to 1.30	1390-1425

Parts should be cooled in the quenching medium until they have reached about 150 to 200°F. They should then be charged into the tempering furnace at once and not permitted to reach room temperature until the tempering operation is complete.

The depth of chill of carbon tool steel can be regulated to some extent by vary ing the quenching temperature. The higher the quenching temperature, the deeper will be the chill. A series of specimens, 3/4 in. round x 3 in. long, were rough-turned from 1 in. round stock of 0.80 and 1.05 shallow-hardening carbon tool steel and hardened by quenching in water at the temperatures given in
the accompanying tables. The resulting Rockwell C hardness, depth of penetration, and fracture rating of
the hardened chill are as shown.

HARDENING SERIES .080 CARBON

Water	**Depth of**	**Fracture**	**Hardness of**
Quenching	**Chill in**	**Rating**	**Chill**
Temperature - °F	**64ths**	**of Chill**	**Rockwell C**
1375	6	8-1/2	61
1400	6-1/2	9-1/4	65
1425	7	9-1/4	67
1450	7-1/2	9-1/4	67
1475	8-1/2	9-1/4	67
1500	9-1/2	9	67
1550	10	8-1/2	67
1600	10-1/2	8	66
1650	11-1/2	7-1/2	66

HARDENING SERIES 1.050 CARBON

Water	Depth of	Fracture	Hardness of
Quenching	Chill in	Rating	Chill
Temperature - °F	64ths	of Chill	Rockwell C
1375	6	7-1/2	61
1400	7	8-1/4	65
1425	8	9-1/4	67
1450	8-1/2	9-1/4	67
1475	9-1/4	9-1/4	66
1500	10	9-1/4	66
1550	12-1/2	8-3/4	66
1600	Through	5-3/4	65
1650	Through	5-1/4	65

Tempering

Carbon tool steels are usually temperated at temperatures between 300 and 600°F. The warm steel, as quenched, should be brought slowly to the desired tempering temperature and held at this temperature for at least two hours per inch of greatest cross section.

Specimens of 1.00 carbon tool steel, 3/4 in. round by 3 in. long were hardened by quenching in water from 1450°F. They were then tempered at various temperatures with the following results:

Temperature - °F	Rockwell C
As Quenched	67
300	64
400	61
500	59
600	55

4140 Prehard/Annealed

Alloy

Specifications

Carbon (Max.)	.38/.46
Manganese	.70/1.00
Phosphorus (Max.)	.035
Sulfur (Max.)	.040
Chromium	.80/1.15
Molybdenum	.15/.25
Silicon	.15/.40
Vanadium (Max.)	.03
Other Elements	--
Heat treatment required	N&T
Surface Brinell Hardness (HB)	262/321 to 3" incl.; 241/321 over 3" to 6-1/2" incl.

FREMAX 15

Low Carbon

Ready to use!
Blanchard ground top and bottom - plus .015" to plus.035".
Width and length saw cut oversize to finish.
Machined oversize widths - plus .077" to plus .125.
Guaranteed FREE OF DECARBURIZATION - all four sides!
Available cut to any length - up to 132" length.

Typical Analysis

Carbon	0.20	Manganese	0.90/1.30
Silicon	0.10/0.30	Sulfur	0.20/0.30
Phosphorus	0.06/0.12		

Applications

- die holders
- fixtures
- rubber molds
- machinery bases
- sprockets
- cams
- bushings
- gears
- steam platens
- strippers

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those herein.

Powdered Metal Products

**Information on specific grades available upon request

CRUCIBLE	CARPENTER	ERASTEEL
CPM® 1V®	MICRO MELT® A11	ASP® 2004
CPM® 3V®	MICRO MELT® A11 LVC	ASP® 2011
CPM® 4V®	MICRO MELT® M4	ASP®2015
CPM® 9V®	MICRO MELT® M48	
CPM® 10V®	MICRO MELT® T15	
CPM® 15V®	MICRO MELT® T15 PLUS	
CPM® 20CV®	MICRO MELT® PD#1	
CPM® REX M4 HC®	MICRO MELT® MAXAMELT®	
CPM® REX 45®		
CPM® REX 75®		
CPM® REX T15®		
CPM®S90V®		

Drill Rod

O1 Oil Hardening

Typical Analysis

Carbon	0.90	Chromium	1.20
Manganese	1.20	Vanadium	0.20
Silicon	0.30		

The most widely used grade of drill rod. It is a general purpose tool steel, outstanding for its reliability in hardening, good wear resistance, and excellent toughness.

W1 Water Hardening

Typical Analysis

Carbon	0.95 to 1.10

Water hardening grade is intended to meet the needs of the machine shop for average work where better grades of tool steel drill rod are not required.

A2 Air Hardening

Typical Analysis

Carbon	1.00	Chromium	5.25
Molybdenum	1.10	Vanadium	0.25
Manganese	0.60		

A2 is recommended rather than O1 when increased wear resistance, safer hardening, and less distortion are required.

S7 Air Hardening Super Shock

Typical Analysis

Carbon	0.50	Chromium	3.25
Silicon	0.25	Molybdenum	1.40
Manganese	0.70		

A new outstanding air-hardening drill rod - the toughest, strongest drill rod for so many jobs that require maximum strength and impact.

D2 High Carbon - High Chrome

Typical Analysis

Carbon	1.50	Molybdenum	0.75
Chromium	12.00	Vanadium	0.25 to 0.80

An air-hardening type steel known for its rnaximum wear resistance qualities. It is ideal for use in tools, dies, etc., used in long production runs.

M2 Moly-Tungsten-High Speed

Typical Analysis

Carbon	0.83	Chromium	4.15
Molybdenum	5.00	Vanadium	1.90
Tungsten	6.35		

The most widely used type of high-speed steel and, in general, can be used for the same applications as T-1 high speed. Its higher carbon content and balanced analysis produce properties applicable to all general-purpose high-speed uses.

Standard Tolerances – Next Page

Standard Tolerances

	DIMENSIONAL TOLERANCES		
	Standard		Standard
	Tolerance*	Straightness	Tolerance*
	(section)	Max T.I.R.	(length)
Round Drill Rod			
2.000" to 1.500" dia.	+/- .001"	.005"	+1/8, -0
1.500" to .125" dia.	+/- .0005"	.005"	+1/8, -0
.124" and smaller dia.	+/- .0003"	.005"	+1/8, -0
Flat and Square Drill Rod			
1.000" to .750" (largest dim.)	+/- .0015"		+1/8, -0
.749" to .250" (largest dim.)	+/- .001"		+1/8, -0
.249" and smaller	+/- .0005"		+1/8, -0
* Closer tolerances than standard can be produced upon special request.			

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Precision Ground Flat Stock

(PGFS)

All grades available in 18" and 36" lengths.
Low Carbon available in 24" lengths only.

O1 Oil Hardening

Typical Analysis

Carbon 0.90	Chromium 1.20
Manganese 1.20	Vanadium 0.20
Silicon 0.30	

The most widely used grade of precision ground flat stock. It is a general purpose tool steel, outstanding for its reliability in hardening, good wear resistance, and excellent toughness.

A2 Air Hardening

Typical Analysis

Carbon 1.00	Chromium 5.25
Molybdenum 1.10	Vanadium 0.25
Manganese 0.60	

A2 is recommended rather than O1 when increased wear resistance, safer hardening, and less distortion are required.

S7 Air Hardening Super Shock

Typical Analysis

Carbon 0.50	Chromium 3.25
Silicon 0.25	Molybdenum 1.40
Manganese 0.70	

A new outstanding air-hardening precision ground flat stock - the toughest, strongest precision ground flat stock for so many jobs that require maximum strength and impact.

D2 High Carbon - High Chrome

Typical Analysis

Carbon 1.50	Molybdenum 0.75
Chromium 12.00	Vanadium 0.25 to 0.80

An air-hardening type steel known for its rnaximum wear resistance qualities. It is ideal for use in tools, dies, etc., used in long production runs.

M2 Moly-Tungsten-High Speed

Typical Analysis

Carbon 0.83	Chromium 4.15
Molybdenum 5.00	Vanadium 1.90
Tungsten 6.35	

The most widely used type of high-speed steel and, in general, can be used for the same applications as T-1 high speed. Its higher carbon content and balanced analysis produce properties applicable to all general-purpose high-speed uses.

Low Carbon

Typical Analysis

Carbon .15 - .20	Phosphorus .04 max.
Manganese .60 - .90	Sulfur .05 max.

Tolerances

	Regular	**Oversize**
Thickness	+/- .001"	+ .010/.015"
Width	+ .000/.005"	+ .010/.015"
Squares	+/- .001"	+ .010/.015"
Length 18"	+ .125/.250"	+ .125/.250"
Length 36"	+ .250/.500"	+ .250/.500"
Length 24"	+ .1875/.375"	+ .1875/.375"
Squareness Edge	.003" per inch	.003" per inch
Squareness End	.004" per inch	.004" per inch

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design.
Data on any particular piece of material may vary from those herein.

Pennsylvania Steel Company

Hardness Conversion Chart

BRINELL							
Diameter							Tensile
3000 Kg.							Strength
Load			ROCKWELL				1000
10 mm.	Hardness						Lb./Sq.
Ball	Number	C	B	A	15 - N	Shore	In.
2.25	745	65.3	-	84.1	92.3	91	-
2.30	712	-	-	-	-	-	-
2.35	682	61.7	-	82 2	91.0	84	-
2.40	653	60.0	-	81.2	90.2	81	-
2.45	627	58.7	-	80.5	89.6	79	-
2.50	601	57.3	-	79.8	89.0	77	-
2 55	578	56.0	-	79.1	88.4	75	-
2.60	555	54.7	-	78.4	87.8	73	298
2.65	534	53.5	-	77.8	87.2	71	288
2.70	514	52.1	-	76.9	86.5	70	274
2.75	495	51.0	-	76.3	85.9	68	264
2.80	477	49.6	-	75.6	85.3	66	252
2.85	461	48.5	-	74.9	84.7	65	242
2.90	444	47.1	-	74.2	84.0	63	230
2.95	429	45.7	-	73.4	83.4	61	219
3.00	415	44.5	-	72.8	82.8	59	212
3 05	401	43.1	-	72.0	82.0	58	202
3.10	388	41.8	-	71.4	81.4	56	193
3.15	375	40.4	-	70.6	80.6	54	184
3.20	363	39.1	-	70.0	80.0	52	177
3.25	352	37.9	(110.0)	69.3	79.3	51	170
3.30	341	36.6	(109.0)	68.7	78.6	50	163
3.35	331	35.5	(108.5)	68.1	78.0	48	158
3.40	321	34.3	(108.0)	67.5	77.3	47	152
3.45	311	33.1	(107.5)	66.9	76.7	46	147
3.50	302	32.1	(107.0)	66.9	76.7	46	143
3.55	293	30.9	(106.0)	65.7	75.5	43	139
3.60	285	29.9	(105.5)	65.3	75.0	-	136
3.65	277	28.8	(104.5)	64.6	74.4	41	131
3.70	269	27.6	(104.0)	64.1	73.7	40	128

3.75	262	26.6	(103.0)	63.6	73.1	39	125
3.80	255	25.4	(102.0)	63.0	72.5	38	121
3.85	248	24.2	(101.0)	62.5	71.7	37	118
3.90	241	22.8	100.0	61.8	70.9	36	114
3.95	235	21.7	99.0	61.4	70.3	35	111
4.00	229	20.5	98.2	60.8	69.7	34	109
4.05	223	(18.8)	97.3	-	-	-	104
4.10	217	(17.5)	96.4	-	-	33	103
4.15	212	(16.0)	95.5	-	-	-	100
4.20	207	(15.2)	94.6	-	-	32	99
4.25	201	(13.8)	93.8	-	-	31	97
4.30	197	(12.7)	92.8	-	-	30	94
4.35	192	(11.5)	91.9	-	-	29	92
4.40	187	(10.0)	90.7	-	-	-	90
4.45	183	(9.0)	90.0	-	-	28	89
4.50	179	(8.0)	89.0	-	-	27	88
4.55	174	(6.4)	87.8	-	-	-	86
4.60	170	(5.4)	86.8	-	-	26	84
4.65	167	(4.4)	86.0	-	-	-	83
4.70	163	(3.3)	85.0	-	-	25	82
4.80	156	(0.9)	82.9	-	-	-	80
4.90	149	-	80.8	-	-	23	-
5.00	143	-	78.7	-	-	22	-
5.10	137	-	76.4	-	-	21	-