

About Steel

Carbon steel is an economical choice for machining and structural applications, and it can be surface hardened.

Alloy steel has greater strength and hardness than carbon steel, making it useful for high-stress applications. Heat treating can further enhance strength and hardness.

Tool steel is used to make cutting tools, and it can be heat treated for extreme hardness.

Use the charts below to identify the best steel for your application. Circles indicate that a majority of a material's shapes and sizes meet the applicable rating. Information is intended for comparison only and is not guaranteed.

- Excellent
- Good
- Poor

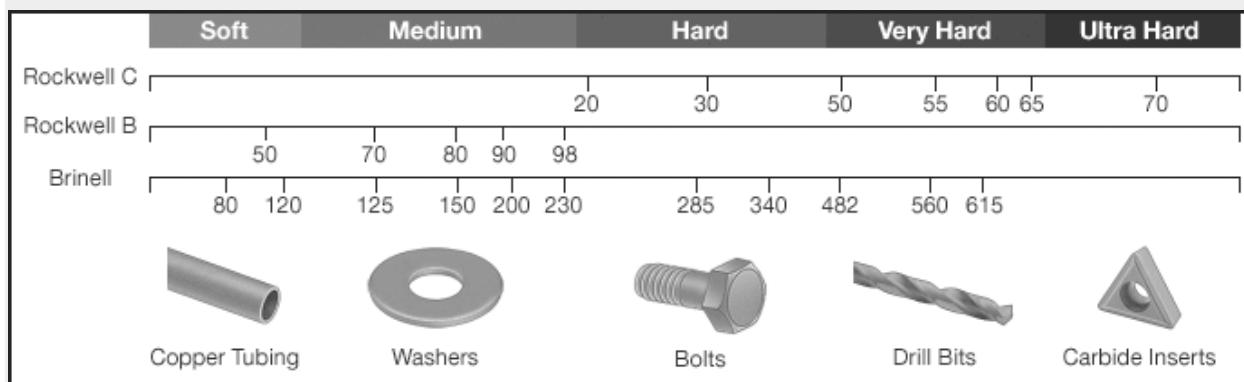
Carbon Steel								
	Min. Yield Strength, psi	Hardness (Rockwell)		Machinability	Weldability	Impact Resistance	Wear Resistance	Formability
		Unhardened	Hardened					
Gen. Purpose Low Carbon	30,000	B50	C60	○	●	—	—	—
High Strength 1045	65,000	B86	C62	○	○	—	—	○
Shaft Quality 1060	50,000	—	C60	—	—	○	○	○
High Strength 1144	100,000	C23	—	○	○	○	○	○
Easy-to-Machine 1117	58,000	B75	B89	●	○	—	—	—
Very Easy-to-Machine 1215	60,000	B85	—	●	○	—	—	○
Ultra Machinable 12L14	60,000	B82	C65	●	○	○	○	○
Abrasion Resistant AR400	140,000	—	C38	●	●	●	●	●
Impact Resistant A516	38,000	B78	—	○	○	○	—	—
Spring Steel	50,000	B88	C66	○	○	●	●	○
Cast Iron	55,000	C20	C60	●	—	—	●	—

Alloy Steel								
	Min. Yield Strength, psi	Hardness (Rockwell)		Machinability	Weldability	Impact Resistance	Wear Resistance	Formability
		Unhardened	Hardened					
Multipurpose 4140/4142	60,000	B90	C60	○	○	○	○	○
Easy-to-Machine 41L40	85,000	B96	C34	●	—	○	○	○
Wear Resistant 4150	48,000	B90	C63	○	○	—	○	—
High Strength A514	100,000	—	C27	○	○	○	○	○
Very High Strength 300M	230,000	C23	C54	○	○	○	○	○
Impact Resistant 4340	68,500	C27	C40	○	○	○	○	—
Ultra Impact Resistant C300	110,000	C30	C55	○	○	●	○	○
Easy-to-Weld 4130	50,000	B85	C60	○	●	—	—	●
Easy-to-Weld 8620	55,000	B85	C60	○	●	○	○	●
Bearing Quality E52100	62,000	C24	C60	○	○	○	○	○

Tool Steel								
	Min. Yield Strength, psi	Hardness (Rockwell)		Machinability	Weldability	Impact Resistance	Wear Resistance	Formability
		Unhardened	Hardened					
Multipurpose O1	50,000	B85	C65	○	○	○	○	●
Ultra Machinable W1	50,000	B88	C65	●	○	○	○	●
Wear Resistant A2	51,000	B88	C65	○	○	○	○	○
Ultra Wear Resistant D2	50,000	B90	C62	○	○	○	●	○
High Temperature H13	52,000	B94	C53	○	○	●	○	○
Shock Resistant S7	50,000	B90	C61	○	○	●	○	○
Easy-to-Machine P20	101,000	—	C26	○	—	○	○	—
High Speed M2	60,000	B97	C66	○	○	○	●	○
Ultra Wear Resistant M4	60,000	B97	C65	○	—	○	●	—
Ultra-Hard Tungsten Carbide	319,000	—	C79	○	—	○	●	○

Hardness

As hardness increases, metals become more wear resistant but they may be less malleable. The chart below shows hardness on different scales.



Guidelines for Heat Treating Tool Steel

A2

Hardening: Preheat thoroughly at 1450°F, raise to hardening temperature of 1725° to 1800°F, and soak uniformly. For larger sections, use the high side of the range; for smaller sections, use the low side. Quench in air or dry air blast at 125° to 175°F, and temper immediately according to the chart below.

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
As Hardened	62-65
300°F	61-64
400°F	59-62
500°F	58-61
600°F	57-60
800°F	56-59
900°F	55-58
1000°F	56-59

Annealing: Heat slowly and uniformly to 1550° to 1600°F, hold at temperature for 2 hours, and then cool slowly at a maximum rate of 40°F per hour.

D2

Hardening: Preheat thoroughly to 1450° to 1500°F, and then raise the temperature to 1800° to 1850°F. Hold until uniformly heated through and soak for 45 to 60 minutes per inch of thickness. To minimize surface decarburization, use a salt bath, controlled atmosphere furnace, or pack harden. Use the high side of the range for larger sections.

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
As Hardened	62-65
400°F	60
500°F	59-62
600°F	57-59
700°F	57-59
800°F	57-59
900°F	59-61

Annealing: To minimize surface decarburization, use a controlled atmosphere furnace or pack harden in inert material in a sealed container. Heat slowly and uniformly to approximately 1650°F, and hold for about 1½ hours for each inch of greatest thickness. Cool at a rate of 20° to 25° F per hour to 1000°F. Allow to cool in the furnace. Material can also be annealed without slow-cooling in the furnace if it has reached about 1200°F, it is reheated to 1425°F, and it is held at that temperature for 5 hours followed by air cooling.

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M2

Hardening: Warm slightly before placing into the furnace, which should be operating at 1350° to 1550°F. After thorough preheating, transfer to a hardening furnace at 2175° to 2225°F, depending on the tool size and degree of hardening required for the application.

Cool in air, oil, or a molten salt bath operating at 1000° to 1100°F. For oil quenching, it is usually good practice to interrupt the quench by removing the tool after it has reached about 1000°F, and allow the cooling to continue in still air. Tools should be allowed to cool to about 150°F or when they are warm to the touch. Temper immediately according to the chart below. Double tempering is always recommended.

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

Annealing: Heat to 1550° to 1600°F, equalize, and cool in a furnace at a maximum rate of 30°F per hour to 1100°F. Air cool. Hardness should be 245 Brinell (Rockwell C23) maximum.

M4

Hardening: Preheat to 1150° to 1250°F, and then preheat a second time to 1500° to 1575°F. A third preheat to 1850° to 1900°F is optional for hardening in a vacuum furnace. Equalize the temperature of the tooling at each preheat stage. Use an austenitizing temperature of 2150° to 2200°F for cutting tools. For cold applications, use a temperature of 1875° to 2200°F.

Quench in salt at 920° to 1050°F, followed by a second quench at 700° to 800°F. Air cool to 125°F. If using a vacuum furnace, pressure quench to 1000°F, equalize, and continue rapid cooling to 125°F. These ranges are critical to achieve optimum heat treating response.

Double temper at 1000°F minimum. Triple tempering is recommended when hardening from 2100°F and higher. Each temper cycle should be 2 hours minimum. Air cool to room temperature between tempers.

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
As Quenched	65
1000°F	65
1100°F	62

Annealing: Heat to 1600°F, hold for 2 hours, then slow cool at 30°F per hour to a maximum of 1000°F. Air or furnace cool to room temperature. Hardness should be 260 Brinell (Rockwell C26) maximum.

O1

Hardening: Heat slowly to 1450° to 1550°F and hold at temperature for 10 to 30 minutes. Oil quench; temper according to the chart below.

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
As Quenched	63-64
300°F	63-64
400°F	59-61
500°F	57-58
600°F	54-56
800°F	47-50
1000°F	42-43

Annealing: Heat to 1400° to 1450°F, cool at a maximum rate of 40°F per hour to 900°F and then air cool. Hardness will be 183 to 212 Brinell (Rockwell B89 to B95).

PM

Hardening: Vacuum, salt, or protective atmosphere methods are generally used to prevent decarburization. Preheat to 1500° to 1550°F until temperature is equalized. Additional preheating to 1200° to 1250°F and 1700° to 1750°F is suggested when using programmed control during vacuum processing. Soak at austenitizing temperature from 1850° to 2050°F, with the specific temperature and soak time determined by the hardness required. Higher hardening temperatures will provide maximum wear resistance and hardness while temperatures lower in the range will increase toughness.

Quench in a salt bath or oil. The rate of cooling from the hardening temperature down to 1300°F is critical to the development of optimum structure and properties. Temperature can then be equalized at 1000° to 1100°F. Continue cooling to below 150°F, or when material is warm to the touch. Temper immediately according to the chart below.

Heat uniformly to the tempering temperature and soak for 2 hours. Double tempering is necessary, and triple tempering is recommended when hardening at 1950°F and higher.

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
1000°F	57-64

Annealing: Heat uniformly in a protective or vacuum atmosphere to 1600°F and soak for 2 hours. Slow cool 30°F per hour until 1000°F. Parts can then be cooled in air or furnace as desired. Hardness should be 225-248 Brinell (Rockwell B97-B100).

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S7

Hardening: Preheat thoroughly to 1200° to 1300°F and raise to a hardening temperature of 1725°F. Hold for one hour and quench in still air. Upon reaching 150°F, this steel should be tempered immediately according to the chart below.

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
As Quenched	59-61
400°F	56-58
500°F	54-56
600°F	53-55
700°F	52-54
800°F	52-54
900°F	51-53
1000°F	50-52
1100°F	46-48
1200°F	40-42
1300°F	33-35

Annealing: Heat to 1500° to 1550°F in an inert material. Hold at temperature for 1 to 2 hours for each inch of greatest thickness. Cool slowly at a maximum rate of 25°F per hour to below 1000°F, then air cool to a hardness of 187 to 223 Brinell (Rockwell B90 to B97).

W1

Hardening: Heat thoroughly at 1425° to 1500°F. Hold for 30 minutes per inch of section, and quench in water (brine).

Tempering Data	
Tempering Temperature	Typical Rockwell C Hardness
As Hardened	66-68
300°F	64-65
400°F	62-64
500°F	58-59
600°F	54-56
700°F	50-51
800°F	46-47

Annealing: Heat to 1375° to 1400°F and soak until uniformly heated, approximately 30 minutes per inch. Furnace cool 50°F per hour to 975°F, and then air cool to room temperature. Hardness will be approximately 200 Brinell (Rockwell B93).