

## More About Steel Alloys

**Chemical Composition Limits (%) of Steel Alloys**—Iron makes up the remaining percentage.

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Grade	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Chromium	Molybdenum	Vanadium	Other
<b>A36</b>	0.25-0.29%	0.60-1.20%	0.15-0.40%	0.04%	0.05%	None	None	None	0-0.20% Copper
<b>1018</b>	0.15-0.20%	0.60-0.90%	0.15-0.30%	0-0.04%	0-0.05%	None	None	None	None
<b>1045</b>	0.43-0.50%	0.60-0.90%	0.15-0.30%	0-0.04%	0-0.05%	None	None	None	None
<b>1065</b>	0.60-0.70%	0.60-0.90%	0.15-0.30%	0-0.035%	0-0.045%	None	None	None	None
<b>1074/1075</b>	0.75%	0.57%	0.17%	0.013%	0-0.015%	0.014%	None	None	0.012% Nickel
<b>1095</b>	0.90-1.03%	0.30-0.50%	0.15-0.30%	0-0.04%	0-0.05%	None	None	None	None
<b>1117</b>	<2%	<2%	<1%	<1%	<1%	None	None	<1%	<1% Aluminum <1% Bismuth <1% Colombian
<b>1144</b>	0.40-0.48%	1.35-1.65%	0.15-0.30%	0-0.04%	0.24-0.33%	None	None	None	Trace Nitrogen
<b>12L14</b>	0.15%	0.85-1.15%	None	0.04-0.09%	0.26-0.35%	None	None	None	0.15-0.35% Lead
<b>1215</b>	0.09%	0.75-1.05%	None	0.04-0.09%	0.26-0.35%	None	None	None	None
<b>4130</b>	0.28-0.33%	0.40-0.60%	0.15-0.35%	0-0.04%	0-0.04%	0.80-1.10%	0.15-0.25%	None	None
<b>4140/4142</b>	0.38-0.45%	0.75-1.00%	0.15-0.35%	0-0.04%	0-0.04%	0.80-1.10%	0.15-0.25%	None	0-0.35% Copper 0-0.25% Nickel
<b>Modified 4140 (ETD-150)</b>	0.40% min.	0.75-1.00%	0.20-0.35%	0-0.035%	0-0.04%	0.80-1.10%	0.15-0.25%	None	None
<b>41L40</b>	0.38-0.43%	0.75-1.00%	0.15-0.30%	None	None	0.80-1.10%	0.15-0.25%	None	0.15-0.35% Lead
<b>4150</b>	0.48-0.53%	0.75-1.00%	0.20-0.35%	0-0.04%	0-0.04%	0.80-1.10%	0.18-0.25%	None	None
<b>4340</b>	0.38-0.43%	0.60-0.80%	0.20-0.35%	0-0.025%	0-0.025%	0.70-0.90%	0.20-0.30%	None	1.65-2.00% Nickel
<b>8620</b>	0.18-0.23%	0.70-0.90%	0.20-0.35%	0-0.04%	0-0.04%	0.40-0.60%	0.15-0.25%	None	0.40-0.70% Nickel
<b>E52100</b>	0.95-1.10%	0.25-0.45%	0.20-0.35%	0-0.025%	0-0.025%	1.30-1.60%	None	None	None
<b>A2</b>	0.95-1.05%	0-1.00%	0-0.50%	None	None	4.75-5.50%	0.90-1.40%	0.15-0.50%	0-0.30% Nickel
<b>A6</b>	0.65-0.75%	1.80-2.45%	0.20-0.40%	None	None	0.90-1.10%	1.20-1.50%	None	None
<b>D2</b>	1.40-1.60%	0-0.60%	0-0.60%	0.03% max.	0.03% max.	11.00-13.00%	0.70-1.20%	0-1.10%	0-0.40% Nickel
<b>H13</b>	0.32-0.45%	0.20-0.50%	0.80-1.20%	0-0.03%	0-0.03%	4.75-5.50%	1.10-1.75%	0.80-1.20%	0-0.75% Copper and Nickel
<b>M2/M7</b>	0.80-1.02%	0.20-0.35%	0.20-0.40%	None	None	3.50-4.40%	4.75-9.10%	1.75-2.20%	1.50-6.75% Tungsten
<b>M4</b>	1.42%	0.30-0.70%	None	None	0.06-0.22%	4.00%	5.25%	4.00%	5.50% Tungsten
<b>M42</b>	1.05-1.13%	0.15-0.30%	0.15-0.40%	None	None	3.50-4.00%	9.25-9.75%	1.05-1.25%	1.40-1.60% Tungsten 7.75-8.25% Cobalt
<b>M50</b>	0.81%	0.25%	0.20%	0.008%	0.008%	4.00%	4.25%	1.00%	None
<b>O1</b>	0.85-1.00%	1.00-1.35%	0.20-0.45%	None	None	0.40-0.60%	None	0-0.25%	0.40-0.60% Tungsten
<b>P20</b>	0.28-0.40%	0.65-0.95%	0.40-0.60%	None	None	1.65-1.80%	0.40-0.48%	None	None
<b>S2</b>	0.47-0.55%	0.30-0.50%	0.90-1.10%	0-0.03%	0-0.03%	None	0.30-0.60%	0-0.50%	None
<b>S7</b>	0.45-0.55%	0.20-0.90%	0.20-1.00%	0-0.03%	0-0.03%	3.00-4.50%	1.30-1.80%	0-0.35%	0-0.75% Copper and Nickel
<b>W1</b>	0.60-1.40%	0.10-0.40%	0.10-0.40%	0-0.03%	0-0.03%	0-0.15% max.	0-0.10%	0-0.10%	0-0.20% Copper 0-0.20% Nickel 0-0.15% Tungsten
<b>Cast Gray Iron</b>	2.6-3.75%	0.60-0.95%	1.8-3.0%	0.12% max.	0.07% max.	None	None	None	None
<b>Cast Ductile Iron</b>	3.5-3.9%	0.15-0.35%	2.25-3.0%	0.05% max.	0.025% max.	None	None	None	None

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Nominal Density, lbs./cu. in.	Modulus of Elasticity, psi × 10 <sup>6</sup>	Electrical Resistivity, microhm-cm @ 68° F (unless noted)	Thermal Conductivity Btu/sq. ft./ft./hr./° F @ 212° F (unless noted)	Thermal Coefficient of Expansion per ° F	Condition	Tensile Strength, ksi	Yield Strength, ksi	Elongation %	Hardness, Brinell
<b>A36</b>									
0.284	29-30	15.9 @ 32° F	30 @ 32° F	7.06 × 10 <sup>-6</sup> (68° to 392° F)	As rolled	58-80	36	18-23	Not rated
<b>1018</b>									
0.283	28-30	15.9 @ 32° F	29.4	7.5 × 10 <sup>-6</sup> (32° to 752° F)	Annealed	60	44	35	127
					Normalized	66	50	36	135
<b>1045</b>									
0.283	29-30	16.2 @ 32° F	29.4	7.4 × 10 <sup>-6</sup> (32° to 752° F)	Annealed	90	55	26	180
					Normalized	95	60	23	190
<b>1065</b>									
0.283	28	16.3 @ 32° F	28.75	7.5 × 10 <sup>-6</sup> (32° to 752° F)	Annealed	91	54	23	180
					Normalized	120	65	16	245
<b>1074/1075</b>									
Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated
<b>1095</b>									
0.283	30	18	27	8.1 × 10 <sup>-6</sup> (70° to 1200° F)	Normalized	142	80	8	285
<b>1117</b>									
Not rated	Not rated	Not rated	Not rated	Not rated	Cold drawn	Not rated	58	Not rated	137
<b>1144</b>									
Not rated	Not rated	Not rated	Not rated	Not rated	Stress relieved	115	105	10	229
<b>12L14</b>									
0.284	Not rated	Not rated	Not rated	Not rated	Cold drawn	78	60	10	163
<b>1215</b>									
Not rated	Not rated	Not rated	Not rated	Not rated	Cold drawn	87.5	75	15	187
<b>4130</b>									
0.283	30	22.3	0.102 cal/sq. cm/cm/ sec./° C (@ 20° C)	7.6 × 10 <sup>-6</sup> (68° to 752° F)	Annealed	75	50	28	150
					Normalized	97	63.3	25	197
<b>4140</b>									
0.283	29	22	24.7	7.67 × 10 <sup>-6</sup> (68° to 752° F)	Annealed	95	60.5	26	197
					Normalized	148	95	18	302
					Quenched and tempered (full hard)	257	238	8	510
<b>4142</b>									
0.283	28-30	22	0.10 cal/sq. cm/cm/ sec./° C (@ 20° C)	7.1 × 10 <sup>-6</sup> (70° to 572° F)	Annealed	95	60.5	25	195
					Normalized	132	93	19	270-302
<b>Modified 4140 (ETD-150)</b>									
0.283	28-30	Not rated	Not rated	7.1 × 10 <sup>-6</sup> (70° to 600° F)	As drawn	150	130	10.5	302
<b>41L40</b>									
0.284	30	23	0.102 cal/sq. cm/cm/ sec./° C (@ 20° C)	6.3 × 10 <sup>-6</sup> (0° to 200° F)	As rolled	137.6	96.8	19	235-277
<b>4150</b>									
0.283	30	22.3	0.102 g/sq. cm/cm/ sec./° C (@ 20° C)	Not rated	Annealed	100	48	22	197
					Normalized	155	105	13	311

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<b>4340</b>									
0.283	29-30	30 @ 120° F	21.67	$8.1 \times 10^{-6}$ (0° to 1200° F)	Annealed	120	80	18	250
					Normalized	180	145	8	370
					Quenched and tempered (full hard)	287	270	11	520
<b>8620</b>									
Not rated	Not rated	Not rated	Not rated	Not rated	Annealed	88	80	18	179
					As drawn	110	101	15	223
<b>E52100</b>									
0.23	29	Not rated	Not rated	$6.9 \times 10^{-6}$	Annealed Cold drawn	107	87.5	17	229
<b>A2</b>									
0.28	29.5	Not rated	Not rated	$7.91 \times 10^{-6}$ (200° to 1200° F)	Annealed	70-103	51	26	Rockwell C18
					Quenched and tempered from 1750° F with 1050° F temper	253	200	3	Rockwell C55
<b>A6</b>									
0.29	29-30	Not rated	Not rated	$7.9 \times 10^{-6}$ (70° to 900° F)	Quenched and tempered from 1550° F with 600° F double temper for 2 hours	292.5	264.3	1	Rockwell C55
<b>D2</b>									
0.28	28	Not rated	11.6-13.3	$5.7-7.4 \times 10^{-6}$ (68° to 750° F)	Quenched and tempered from 1825° F with 1000° F temper	278	214	1	Rockwell C56
<b>H13</b>									
0.28	30	Not rated	15	$6.1 \times 10^{-6}$	Annealed	Not rated	Not rated	Not rated	Not rated
<b>M2</b>									
0.294	Not rated	Not rated	Not rated	$6.63 \times 10^{-6}$ (68° to 752° F)	Quenched and tempered from 2150°-2275° F with double temper above 900° F	Not rated	408	Not rated	255
<b>M4</b>									
0.288	31	Not rated	12.03	$6.58 \times 10^{-6}$ (100° to 800° F)	Annealed	Not rated	60	Not rated	225-255
<b>M7</b>									
0.287	29-30	Not rated	Not rated	$7.0 \times 10^{-6}$ (70° to 800° F)	Quenched and tempered from 2200° F with double temper above 900° F	392.8	Not rated	Not rated	Rockwell C65

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Nominal Density, lbs./cu. in.	Modulus of Elasticity, psi × 10 <sup>6</sup>	Electrical Resistivity, microhm-cm @ 68° F (unless noted)	Thermal Conductivity Btu/sq. ft./ft./hr./° F @ 212° F (unless noted)	Thermal Coefficient of Expansion per ° F	Condition	Tensile Strength, ksi	Yield Strength, ksi	Elongation %	Hardness, Brinell (unless noted)
<b>M42</b>									
0.282	30	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated
<b>M50</b>									
0.281	30-31	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated
<b>O1</b>									
0.283	31-32	Not rated	Not rated	7.1 × 10 <sup>-6</sup> (100° to 800° F)	Annealed	85	70	25	185
					Quenched and tempered from 1475° F to 600° F temper	280	272	Not rated	Rockwell C57-62
<b>P20</b>									
0.283	28-30	Not rated	Not rated	7.6 × 10 <sup>-6</sup> (70° to 800° F)	Quenched and tempered from 1550° F with 1150° F temper	144.5	110	18	262-321
<b>S2</b>									
0.281	30	Not rated	Not rated	7.5 × 10 <sup>-6</sup> (100° to 800° F)	Quenched and tempered from 1550°-1600° F with 400° F temper	330	290	4	Rockwell C58
<b>S7</b>									
0.281	29-30	Not rated	16.5	7.6 × 10 <sup>-6</sup> (70° to 932° F)	Quenched and tempered from 1725° F with 600° F temper	Not rated	Not rated	Not rated	Rockwell C53-55
<b>W1</b>									
0.284	30	Not rated	27.9	6.7 × 10 <sup>-6</sup>	Quenched and tempered from 1450° F to 400° F temper	Not rated	Not rated	Not rated	Rockwell C62-64
<b>Cast Gray Iron</b>									
0.26	20	110 microhms×cm	30.84	5.5 × 10 <sup>-6</sup>	As cast	40	Not rated	Not rated	241
<b>Cast Ductile Iron</b>									
0.26	25	75 microhms×cm	18.68	6.4 × 10 <sup>-6</sup>	As cast	80	55	6	229

## Guidelines for Heat Treating Tool Steel

### A2

**Hardening:** Preheat thoroughly at 1450°-1500°F, then raise to a hardening temperature between 1700° and 1800°F, and cool in air to 150°F. For larger sections, use high-end hardness range; for thin or smaller sections, use the lower end. Quench in still air and then temper immediately.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Quenched	63.5C-65C
300° F	62.5C-64C
400° F	61C-62C
500° F	59C-59.5C
600° F	58C
800° F	56C-57C

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

### D2

**Hardening:** When heating for hardening, it is necessary to protect the steel with some inert material packed in sealed containers, or to heat it in a well-regulated salt bath or controlled atmosphere furnace. Preheat to 1200°F and hold this temperature until thoroughly soaked, usually about an hour for each inch of greatest thickness. Heat to 1850°F and hold at this temperature at least 1½ hours for each inch of thickness. The pieces may then be removed from the container or furnace and cooled in still air to a temperature of 150° F and tempered immediately. Air blast cooling may be used on heavy sections.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
300° F	63C
400° F	61C
500° F	59C
600° F	58C
800° F	58C

**Annealing:** Packing in some inert material in a sealed container to prevent decarburization is recommended; otherwise, use a controlled atmosphere furnace. Heat slowly to approximately 1650° F and hold at that temperature for about 1½ hours for each inch of greatest thickness. Cool slowly at a rate of about 20°-25° F per hour to 1000° F, after which it may be allowed to cool down with the furnace. It may also be annealed without slow-cooling in the furnace, provided that after it has reached about 1200° F it is reheated to 1425° F and held at that temperature for 5 hours followed by air cooling.

### M2

**Hardening:** Preheat slowly to 1350°-1550° F and hold until thoroughly heated. Next, heat rapidly to 2150°-2275° F. Total heating time varies from a few minutes to a maximum of 15 minutes depending on the size of the piece. Oil quenching is recommended for developing full hardness, although air quenching and quenching in hot salt can also be done. When the material has reached a temperature of 150° to 200° F in the quench, temper immediately. The best tempering range is 1000°-1100° F. Double tempering is recommended.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Hardened	64C-65C
300° F	64C-65C
400° F	62C-63C
600° F	61C
800° F	61C-62C
1000° F	64C-65C
1100° F	63C-64C

**Annealing:** Heat to 1600°-1650° F, then cool in a furnace at 30°-40° F per hour to 900° F. Air cool. Hardness will be 241 Brinell maximum.

### A6

**Hardening:** Preheating is unnecessary. Heat to 1550°-1625° F and hold until the material is heated throughout. Cool the material in freely circulating air to below 150° F before tempering. Tempering time is 2 hours, but sections larger than 2" should be tempered for a minimum of 1 hour per inch.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
300° F	60C-61C
400° F	58C-59C
600° F	55C-56C
800° F	52C-53C
1000° F	48C-49C

**Annealing:** Heat slowly and uniformly to 1400°-1425° F. Cool in furnace at a rate of 20° F per hour maximum. Hardness will be 241 Brinell maximum.

### H13

**Hardening:** Heat slowly to 1500° F at a rate not to exceed 200° F per hour. Hold for 1 hour per inch of thickness. Austenitize at 1825°-1905° F for 15-40 minutes. Quench in air or in a salt bath held at 1105°-1200° F. Hold in the quench until material reaches the temperature of the bath, withdraw, and allow to cool in air.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
1100° F	46C-48C

**Annealing:** Heat to 1555°-1650° F. Hold 1 hour per inch of cross section. Cool slowly in furnace to 1000° F at a rate not to exceed 55° F per hour, after which a faster cooling rate will not affect final hardness. Hardness will be 192-229 Brinell.

### M4

**Hardening:** Preheat to 1500°-1550° F. Preheat a second time to 1850°-1900° F, which is suggested for high-temperature hardening in a vacuum. Use a high heat of 2150°-2200° F for cutting tools. For cold applications, use a temperature of 1876°-2125° F. Quench is oil, salt, or atmosphere to 1000°-1100° F, then air cool to below 125° F. Vacuum or atmosphere quench between 1850° and 1300° F. This range is critical to achieve optimum heat treat response. Double temper at 1000° F minimum. Triple temper recommended when hardening from 2100° F and higher. Two hours minimum each temper. Air cool to room temperature between tempers.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Quenched	59.5C-66C
1000° F	58.5C-66C
1100° F	54C-62.5C

**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 will be 225-255 Brinell.

## Guidelines for Heat Treating Tool Steel

### M42

**Hardening:** Preheat at 1350°-1555° F. Preheating time, after all sections of the material have reached equal temperature, should be twice the length of required time required at the austenitizing temperature. Heat rapidly from the preheated temperature to the austenitizing temperature. Austenitize at 2125°-2175° F for 2-5 minutes. Quench in oil, air, or salt.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Quenched	64C-65C
200° F	63C-64C
400° F	63C
600° F	62C
800° F	64C
1000° F	70C
1200° F	53C

**Annealing:** Heat to 1600°-1650° F. Material should be held at temperature for 1 hour per inch of thickness. Cool slowly in the furnace to 1200° F at a rate not to exceed 40° F per hour. Hardness will be 235-269 Brinell.

### O1

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

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Quenched	64C-65C
300° F	64C-65C
400° F	61C-62C
500° F	58C-59C
600° F	56C-57C
800° F	51C-52C
1000° F	44C

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

### S2

**Hardening:** Heat slowly. Preheat to 1200° F. Austenitize at 1555°-1650° F, hold for 5-20 minutes, then quench in brine (salt water) or water.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Quenched	58C-62C
200° F	57C-61C
400° F	56C-58C
600° F	54C-55C
800° F	49C-50C

**Annealing:** Heat to 1400°-1455° F. Use lower limit for small sections and upper limit for large sections. Holding time varies from approximately 1 hour for small sections to approximately 4 hours for large sections. Cool at a rate not to exceed 40° F per hour. Hardness will be 192-217 Brinell.

### M50

**Hardening:** Preheat to 1500° F and equalize. Transfer parts to superheated furnace at 2010° F. Superheat only long enough to allow material to reach temperature of superheated furnace; follow immediately by quenching to room temperature. Then cool material to approximately -105° F and hold for 1 hour. Double temper at 1000° F.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
As Quenched	64C-65C
900° F	60C-62C
950° F	61C-63C
1000° F	62C-64C
1050° F	61C-63C
1100° F	60C-62C
1150° F	55C-58C
1200° F	53C-56C

**Annealing:** Heat uniformly to 1555°-1650° F, then cool slowly at a rate not to exceed 20° F per hour. Hardness will be 235 Brinell.

### P20

**Hardening:** Heat to 1500°-1650° F, using the higher end for larger pieces. Hold at the hardening temperature for 1 hour per inch of the greatest thickness. Quench in oil to 150° F and temper immediately.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
400° F	53C
600° F	50C
800° F	46C
1000° F	41C
1200° F	26C

**Annealing:** Heat to 1400°-1500° F and hold for 1 hour per inch of the greatest thickness. Cool at the rate of 40° F per hour to 1000° F, then air cool to room temperature. Hardness will be 212 Brinell maximum.

### S7

**Hardening:** Preheat thoroughly to 1200°-1300° F and raise to an austenitizing temperature of 1700°-1750° F in a furnace for 30 minutes per inch of greatest thickness. Sections up to 2<sup>1</sup>/<sub>2</sub>" thick may be cooled in air. Sections 2<sup>1</sup>/<sub>2</sub>" to 6" thick should be quenched in oil until black (1000° F) then air cooled to 150° F. Sections larger than 6" should be oil quenched to 150° F and tempered immediately. Material should be held at least 2 hours at the tempering temperature before air cooling.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
400° F	56C-58.5C
600° F	53C-55C
800° F	52C-54.5C
1000° F	49C-52C
1200° F	37.5C-41C

**Annealing:** Heat to 1500°-1550° F in an inert material. Hold at temperature for 1-2 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 187-223 Brinell.

## Guidelines for Heat Treating Tool Steel

### W1

**Hardening:** Heat slowly to 1400°-1555° F; using temperatures at the upper end of the temperature range will increase hardenability. Austenitize for 10 minutes for small sections; up to 30 minutes for large sections. Quench in agitated water or brine (salt water).

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

**Annealing:** Heat to 1400°-1450° F and hold for 2 hours. Cool to 1000° F at a rate not to exceed 50° F per hour, after which controlled cooling is not necessary. Hardness will be 156-201 Brinell.

### Cast Gray Iron and Cast Ductile Iron

**Hardening:** Can be hardened by conventional quench and temper methods.

Tempering Data	
Tempering Temperature	Typical Rockwell Hardness
Oil quench 1600° F	50C