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
A36	0.25-0.29%	0.6-1.20%	0.15-0.40%	0.04%	0.05%	None	None	None	0-0.20% Copper
1018	0.15-0.20%	0.60-0.90%	0.15-0.30%	0-0.04%	0-0.05%	None	None	None	None
1045	0.43-0.50%	0.60-0.90%	0.15-0.30%	0-0.04%	0-0.05%	None	None	None	None
1065	0.60-0.70%	0.60-0.90%	0.15-0.30%	0-0.035%	0-0.045%	None	None	None	None
1074/1075	0.75%	0.57%	0.17%	0.013%	0-0.015%	0.014%	None	None	0.012% Nickel
1095	0.90-1.03%	0.30-0.50%	0.15-0.30%	0-0.04%	0-0.05%	None	None	None	None
1117	<2%	<2%	<1%	<1%	<1%	None	None	<1%	<1% Aluminum, <1% Bismuth, and <1% Colombian
1144	0.40-0.48%	1.35-1.65%	0.15-0.30%	0-0.04%	0.24-0.33%	None	None	None	Trace Nitrogen
12L14	0.15%	0.85-1.15%	None	0.04-0.09%	0.26-0.35%	None	None	None	0.15-0.35% Lead
1215	0.09%	0.75-1.05%	None	0.04-0.09%	0.26-0.35%	None	None	None	None
4130	0.28-0.33%	0.40-0.060%	0.15-0.35%	0-0.04%	0-0.04%	0.80-1.10%	0.15-0.25%	None	None
4140/4142	0.38-0.45%	0.75-1.00%	0.15-0.30%	0-0.04%	0-0.04%	0.80-1.10%	0.15-0.25%	None	None
Modified 4140 (ETD-150)	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
41L40	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
4150	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
4340	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
8620	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
E52100	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
A2	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
A6	0.65-0.75%	1.80-2.45%	0.20-0.40%	None	None	0.90-1.10%	1.20-1.50%	None	None
D2	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
H13	0.32-0.45%	0.20-0.50%	0.80-1.20%	None	None	4.75-5.50%	1.10-1.75%	0.80-1.20%	0-0.30% Nickel
M2/M7	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
M4	1.42%	0.30-0.70%	None	None	0.06-0.22%	4.00%	5.25%	4.00%	5.50% Tungsten
M42	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
M50	0.81%	0.25%	0.20%	0.008%	0.008%	4.00%	4.25%	1.00%	None
O1	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
P20	0.28-0.40%	0.65-0.95%	0.40-0.60%	None	None	1.65-1.80%	0.40-0.48%	None	None
S2	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
S7	0.45-0.55%	0.20-0.70%	0.20-1.00%	None	None	3.00-3.50%	1.30-1.50%	0-0.30%	None
W1	0.60-1.40%	0.10-0.40%	0.10-0.40%	0-0.025%	0-0.025%	0-0.15% max.	None	0-0.10% max.	None
Cast Gray Iron	2.6-3.75%	0.60-0.95%	1.8-3.0%	0.12% max.	0.07% max.	None	None	None	None
Cast Ductile Iron	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×10^6	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)
A36									
0.284	29-30	15.9 @ 32° F	30 @ 32° F	7.06×10^{-6} (68°-392° F)	As rolled	58-80	36	18-23	Not rated
1018									
0.283	28-30	15.9° @ 32° F	29.4	7.5×10^{-6} (32° to 752° F)	Annealed	60	44	35	127
					Normalized	66	50	36	135
1045									
0.283	29-30	16.2 @ 32° F	29.4	7.4×10^{-6} (32° to 752° F)	Annealed	90	55	26	180
					Normalized	95	60	23	190
1065									
0.283	28	16.3 @ 32° F	28.75	7.5×10^{-6} (32° to 752° F)	Annealed	91	54	23	180
					Normalized	120	65	16	245
1074/1075									
Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated
1095									
0.283	30	18	27	8.1×10^{-6} (70° to 1200° F)	Normalized	142	80	8	285
1117									
Not rated	Not rated	Not rated	Not rated	Not rated	Cold drawn	Not rated	58	Not rated	137
1144									
Not rated	Not rated	Not rated	Not rated	Not rated	Stress relieved	115	105	10	229
12L14									
0.284	Not rated	Not rated	Not rated	Not rated	Cold drawn	78	60	10	163
1215									
Not rated	Not rated	Not rated	Not rated	Not rated	Cold drawn	87.5	75	15	187
4130									
0.283	30	22.3	0.102 cal/sq. cm/cm/ sec./° C (@ 20° C)	7.6×10^{-6} (68° to 752° F)	Annealed	75	50	28	150
					Normalized	97	63.3	25	197
4140									
0.283	29	22	24.7	7.67×10^{-6} (68° to 752° F)	Annealed	95	60.5	26	197
					Normalized	148	95	18	302
					Quenched and tempered (full hard)	257	238	8	510
4142									
0.283	28-30	22	0.10 cal/sq. cm/cm/ sec./° C (@ 20° C)	7.1×10^{-6} (70° to 572° F)	Annealed	95	64	25	195
					Normalized	132	93	19	270
Modified 4140 (ETD-150)									
0.283	28-30	Not rated	Not rated	7.1×10^{-6} (70° to 600° F)	As drawn	150	130	10.5	302
41L40									
0.284	30	23	0.102 cal/sq. cm/cm/ sec./° C (@ 20° C)	6.3×10^{-6} (0° to 200° F)	As rolled	137.6	96.8	19	235-277
4150									
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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Nominal Density, lbs./cu. in.	Modulus of Elasticity, psi×10^6	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)
4340									
0.283	29-30	30 @ 120° F	21.67	8.1×10^{-6} (0° to 1200° F)	Annealed	120	80	18	250
					Normalized	180	145	8	370
					Quenched and tempered (full hard)	287	270	11	520
8620									
Not rated	Not rated	Not rated	Not rated	Not rated	Annealed	88	80	18	179
					As drawn	110	101	15	223
E52100									
0.23	29	Not rated	Not rated	6.9×10^{-6}	Annealed Cold drawn	107	87.5	17	229
A2									
0.28	29.5	Not rated	Not rated	7.91×10^{-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
A6									
0.29	29-30	Not rated	Not rated	7.9×10^{-6} (70° to 900° F)	Quenched and tempered from 1550° F w/ 600° F double temper for 2 hours	292.5	264.3	1	Rockwell C55
D2									
0.28	28	Not rated	11.6-13.3	5.7-7.4×10^{-6} (68° to 750° F)	Quenched and tempered from 1825° F w/ 1000° F temper	278	214	1	Rockwell C56
H13									
0.279	30.5	Not rated	16.6 Btu/sq. ft./inch/ hr./° F @ 1200° F	8.1×10^{-6} (70° to 800° F)	Annealed	98	74	28	Rockwell B92-99
M2									
0.294	Not rated	Not rated	Not rated	6.63×10^{-6} (68° to 752° F)	Quenched and tempered from 2150°-2275° F w/ double temper above 900° F	Not rated	408	Not rated	255
M4									
0.288	31	Not rated	12.03	6.58×10^{-6} (100° to 800° F)	Annealed	Not rated	60	Not rated	225-255
M7									
0.287	29-30	Not rated	Not rated	7.0×10^{-6} (70° to 800° F)	Quenched and tempered from 2200° F w/ double temper above 900° F	392.8	Not rated	Not rated	Rockwell C65

(Continued on next page)

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Nominal Density, lbs./cu. in.	Modulus of Elasticity, psi×10^6	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)
M42									
0.282	30	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated
M50									
0.281	30-31	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated
O1									
0.283	31-32	Not rated	Not rated	7.1×10^{-6} (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
P20									
0.283	28-30	Not rated	Not rated	7.6×10^{-6} (70° to 800° F)	Quenched and tempered from 1550° F w/ 1150° F temper	144.5	110	18	262-321
S2									
0.281	30	Not rated	Not rated	7.5×10^{-6} (100° to 800° F)	Quenched and tempered from 1550°-1600° F w/ 400° F temper	330	290	4	Rockwell C58
S7									
0.281	29-30	Not rated	16.5	7.6×10^{-6} (70° to 932° F)	Quenched and tempered from 1725° F w/ 600° F temper	285	230	10	Rockwell C55
W1									
0.283	30	18.0 ohm-cir. mil./ft.	Not rated	7.64×10^{-6} (68° to 932° F)	Quenched and tempered from 1450° F to 400° F temper	218	150	11	Rockwell C60
Cast Gray Iron									
0.26	20	110 microhms × cm	30.84	5.5×10^{-6}	As cast	40	Not rated	Not rated	241
Cast Ductile Iron									
0.26	25	75 microhms × cm	18.68	6.4×10^{-6}	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.

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.

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 at 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.

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*
300° F	49C-50C
500° F	50C
700° F	50C-51C
900° F	52C-53C
1100° F	46C-50C

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.

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.

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 in 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°, 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.

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	63-64C
400°	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.

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.

Guidelines for Heat Treating Tool Steel

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.

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 a rate of 40° F per hour to 1000° F, then air cool to room temperature. Hardness will be 212 Brinell max.

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.

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 2½″ thick may be cooled in air. Sections 2½″ 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	57C-58.5C
600° F	54C
800° F	52.5C
1000° F	50.5C-51.5C
1200° F	37.5C

Annealing: Heat to 1500°-1550° F in an inert material. Hold at temperature for 1-1½ 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.

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-67C
300° F	64C-65C
400° F	61C-62C
500° F	58C-59C
600° F	54C-55C
700° F	50C-51C
800° F	46C-47C

Annealing: Heat to 1365°-1455° F. Use lower limit for small sections and upper limit for large sections. Holding time varies. Sections up to 1″ require at least 20 minutes; 8″ sections require 2½ hours. For pack annealing, hold for 1 hour per inch of cross section. 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