Heat Treating Data Book

Tenth Edition

SECO/WARWICK

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Heat Treating Data Book

Tenth Edition E-Book

Published by
SECO/Warwick Corporation
180 Mercer St., PO Box 908, Meadville, PA 16335 USA
www.secowarwick.com

SECO/WARWICK Corp. is a member of
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The SECO/WARWICK Heat Treating Data Book contains information about heat treating metals. This book is not intended as a text, but rather as a collection of frequently used reference data to serve persons interested in heat treating technology.

If it saves you time, we feel it will have accomplished its purpose.

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A.I.S.I. - S.A.E. STEEL SPECIFICATIONS

BASIC NUMBERING SYSTEM FOR SAE STEELS

Numerals & Digits	Type of Steel & Nominal Alloy Content, %
	CARBON STEELS
10xx(a)	Plain Carbon (Mn 1.00% max)
11xx	Resulphurized
12xx	Resulphurized & Rephosphorized
15xx	Plain Carbon (max Mn range-over 1.00-1.65)
	MANGANESE STEELS
13xx	Mn 1.75
	NICKEL STEELS
23xx	Ni 3.50
25xx	Ni 5.00
	NICKEL-CHROMIUM STEELS
31xx	Ni 1.25;Cr 0.65 and 0.80
32xx	Ni 1.75;Cr 1.07
33xx	Ni 3.50;Cr 1.50 and 1.57
34xx	Ni 3.00;Cr 0.77
	MOLYBDENUM STEELS
40xx	Mo 0.20 and 0.25
44xx	Mo 0.40 and 0.52
	CHROMIUM-MOLYBDENUM STEELS
41xx	Cr 0.50, 0.80 and 0.95;Mo 0.12, 0.20, 0.25 and 0.30
	NICKEL-CHROMIUM-MOLYBDENUM STEELS
43xx	Ni 1.82; Cr 0.50 and 0.80; Mo 0.25
43BVxx	Ni 1.82; Cr 0.50; Mo 0.12 and 0.25;V 0.03 minimum
47xx	Ni 1.05; Cr 0.45; Mo 0.20 and 0.35
81xx	Ni 0.30; Cr 0.40; Mo 0.12
86xx	Ni 0.55; Cr 0.50; Mo 0.20
87xx	Ni 0.55; Cr 0.50; Mo 0.25
88xx	Ni 0.55; Cr 0.50; Mo 0.35
93xx	Ni 3.25; Cr 1.20; Mo 0.12
94xx	Ni 0.45; Cr 0.40; Mo 0.12

97xx	Ni 0.55; Cr 0.20; Mo 0.20
98xx	Ni 1.00; Cr 0.80; Mo 0.25
	NICKEL-MOLYBDENUM STEELS
46xx	Ni 0.85 and 1.82; Mo 0.20 and 0.25
48xx	Ni 3.50; Mo 0.25
	CHROMIUM STEELS
50xx	Cr 0.27, 0.40, 0.50 and 0.65
51xx	Cr 0.80; 0.87, 0.92, 0.95, 1.00 and 1.05
	CHROMIUM (bearing) STEEL
501xx	Cr 0.50
511xx	Cr 1.02
521xx	Cr 1.45
	CHROMIUM VANDIUM STEEL
61xx	Cr 0.60,0.80 and 0.95; V 0.10 & 0.15 minimum
	TUNGSTEN CHROMIUM STEEL
72xx	W 1.75; Cr 0.75
	SILICON MANGANESE STEEL
92xx	Si 1.40 and 2.00; Mn 0.65, 0.82 and 0.85; Cr 0 and 0.65
	HIGH-STRENGTH LOW-ALLOY STEEL
9xx	Various SAE grades
	BORON STEEL
xxBxx	B denotes Boron Steel
	LEADED STEEL
xxLxx	L denotes Leaded Steel

(a) The xx in the last two digits of these designations indicates that the carbon content (in hundredths of a percent) is to be inserted.

Source: ASM Handbook Vol. 1, page 148, table 11.
http://products.asminternational.org/hbk/index.jsp

TABLE 1A - CARBON STEEL COMPOSITIONS APPLICABLE TO SEMIFINISHED PRODUCTS FOR FORGING, HOT ROLLED AND COLD FINISHED BARS, WIRE RODS, AND SEAMLESS TUBING

UNS #	SAE #	Cast or heat chemical ranges and limits, % (a)			
		C	Mn	P, max	S, max
G10050	1005	0.06 max	0.35 max	0.040	0.050
G10060	1006	0.08 max	0.25-0.40	0.040	0.050
G10080	1008	0.10 max	0.30-0.50	0.040	0.050
G10100	1010	0.08-0.13	0.30-0.60	0.040	0.050
G10120	1012	0.10-0.15	0.30-0.60	0.040	0.050
G10130	1013	0.11-0.16	0.50-0.80	0.040	0.050
G10150	1015	0.13-0.18	0.30-0.60	0.040	0.050
G10160	1016	0.13-0.18	0.60-0.90	0.040	0.050
G10170	1017	0.15-0.20	0.30-0.60	0.040	0.050
G10180	1018	0.15-0.20	0.60-0.90	0.040	0.050
G10190	1019	0.15-0.20	0.70-1.00	0.040	0.050
G10200	1020	0.18-0.23	0.30-0.60	0.040	0.050
G10210	1021	0.18-0.23	0.60-0.90	0.040	0.050
G10220	1022	0.18-0.23	0.70-1.00	0.040	0.050
G10230	1023	0.20-0.25	0.30-0.60	0.040	0.050
G10250	1025	0.22-0.28	0.30-0.60	0.040	0.050
G10260	1026	0.22-0.28	0.60-0.90	0.040	0.050
G10290	1029	0.25-0.31	0.60-1.90	0.040	0.050
G10300	1030	0.28-0.34	0.60-0.90	0.040	0.050
G10350	1035	0.32-0.38	0.60-0.90	0.040	0.050
G10370	1037	0.32-0.38	0.70-1.00	0.040	0.050
G10380	1038	0.35-0.42	0.60-0.90	0.040	0.050
G10390	1039	0.37-0.44	0.70-1.00	0.040	0.050
G10400	1040	0.37-0.44	0.60-0.90	0.040	0.050
G10420	1042	0.40-0.47	0.60-0.90	0.040	0.050
G10430	1043	0.40-0.47	0.70-1.00	0.040	0.050
G10440	1044	0.43-0.50	0.30-0.60	0.040	0.050
G10450	1045	0.43-0.50	0.60-0.90	0.040	0.050
G10460	1046	0.43-0.50	0.70-1.00	0.040	0.050
G10490	1049	0.46-0.53	0.60-0.90	0.040	0.050
G10500	1050	0.48-0.55	0.60-0.90	0.040	0.050
G10530	1053	0.48-0.55	0.70-1.00	0.040	0.050
G10550	1055	0.50-0.60	0.60-0.90	0.040	0.050

G10590	1059	0.55-0.65	0.50-0.80	0.040	0.050
G10600	1060	0.55-0.65	0.60-0.90	0.040	0.050
G10640	1064	0.60-0.70	0.50-0.80	0.040	0.050
G10650	1065	0.60-0.70	0.60-0.90	0.040	0.050
G10690	1069	0.65-0.75	0.40-0.70	0.040	0.050
G10700	1070	0.65-0.75	0.60-0.90	0.040	0.050
G10740	1074	0.70-0.80	0.50-0.80	0.040	0.050
G10750	1075	0.70-0.80	0.40-0.70	0.040	0.050
G10780	1078	0.72-0.85	0.30-0.60	0.040	0.050
G10800	1080	0.75-0.88	0.60-0.90	0.040	0.050
G10840	1084	0.80-0.93	0.60-0.90	0.040	0.050
G10850	1085	0.80-0.93	0.70-1.00	0.040	0.050
G10860	1086	0.80-0.93	0.30-0.50	0.040	0.050
G10900	1090	0.85-0.98	0.60-0.90	0.040	0.050
G10950	1095	0.90-1.03	0.30-0.50	0.040	0.050

(a) When silicon ranges or limits are required for bar and semi-finished products, the values in Table 4 apply. For rods, the following ranges are commonly used: 0.10 max; 0.07-0.15%; 0.10-0.20%; 0.15-0.35%; 0.20-0.40%; and 0.30-0.60%. Steels listed in this table can be produced with additions of lead or boron. Leaded steels typically contain 0.15-0.35% Pb and are identified by inserting the letter L in the designation (10L45); boron steels can be expected to contain 0.0005-0.003% B and are identified by inserting the letter B in the designation (10B46).

Source: ASM Handbook Vol. 1, page 149, table 12.
http://products.asminternational.org/hbk/index.jsp

TABLE 1B - CARBON STEEL COMPOSITONS APPLICABLE ONLY TO STRUCTURAL SHAPES, PLATES, STRIP, SHEETS AND WELDED TUBING

UNS #	**SAE -**	**Cast or heat chemical ranges and limits, % (a)**			
	AISI #	**C**	**Mn**	**P, max**	**S, max**
G10060	1006	0.80 max	0.45 max	0.040	0.050
G10080	1008	0.10 max	0.50 max	0.040	0.050
G10090	1009	0.15 max	0.60 max	0.040	0.050
G10100	1010	0.80-0.13	0.30-0.60	0.040	0.050
G10120	1012	0.10-0.15	0.30-0.60	0.040	0.050
G10150	1015	0.12-0.18	0.30-0.60	0.040	0.050
G10160	1016	0.12-0.18	0.60-0.90	0.040	0.050
G10170	1017	0.14-0.20	0.30-0.60	0.040	0.050
G10180	1018	0.14-0.20	0.60-0.90	0.040	0.050
G10190	1019	0.14-0.20	0.70-1.00	0.040	0.050
G10200	1020	0.17-0.23	0.30-0.60	0.040	0.050
G10210	1021	0.17-0.23	0.60-0.90	0.040	0.050
G10220	1022	0.17-0.23	0.70-1.00	0.040	0.050
G10230	1023	0.19-0.25	0.30-0.60	0.040	0.050
G10250	1025	0.22-0.28	0.30-0.60	0.040	0.050
G10260	1026	0.22-0.28	0.60-0.90	0.040	0.050
G10300	1030	0.27-0.34	0.60-0.90	0.040	0.050
G10330	1033	0.29-0.36	0.70-1.00	0.040	0.050
G10350	1035	0.31-0.38	0.60-0.90	0.040	0.050
G10370	1037	0.31-0.38	0.70-1.00	0.040	0.050
G10380	1038	0.34-0.42	0.60-0.90	0.040	0.050
G10390	1039	0.36-0.44	0.70-1.00	0.040	0.050
G10400	1040	0.36-0.44	0.60-0.90	0.040	0.050
G10420	1042	0.39-0.47	0.60-0.90	0.040	0.050
G10430	1043	0.39-0.47	0.70-1.00	0.040	0.050

G10450	1045	0.42-0.50	0.60-0.90	0.040	0.050
G10460	1046	0.42-0.50	0.70-1.00	0.040	0.050
G10490	1049	0.45-0.53	0.60-0.90	0.040	0.050
G10500	1050	0.47-0.55	0.60-0.90	0.040	0.050
G10550	1055	0.52-0.60	0.60-0.90	0.040	0.050
G10600	1060	0.55-0.66	0.60-0.90	0.040	0.050
G10640	1064	0.59-0.70	0.50-0.80	0.040	0.050
G10650	1065	0.59-0.70	0.60-0.90	0.040	0.050
G10700	1070	0.65-0.76	0.60-0.90	0.040	0.050
G10740	1074	0.69-0.80	0.50-0.80	0.040	0.050
G10750	1075	0.69-0.80	0.40-0.70	0.040	0.050
G10780	1078	0.72-0.86	0.30-0.60	0.040	0.050
G10800	1080	0.74-0.88	0.60-0.90	0.040	0.050
G10840	1084	0.80-0.94	0.60-0.90	0.040	0.050
G10850	1085	0.80-0.94	0.70-1.00	0.040	0.050
G10860	1086	0.80-0.94	0.30-0.50	0.040	0.050
G10900	1090	0.84-0.98	0.60-0.90	0.040	0.050
G10950	1095	0.90-1.04	0.30-0.50	0.040	0.050

(a) When silicon ranges or limits are required, the following ranges and limits are commonly used: up to SAE 1025 inclusive, 0.10% max, 0.10-0.25%, or 0.15-0.35%. Over SAE 1025, or 0.15-0.35%.

Source: ASM Handbook Vol. 1, page 150, table 13.
http://products.asminternational.org/hbk/index.jsp

TABLE 2A - FREE CUTTING (RESULFURIZED) CARBON STEEL COMPOSITIONS

Applicable to semi-finished products for forging, hot-rolled and cold-finished bars, wire rods, and seamless tubing

UNS #	**SAE - AISI #**	**Cast or heat chemical ranges and limits, % (a)**			
		C	**Mn**	**P**	**S**
G11080	1108	0.08-0.13	0.50-0.80	0.040	0.80-0.13
G11100	1110	0.08-0.13	0.30-0.60	0.040	0.08-0.13
G11170	1117	0.14-0.20	1.00-1.30	0.040	0.08-0.13
G11180	1118	0.14-0.20	1.30-1.60	0.040	0.08-0.13
G11370	1137	0.32-0.39	1.35-1.65	0.040	0.08-0.13
G11390	1139	0.35-0.43	1.35-1.65	0.040	0.13-0.20
G11400	1140	0.37-0.44	0.70-1.00	0.040	0.08-0.13
G11410	1141	0.37-0.45	1.35-1.65	0.040	0.08-0.13
G11440	1144	0.40-0.48	1.35-1.65	0.040	0.24-0.33
G11460	1146	0.42-0.49	0.70-1.00	0.040	0.08-0.13
G11510	1151	0.48-0.55	0.70-1.00	0.040	0.08-0.13

(a) When lead ranges or limits are required, or when silicon ranges or limits are required for bars or semi-finished products, the values in Table 4 apply. For rods, the following ranges and limits for silicon are commonly used: up to SAE 1110 inclusive, 0.10% max; SAE 1117 and over, 0.10% max, 0.10-0.20% or 0.15-0.35%.

Source: ASM Handbook Vol. 1, page 150, table 15.
http://products.asminternational.org/hbk/index.jsp

TABLE 2B - FREE CUTTING (REPHOSPHORIZED AND RESULFURIZED) CARBON STEEL COMPOSITIONS

Applicable to semi-finished products for forging, hot-rolled and cold-finished bars, wire rods, and seamless tubing

UNS #	**SAE - AISI #**	**Cast or heat chemical ranges and limits, % (a)**				
		C max	**Mn**	**P**	**S**	**Pb**
G12110	1211	0.13	0.60-0.90	0.07-0.12	0.10-0.15	-
G12120	1212	0.13	0.70-1.00	0.07-0.12	0.16-0.23	
G1230	1213	0.13	0.70-1.00	0.07-0.12	0.24-0.33	-
G12150	1215	0.09	0.75-1.05	0.04-0.09	0.26-0.35	-
G12144	12L14b	0.15	0.85-1.15	0.04-0.09	0.26-0.35	0.15-0.35

(a) When lead ranges or limits are required, the values in Table 4 apply. It is not common practice to produce the 12xx series of steels to specified limits for silicon because of its adverse effect on machinability.

Source: ASM Handbook Vol. 1, page 151, table 16.
http://products.asminternational.org/hbk/index.jsp

TABLE 3A - HIGH MANGANESE CARBON STEEL COMPOSITIONS

Applicable only to semi-finished products for forging, hot-rolled and cold-finished bars, wire rods, and seamless tubing

UNS #	**SAE - AISI #**	**Cast or heat chemical ranges and limits, %** [a]			
		C	Mn	P, max	S, max
G15130	1513	0.10-0.16	1.10-1.40	0.040	0.050
G15220	1522	0.18-0.24	1.10-1.40	0.040	0.050
G15240	1524	0.19-0.25	1.35-1.65	0.040	0.050
G15260	1526	0.22-0.29	1.10-1.40	0.040	0.050
G15270	1527	0.22-0.29	1.20-1.50	0.040	0.050
G15360	1536	0.30-0.37	1.20-1.50	0.040	0.050
G15410	1541	0.36-0.44	1.35-1.65	0.040	0.050
G15480	1548	0.44-0.52	1.10-1.40	0.040	0.050
G15510	1551	0.45-0.56	0.85-1.15	0.040	0.050
G15520	1552	0.47-0.55	1.20-1.50	0.040	0.050
G15610	1561	0.55-0.65	0.75-1.05	0.040	0.050
G15660	1566	0.60-0.71	0.85-1.15	0.040	0.050

(a) When silicon, lead, and boron ranges or limits are required, the values in Tables 4 and 5 apply.

Source: ASM Handbook Vol. 1, page 151, table 17.
http://products.asminternational.org/hbk/index.jsp

TABLE 3B - HIGH MANGANESE CARBON STEEL COMPOSITIONS

Applicable only to structural shapes, plates, strip, sheets, and welded tubing.

UNS #	**SAE - AISI #**	**Cast or heat chemical ranges and limits, %** [a]				**Former**
		C	Mn	P, max	S, max	SAE #
G15240	1524	0.18-0.25	1.30-1.65	0.040	0.050	1024
G15270	1527	0.22-0.29	1.20-1.55	0.040	0.050	1027
G15360	1536	0.30-0.28	1.20-1.55	0.040	0.050	1036
G15410	1541	0.36-0.45	1.30-1.65	0.040	0.050	1041
G15480	1548	0.43-0.52	1.05-1.40	0.040	0.050	1048
G15520	1552	0.46-0.55	1.20-1.55	0.040	0.050	1052

(a) When silicon ranges or limits are required, the values shown in Table 5 apply.

Source: ASM Handbook Vol. 1, page 151, table 18.
http://products.asminternational.org/hbk/index.jsp

TABLE 4 - CARBON STEEL CAST OR HEAT CHEMICAL LIMITS AND RANGES

Applicable only to semi-finished products for forging, hot-rolled and cold-finished bars, wire rods, and seamless tubing

Element	**Maximum of specified element, %**		**Range, %**
Carbon (a)		To 0.12	-
		Over 0.12 to 0.25 incl.	0.05
		Over 0.25 to 0.40 incl.	0.06
		Over 0.40 to 0.55 incl.	0.07
		Over 0.55 to 0.80 incl.	0.10
		Over 0.80	0.13
Manganese		To 0.40	0.15
		Over 0.40 to 0.50 incl.	0.20
		Over 0.50 to 1.65 incl.	0.30
Phosphorus		Over 0.040-0.08 incl.	0.03
		Over 0.08 to 0.13 incl.	0.05
Sulfur		Over 0.050 to 0.09 incl.	0.03
		Over 0.09 to 0.15 incl.	0.05
		Over 0.15 to 0.23 incl.	0.07
		Over 0.23 to 0.35 incl.	0.09
Silicon(for bars) (b) (c)		To 0.15	0.08
		Over 0.15 to 0.20 incl.	0.10
		Over 0.20 to 0.30 incl.	0.15
		Over 0.30 to 0.60 incl.	0.20
Copper When copper is required; 0.20% minimum is generally used.			
Lead (d) When lead is required; a range of 0.15 to 0.35 is generally used.			

Note: Boron-treated fine grain steels are produced to a range of 0.005-0.003% B. Incl, inclusive.
(a) The carbon ranges shown customarily apply when the specified maximum limit for manganese does not exceed 1.10%. When the maximum manganese limit exceeds 1.10%, it is customary to add 0.01 to the carbon range shown.
(b) It is not a common practice to produce a re-phosphorized and re-sulferized carbon steel to specified limits for silicon because of its adverse effect on machinablility.
(c)When silicon is required for rods the following ranges and limits are commonly used: 0.10 max; 0.07-0.15, 0.10-0.20, 0.15-0.35, 0.20-0.40, or 0.30-0.60. (d) Lead is reported only as a range of 0.15-0.35% because it is usually added to the mold or ladle stream as the steel is poured.

Source: ASM Handbook Vol. 1, page 141, table 1.
http://products.asminternational.org/hbk/index.jsp

TABLE 5 - CARBON STEEL CAST OR HEAT CHEMICAL LIMITS AND RANGES

Applicable only to structural shapes, plates, strip, sheets, and welded tubing.

Element	Maximum of specified element, %	Range %
Carbon (a)(b)	To 0.15 incl.	0.05
	Over 0.15 to 0.30 incl.	0.06
	Over 0.30 to 0.40 incl.	0.07
	Over 0.40 to 0.60 incl.	0.08
	Over 0.60 to 0.80 incl.	0.11
	Over 0.80 to 1.35 incl.	0.14
Manganese	To 0.50 incl.	0.20
	Over 0.050 to 1.15 incl.	0.30
	Over 1.15 to 1.65 incl.	0.35
Phosphorus	To 0.08 incl.	0.03
	Over 0.08 to 0.15 incl.	0.05
Sulfur	To 0.08 incl.	0.03
	Over 0.08 to 0.15 incl.	0.05
	Over 0.15 to 0.23 incl.	0.07
	Over 0.23 to 0.33	0.10
Silicon	To 0.15 incl.	0.08
	Over 0.15 to 0.30 incl.	0.15
	Over 0.30 to 0.60 incl.	0.30
Copper	When copper is required, 0.20% minimum is commonly specified.	

(a) The carbon ranges shown in the column headed Ranges apply when the specified maximum limit for manganese does not exceed 1.00%. When the maximum manganese limit exceeds 1.00%, add 0.01 to the carbon ranges shown in the table.

(b) 0.12 carbon maximum for structural shapes and plates

Source: ASM Handbook Vol. 1, page 141, table 2.
http://products.asminternational.org/hbk/index.jsp

TABLE 1A - LOW-ALLOY STEEL COMPOSITIONS APPLICABLE TO BILLETS, BLOOMS, SLABS, AND HOT-ROLLED AND COLD-FINISHED BARS

Slightly wider ranges of compositions apply to plates

		Ladle Chemical Composition Limits, %									
UNS #	SAE #										*Corresponding*
		C	Mn	P	S	Si	Ni	Cr	Mo	V	AISI #
G13300	1330	0.28-0.33	1.60-1.90	0.035	0.040	0.15-0.35	-	-	-	-	1330
G13350	1335	0.33-0.38	1.60-1.90	0.035	0.040	0.15-0.35	-	-	-	-	1335
G13400	1340	0.38-0.43	1.60-1.90	0.035	0.040	0.15-0.35	-	-	-	-	1340
G13450	1345	0.43-0.48	1.60-1.90	0.035	0.040	0.15-0.35	-	-	-	-	1345
G40230	4023	0.20-0.25	0.70-0.90	0.035	0.040	0.15-0.35	-	-	-	-	4023
G40240	4024	0.20-0.25	0.70-0.90	0.035	0.035-0.050	0.15-0.35	-	-	0.20-0.30	-	4024
G40270	4027	0.25-0.30	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.20-0.30	-	4027
G40280	4028	0.25-0.30	0.70-0.90	0.035	0.035-0.050	0.15-0.35	-	-	0.20-0.30	-	4028
G40320	4032	0.30-0.35	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.20-0.30	-	-
G40370	4037	0.35-0.40	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.20-0.30	-	4037
G40420	4042	0.40-0.45	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.20-0.30	-	-
G40470	4047	0.45-0.50	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.20-0.30	-	4047
G41180	4118	0.18-0.23	0.70-0.90	0.035	0.040	0.15-0.35	-	0.40-0.60	0.08-0.15	-	4118
G41300	4130	0.28-0.33	0.40-0.60	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4130
G41350	4135	0.33-0.38	0.70-0.90	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	-
G41370	4137	0.35-0.40	0.70-0.90	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4137
G41400	4140	0.38-0.43	0.75-1.00	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4140
G41420	4142	0.40-0.45	0.75-1.00	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4142
G41450	4145	0.41-0.48	0.75-1.00	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4145
G41470	4147	0.45-0.50	0.75-1.00	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4147
G41500	4150	0.48-0.53	0.75-1.00	0.035	0.040	0.15-0.35	-	0.80-1.10	0.15-0.25	-	4150
G41610	4161	0.56-0.64	0.75-1.00	0.035	0.040	0.15-0.35	-	0.70-0.90	0.25-0.35	-	4161
G43200	4320	0.17-0.22	0.45-0.65	0.035	0.040	0.15-0.35	1.65-2.00	0.40-0.60	0.20-0.30	-	4320
G43400	4340	0.38-0.43	0.60-0.80	0.035	0.040	0.15-0.35	1.65-2.00	0.70-0.90	0.20-0.30	-	4340
G43406	E4340b	0.38-0.43	0.65-0.85	0.025	0.025	0.15-0.35	1.65-2.00	0.70-0.90	0.20-0.30	-	E4340
G44220	4422	0.20-0.25	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.35-0.45	-	-
G44270	4427	0.24-0.29	0.70-0.90	0.035	0.040	0.15-0.35	-	-	0.35-0.45	-	-
G46150	4615	0.13-0.18	0.45-0.65	0.035	0.040	0.15-0.25	1.65-2.00	-	0.20-0.30	-	4615
G46170	4617	0.15-0.20	0.45-0.65	0.035	0.040	0.15-0.35	1.65-2.00	-	0.20-0.30	-	-
G46200	4620	0.17-0.22	0.45-0.65	0.035	0.040	0.15-0.35	1.65-2.00	-	0.20-0.30	-	4620
G46260	4626	0.24-0.29	0.45-0.65	0.035	0.04 max	0.15-0.35	0.70-1.00	-	0.15-0.25	-	-
G47180	4718	0.16-0.21	0.70-0.90	-	-	-	0.90-1.20	0.35-0.55	0.30-0.40	-	4718
G47200	4720	0.17-0.22	0.50-0.70	0.035	0.040	0.15-0.35	0.90-1.20	0.35-0.55	0.15-0.25	-	4720
G48150	4815	0.13-0.18	0.40-0.60	0.035	0.040	0.15-0.35	3.25-3.75	-	0.20-0.30	-	4815
G48170	4817	0.15-0.20	0.40-0.60	0.035	0.040	0.15-0.35	3.25-3.75	-	0.20-0.30	-	4817
G48200	4820	0.18-0.23	0.50-0.70	0.035	0.040	0.15-0.35	3.25-3.75	-	0.20-0.30	-	4820
G50401	50B40c	0.38-0.43	0.75-1.00	0.035	0.040	0.15-0.35	-	0.40-0.60	-	-	-
G50441	50B44c	0.43-0.48	0.75-1.00	0.035	0.040	0.15-0.35	-	0.40-0.60	-	-	50B44
G50460	5046	0.43-0.48	0.75-1.00	0.035	0.040	0.15-0.35	-	0.20-0.35	-	-	-
G50461	50B46c	0.44-0.49	0.75-1.00	0.035	0.040	0.15-0.35	-	0.20-0.35	-	-	50B46
G50501	50B50c	0.48-0.53	0.75-1.00	0.035	0.040	0.15-0.35	-	0.40-0.60	-	-	50B50
G50600	5060	0.56-0.64	0.75-1.00	0.035	0.040	0.15-0.35	-	0.40-0.60	-	-	-
G50601	50B60c	0.56-0.64	0.75-1.00	0.035	0.040	0.15-0.35	-	0.40-0.60	-	-	50B60
G51150	5115	0.13-0.18	0.70-0.90	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	-
G51170	5117	0.15-0.20	0.70-0.90	0.04	0.040	0.15-0.35	-	0.70.90	-	-	5117

G51200	5120	0.17-0.22	0.70-0.90	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	5120
G51300	5130	0.28-0.33	0.70-0.90	0.035	0.040	0.15-0.35	-	0.80-1.10	-	-	5130
G51320	5132	0.30-0.35	0.60-0.80	0.035	0.040	0.15-0.35	-	0.75-1.00	-	-	5132
G51350	5135	0.33-0.38	0.60-0.80	0.035	0.040	0.15-0.35	-	0.80-1.05	-	-	5135
G51400	5140	0.38-0.43	0.70-0.90	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	5140
G51470	5147	0.46-0.51	0.70-0.95	0.035	0.040	0.15-0.35	-	0.85-1.15	-	-	5147
G51500	5150	0.48-0.53	0.70-0.90	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	5150
G51550	5155	0.51-0.59	0.70-0.90	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	5155
G51600	5160	0.56-0.64	0.75-1.00	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	5160
G51601	51B60c	0.56-0.64	0.75-1.00	0.035	0.040	0.15-0.35	-	0.70-0.90	-	-	51B60
G50986	50100b	0.98-1.10	0.25-0.45	0.025	0.025	0.15-0.35	-	0.40-0.60	-	-	-
G51986	51100b	0.98-1.10	0.25-0.45	0.025	0.025	0.15-0.35	-	0.90-1.15	-	-	E51100
G52986	52100b	0.98-1.10	0.25-0.45	0.025	0.025	0.15-0.35	-	1.30-1.60	-	-	E52100
G61180	6118	0.16-0.21	0.50-0.70	0.035	0.040	0.15-0.35	-	0.50-0.70	-	0.10-0.15	6118
G61500	6150	0.48-0.53	0.70-0.90	0.035	0.040	0.15-0.35	-	0.80-1.10	-	0.15 min	6150
G81150	8115	0.13-0.18	0.70-0.90	0.035	0.040	0.15-0.35	0.20-0.40	0.30-0.50	0.08-0.15	-	8115
G81451	81B45c	0.43-0.48	0.75-1.00	0.035	0.040	0.15-0.35	0.20-0.40	0.35-0.55	0.08-0.15	-	81B45
G86150	8615	0.13-0.18	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8615
G86170	8617	0.15-0.20	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8617
G86200	8620	0.18-0.23	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8620
G86220	8622	0.20-0.25	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8622
G86250	8625	0.23-0.28	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8625
G86270	8627	0.25-0.30	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8627
G86300	8630	0.28-0.33	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8630
G86370	8637	0.35-0.40	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8637
G86400	8640	0.38-0.43	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8640
G86420	8642	0.40-0.45	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8642
G86450	8645	0.43-0.48	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8645
G86451	86B45c	0.43-0.48	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	-
G86500	8650	0.48-0.53	0.75-1.00	0.035	0.040	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	-
G86550	8655	0.51-0.59	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	8655
G86600	8660	0.56-0.64	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	-	-
G87200	8720	0.18-0.23	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.20-0.30	-	8720
G87400	8740	0.38-0.43	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.20-0.30	-	8740
G88220	8822	0.20-0.25	0.75-1.00	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.30-0.40	-	8822
G92540	9254	0.51-0.59	0.60-0.80	0.035	0.040	1.20-1.60	-	0.60-0.80	-	-	-
G92600	9260	0.56-0.64	0.75-1.00	0.035	0.040	1.80-2.20	-	-	-	-	9260
G93106	9310b	0.08-0.13	0.45-0.65	0.025	0.025	0.15-0.35	3.00-3.50	1.00-1.40	0.08-0.15	-	-
G94151	94B15c	0.13-0.18	0.75-1.00	0.035	0.040	0.15-0.35	0.30-0.60	0.30-0.50	0.08-0.15	-	-
G94171	94B17c	0.15-0.20	0.75-1.00	0.035	0.040	0.15-0.35	0.30-0.60	0.30-0.50	0.08-0.15	-	94B17
G94301	94B30c	0.28-0.33	0.75-1.00	0.035	0.040	0.15-0.35	0.30-0.60	0.30-0.50	0.08-0.15	-	94B30

(a) Small quantities of certain elements that are not specified or required may be found in alloy steels. These elements are to be considered as incidental and are acceptable to the following maximum amount: copper to 0.35%, nickel to 0.25%, chromium to 0.20%, and molybdenum to 0.06%.

(b) Electric furnace steel.

(c) Boron content is 0.0005-0.003%.

Source: ASM Handbook Vol. 1, page 152-153, table 19.
http://products.asminternational.org/hbk/index.jsp

TABLE 1B - COMPOSITION RANGES AND LIMITS FOR AISI-SAE STANDARD LOW-ALLOY STEEL PLATE APPLICABLE FOR STRUCTURAL APPLICATIONS

Boron or lead can be added to these compositions. Small quantities of certain elements not required may be found. These elements are to be considered incidental and are acceptable to the following maximum amounts: copper to 0.35% , nickel to 0.25% , chromium to 0.20%, and molybdenum to 0.06%.

Heat composition ranges and limits, % (a)							
SAE #	UNS Designation	C	Mn	Si (b)	Ni	Cr	Mo
1330	G13300	0.27-0.34	1.50-1.90	0.15-0.30	-	-	-
1335	G13350	0.32-0.39	1.50-1.90	0.15-0.30	-	-	-
1340	G13400	0.36-0.44	1.50-1.90	0.15-0.30	-	-	-
1345	G13450	0.41-0.49	1.50-1.90	0.15-0.30	-	-	-
4118	G41180	0.17-0.23	0.60-0.90	0.15-0.30	-	0.40-0.65	0.08-0.15
4130	G41300	0.27-0.34	0.35-0.60	0.15-0.30	-	0.80-1.15	0.15-0.25
4135	G41350	0.32-0.39	0.65-0.95	0.15-0.30	-	0.08-1.15	0.15-0.25
4137	G41370	0.33-0.40	0.65-0.95	0.15-0.30	-	0.80-1.15	0.15-0.25
4140	G41400	0.36-0.44	0.70-1.00	0.15-0.30	-	0.08-1.15	0.15-0.25
4142	G41420	0.38-0.46	0.70-1.00	0.15-0.30	-	0.80-1.15	0.15-0.25
4145	G41450	0.41-0.49	0.70-1.00	0.15-0.30	-	0.80-1.15	0.15-0.25
4340	G43400	0.36-0.44	0.55-0.80	0.15-0.30	1.65-2.00	0.60-0.90	0.20-0.30
E4340	G43406	0.37-0.44	0.60-0.85	0.15-0.30	1.65-2.00	0.65-0.90	0.20-0.30
4615	G46150	0.12-0.18	0.40-0.65	0.15-0.30	1.65-2.00	-	0.20-0.30
4617	G46170	0.15-0.21	0.40-0.65	0.15-0.30	1.65-2.00	-	0.20-0.30
4620	G46200	0.16-0.22	0.40-0.65	0.15-0.30	1.65-2.00	-	0.20-0.30
5160	G51600	0.54-0.65	0.70-1.00	0.15-0.30	-	0.60-0.90	-
6150	G61500	0.46-0.54	0.60-0.90	0.15-0.30	-	0.80-1.15	-
8615	G86150	0.12-0.18	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8617	G86170	0.15-0.21	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8620	G86200	0.17-0.23	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8622	G86220	0.19-0.25	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8625	G86250	0.22-0.29	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8627	G86270	0.24-0.31	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8630	G86300	0.27-0.34	0.60-0.90	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8637	G86370	0.33-0.40	0.70-1.00	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8640	G86400	0.36-0.44	0.70-1.00	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8655	G86550	0.49-0.60	0.70-1.00	0.15-0.30	0.40-0.70	0.35-0.60	0.15-0.25
8742	G87420	0.38-0.46	0.70-1.00	0.15-0.30	0.40-0.70	0.35-0.60	0.20-0.30

(a) Indicated ranges and limits apply to steels made by the open hearth or basic oxygen processes; maximum content for phosphorus is 0.035% and for sulfur 0.040%. For steels made by the electric furnace process, the ranges and limits are reduced as follows: C - 0.01%; Mn - 0.05%; Cr - 0.05% (<1.25%), 0.10% (>1.25%); maximum content for either phosphorus or sulfur is 0.025%.

(b) Other silicon ranges may be negotiated. Silicon is available in ranges of 0.10-0.20%, 0.20-0.30%, and 0.35% maximum (when carbon deoxidized) when so specified by the purchaser.

(c) Prefix "E" indicates that the steel is made by the electric furnace process.
(d) Contains 0.15% V minimum.

Source: ASM Handbook Vol. 1, page 227, table 3.
http://products.asminternational.org/hbk/index.jsp

CHEMICAL COMPOSITION LIMITS, %

Type	UNS Designation	C	Mn	Si	Cr	Ni	P	S	Other Elements
Austenitic types									
201	S20100	0.15	5.5-7.5	1.00	16.0-18.0	3.5-5.5	0.06	0.03	0.25 N
202	S20200	0.15	7.5-10.0	1.00	17.0-19.0	4.0-6.0	0.06	0.03	0.25 N
205	S20500	0.12-0.25	14.0-15.5	1.00	16.5-18.0	1.0-1.75	0.06	0.03	0.32-0.40 N
301	S30100	0.15	2.00	1.00	16.0-18.0	6.0-8.0	0.045	0.03	-
302	S30200	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	-
302B	S30215	0.15	2.00	2.0-3.0	17.0-19.0	8.0-10.0	0.045	0.03	-
303	S30300	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.15 min	0.6 Mo (b)
303Se	S30323	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.06	0.15 min Se
304	S30400	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	-
304H	S30409	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	-
304L	S30403	0.03	2.00	1.00	18.0-20.0	8.0-12.0	0.045	0.03	-
304LN	S30453	0.03	2.00	1.00	18.0-20.0	8.0-12.0	0.045	0.03	0.10-0.16 N
302Cu	S30430	0.08	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	3.0-4.0 Cu
304N	S30451	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
305	S30500	0.12	2.00	1.00	17.0-19.0	10.5-13.0	0.045	0.03	-
308	S30800	0.08	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	-
309	S30900	0.20	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	-
309S	S30908	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	-
310	S31000	0.25	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	-
310S	S31008	0.08	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	-
314	S31400	0.25	2.00	1.5-3.0	23.0-26.0	19.0-22.0	0.045	0.03	-
316	S31600	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316F	S31620	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.20	0.10 min	1.75-2.5 Mo
316H	S31609	0.04-0.10	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316L	S31603	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316LN	S31653	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.16 N
316N	S31651	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.16 N
317	S31700	0.08	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo

317L	S31703	0.03	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
321	S32100	0.08	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min Ti
321H	S32109	0.04-0.10	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min Ti
330	N08330	0.08	2.00	0.75-1.5	17.0-20.0	34.0-37.0	0.04	0.03	-
347	S34700	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min Nb
347H	S34709	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	8 x %C min - 1.0 max Nb
348	S34800	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Co; 10 x %C min Nb; 0.10 Ta
348H	S34809	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Co; 8 x %C min - 1.0 max Nb; 0.10 Ta
384	S38400	0.08	2.00	1.00	15.0-17.0	17.0-19.0	0.045	0.03	-
Ferritic types									
405	S40500	0.08	1.00	1.00	11.5-14.5	-	0.04	0.03	0.10-0.30 Al
409	S40900	0.08	1.00	1.00	10.5-11.75	0.50	0.045	0.045	6 x %C min - 0.75 max Ti
429	S42900	0.12	1.00	1.00	14.0-16.0	-	0.04	0.03	-
430	S43000	0.12	1.00	1.00	16.0-18.0	-	0.04	0.03	-
430F	S43020	0.12	1.25	1.00	16.0-18.0	-	0.06	0.15 min	0.6 Mo (b)
430FSe	S43023	0.12	1.25	1.00	16.0-18.0	-	0.06	0.06	0.15 min Se
434	S43400	0.12	1.00	1.00	16.0-18.0	-	0.04	0.03	0.75-1.25 Mo
436	S43600	0.12	1.00	1.00	16.0-18.0	-	0.04	0.03	0.75-1.25 Mo; 5 x %C min - 0.70 max Nb
439	S43035	0.07	1.00	1.00	17.0-19.0	0.50	0.04	0.03	0.15 Al; 12 x %C min - 1.10 Ti
442	S44200	0.20	1.00	1.00	18.0-23.0	-	0.04	0.03	-
444	S44400	0.025	1.00	1.00	17.5-19.5	1.00	0.04	0.03	1.75-2.50 Mo; 0.025 N ; 0.2+4 (%C+ %N) min - 0.8 max (Ti+Nb)
446	S44600	0.20	1.50	1.00	23.0-27.0	-	0.04	0.03	0.25 N
Duplex (ferritic-austenitic) type									
329	S32900	0.20	1.00	0.75	23.0-28.0	2.50-5.00	0.04	0.03	1.00-2.00 Mo
Martensitic types									
403	S40300	0.15	1.00	0.50	11.5-13.0	-	0.04	0.03	-
410	S41000	0.15	1.00	1.00	11.5-13.5	-	0.04	0.03	-
414	S41400	0.15	1.00	1.00	11.5-13.5	1.25-2.50	0.04	0.03	-
416	S41600	0.15	1.25	1.00	12.0-14.0	-	0.06	0.15 min	0.6 Mo (b)
416Se	S41623	0.15	1.25	1.00	12.0-14.0	-	0.06	0.06	0.15 min Se
420	S42000	0.15 min	1.00	1.00	12.0-14.0	-	0.04	0.03	-
420F	S42020	0.15 min	1.25	1.00	12.0-14.0	-	0.06	0.15 min	0.6 Mo (b)
422	S42200	0.20-0.25	1.00	0.75	11.5-13.5	0.5-1.0	0.04	0.03	0.75-1.25 Mo; 0.75-1.25 W; 0.15-0.3 V

431	S43100	0.20	1.00	1.00	15.0-17.0	1.25-2.50	0.04	0.03	-
440A	S44002	0.60-0.75	1.00	1.00	16.0-18.0	-	0.04	0.03	0.75 Mo
440B	S44003	0.75-0.95	1.00	1.00	16.0-18.0	-	0.04	0.03	0.75 Mo
440C	S44004	0.95-1.20	1.00	1.00	16.0-18.0	-	0.04	0.03	0.75 Mo
Precipitation-hardening types									
PH 13-8 Mo	S13800	0.05	0.20	0.10	12.25-13.25	7.5-8.5	0.01	0.008	2.0-2.5 Mo; 0.90-1.35 Al; 0.01 N
15-5 PH	S15500	0.07	1.00	1.00	14.0-15.5	3.5-5.5	0.04	0.03	2.5-4.5 Cu; 0.15-0.45 Nb
17-4 PH	S17400	0.07	1.00	1.00	15.5-17.5	3.0-5.0	0.04	0.03	3.0-5.0 Cu; 0.15-0.45 Nb
17-7 PH	S17700	0.09	1.00	1.00	16.0-18.0	6.5-7.75	0.04	0.04	0.75-1.5 Al

Single values are maximum values unless otherwise indicated.

Source: ASM Handbook Vol. 1, page 843, table 2.
http://products.asminternational.org/hbk/index.jsp

FUNCTIONS OF THE STEEL MAKING ELEMENTS IN QUANTITIES NORMALLY USED IN CONSTRUCTIONAL ALLOY STEELS

Element	*To Increase Hardenability	To Strengthen Ferrite	To Form Carbides	To Improve Creep Strength	Principal Functions
C	Strong to Moderate	Mild		Moderate to Mild	To control strength level
Mn	Moderate to Strong	Strong	Mild	Mild	Hardenability
P	Moderate	Strong	Nil	Moderate	Ferrite strengthening & to improve corrosion resistance
S	Slightly Negative	Nil	Nil	Nil	To improve machinability
Si	Moderate	Strong	Negative	Mild	As a deoxidizer or to reduce core losses in electrical sheets
Ni	Moderate	Moderate	Nil	Mild	Hardenability & to improve notch toughness at low temperatures
Cr	Strong	Mild	Strong	Mild	Hardenability & oxidation resistance
Mo	Strong	Moderate	Strong	Strong	Hardenability & to improve creep strength
W	Mild	Mild	Strong	Strong	To improve creep strength
V	Strong	Mild	Strong	Strong	To control grain size & improve creep strength
Ti	Strong	Strong	Strong	Moderate	To stabilize carbides
Co	Negative	Mild	Nil	Mild	To improve creep strength
Al	Mild	Moderate	Negative	Negative	As a deoxidizer, to control grain coarsening temperatures & for nitriding steels
Zr	Mild	Unknown	Strong	Unknown	To decrease strain aging
Cu	Moderate	Strong	Nil	Unknown	Corrosion resistance
B	Strong	Unknown	Unknown	Unknown	Hardenability
Cb	Strong	Unknown	Strong	Moderate	Not used extensively

* Assuming complete solution in Austenite.

Source: U.S.S. Carilloy Steels, published by United States Steel Corporation, 1948.

Chapter 2 -Aluminum Metallurgy

ALUMINUM 101

In high-purity form, aluminum is soft and ductile. Most commercial uses, however, require greater strength than pure aluminum affords. This is achieved in aluminum first by the addition of other elements to produce various alloys, which singly or in combination impart strength to the metal. Further strengthening is possible by means which classify the alloys roughly into two categories, non-heat-treatable and heat-treatable.

Non-heat-treatable Alloys- The initial strength of alloys in the group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat-treatable alloys are usually designated, therefore, in the 1000, 3000, 4000 or 5000 series. Since these alloys are work-hardenable, further strengthening is possible by various degrees of cold-working, denoted by the "H" series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated-temperature treatment called stabilizing to insure stability of properties.

Heat-treatable Alloys- The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc and silicon. Since these elements singly or in various combinations show increasing solid solubility in aluminum with increasing temperature, it is possible to subject them to thermal treatments which will impart pronounced strengthening.

The first step, called heat treatment or solution heat treatment, is an elevated temperature process designed to put the soluble element or elements in solid solution. This is followed by rapid quenching, usually in water, which momentarily "freezes" the structure and for a short time rendering the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at below freezing temperatures until they are ready to form them. At room or elevated temperatures the alloys are not stable after quenching, however, and precipitation of the constituents from the supersaturated solution begins. After a period of several days at room temperature, termed aging or room temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age-harden for long periods of time at room temperature.

By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening. By the proper combination of solution heat treatment, quenching, cold working and artificial aging, the highest strengths are obtained.

Clad Alloys- The heat-treatable alloys in which copper or zinc are major alloying constituents, are less resistant to corrosive attack than the majority of non-heat-treatable alloys. To increase the corrosion resistance of these alloys in sheet and plate form they are often clad with high-purity aluminum, a low magnesium-silicon alloy, or an alloy containing 1% zinc. The cladding, usually from 2 ½ to 5% of the total thickness on each side, not only protects the composite due to its own inherently excellent corrosion resistance, but also exerts a galvanic effect which further protects the core material.

Special composites may be obtained such as clad non-heat-treatable alloys for extra corrosion protection, for brazing purposes, or for special surface finishes. Some alloys in wire and tubular form are clad for similar reasons and on an experimental basis extrusions also have been clad.

1000 Series- Aluminum of 99% or higher purity has many applications, especially in the electrical and chemical fields. These alloys are characterized by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties and excellent workability. Moderate increases in strength may be obtained by strain-hardening. Iron and silicon are the major impurities.

2000 Series- Copper is the principal alloying element in this group. These alloys require solution heat-treatment to obtain optimum properties; in the heat treated condition mechanical properties are similar to, and sometimes exceed, those of mild steel. In some instances artificial aging is employed to further increase yield strength, with attendant loss in elongation; its effect on tensile (ultimate) strength is not as great. The alloys in the 2000 series do not have as good corrosion resistance as most other aluminum alloys and under certain conditions they may be subject to intergranular corrosion. Therefore, these alloys in the form of sheet are usually clad with a high purity alloy or a magnesium-silicon alloy of the 6000 series which provides galvanic protection to the core material and thus greatly increases resistance to corrosion. Alloy 2024 is perhaps the best known and most widely used aircraft alloy.

3000 Series- Manganese is the major alloying element of alloys in this group, which are generally non-heat-treatable. Because only a limited percentage of manganese, up to about 1.5%, can be effectively added to aluminum, it is used as a major element in only a few instances. One of these, however, is the popular 3003, which is widely used as a general-purpose alloy for moderate-strength applications requiring good workability.

4000 Series- Major alloying element of this group is silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons aluminum-silicon alloys are used in welding wire and as brazing alloys where lower melting point than that of the parent metal is required. Most alloys in this series are non-heat-treatable, but when used in welding heat-treatable alloys they will pick up some of the alloying constituents of the latter and so respond to heat treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark gray when anodic oxide finishes are applied, and hence are in demand for architectural applications.

5000 Series- Magnesium is one of the most effective and widely used alloying elements for aluminum. When it is used as the major alloying element or with manganese, the result is a moderate to high strength non-heat-treatable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8% magnesium being equal to 1.25% manganese, and it can be added in considerably higher quantities. Alloys in this series posses good welding characteristics and good resistance to corrosion in marine atmosphere. However, certain limitations should be placed on the amount of cold work and the safe operating temperatures permissible for the higher magnesium content alloys (over about 3 ½% for operating temperatures above about 150°F (66°C) to avoid susceptibility to stress corrosion.

6000 Series- Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicide, thus making them heat-treatable. Major alloy in this series is 6061, one of the most versatile of the heat-treatable alloys. Though less strong than most of the 2000 or 7000 alloys, the magnesium-silicon (or magnesium-silicide) alloys posses good formability and corrosion resistance, with medium strength. Alloys in the heat-treatable group may be formed in the T4 temper (solution heat-treated but not artificially aged) and then reach full T6 properties by artificial aging.

7000 Series- Zinc is the major alloying element in this group, and when coupled with a smaller percentage of magnesium results in heat-treatable alloys of very high strength. Usually other elements such as copper and chromium are also added in small quantities. Outstanding member of this group is 7075, which is among the highest strength alloys available and is used in air-frame structures and for highly stressed parts.

Source: The Aluminum Association, Aluminum Standards and Data 1974-75.
http://www.aluminum.org/

GUIDE TO RECOMMENDED USE OF SECO/WARWICK ATMOSPHERE GENERATORS

Metals to be Processed	Process	Time Cycle		Appearance		Temperature Range		Suggested
		Long[1]	Short	Bright	Clean	°F	°C	Atmosphere Generator
Low Carbon Steels	Anneal		X	*		1200-1350	(649-732)	Exogas[4, 7]
Medium & High Carbon Steels	Anneal (no Decarb)	X	X	*		12-00-1450	(649-788)	Endogas
Alloy Steels, Med. & High Carbon	Anneal (no Decarb)	X	X	*		1300-1600	(704-871)	Endogas
High Speed Tool Steels including Molybdenum High Steels	Anneal (no Decarb)	X	X	*		1400-1600	(760-871)	Endogas
Stainless Steels, Chromium & Nickel Chromium	Anneal	X	X	*		1800-2100	(982-1149)	Endogas
Copper	Anneal	X	X	*		400-1200	(204-649)	Exogas[5]
Various Brasses	Anneal	X	X		*	800-1350	(427-732)	Exogas[5] Ammogas
Copper-Nickel Alloys	Anneal	X	X	*		800-1400	(427-760)	Exogas[5]
Silicon-Copper Alloys	Anneal	X	X	*		1200-1400	(649-760)	Exogas[4, 7]
Aluminum Alloys	Anneal & Homogenize	X	X	*		700-1100	(371-593)	Exogas[4, 5, 7]
Low Carbon & Silicon Steels	Anneal		X		*1	1400-1500	(760-816)	Exogas[4,7]
Low Carbon & Silicon Steels	Blueing		X		*	850-950	(454-510)	Exogas[6, 7]
Low Carbon Steels	Copper Brazing		X	*		2050	(1121-)	Exogas[4, 7]
Med., High Carbon & Alloy Steels	Copper Brazing (no Decarb)		X	*		2050	(1121-)	Endogas
High Carbon, High	Copper Brazing		X	*		2050	(1121-)	Ammogas

Chromium Steels	(no Decarb)							
Stainless Steels	Copper Brazing		X	*		2050	(1121-)	Ammogas
Copper or Brass	Phosphorous Copper Brazing or Silver Soldering		X	*		1200-1600	(649-871)	Exogas[5]
Carbon & Alloy Steels	Hardening (no Decarb)		X		*	1400-2400	(760-1316)	Endogas
Med & High Carbon Steels	Hardening (no Decarb)		X	*		1400-1800	(760-982)	Endogas
Alloy Steels, Med & High Carbon	Hardening (no Decarb)		X	*		1400-1800	(760-982)	Endogas
High Speed Tool Steels including Molybdenum	Hardening (no Decarb)		X	*		1800-2400	(982-1316)	Endogas
All Classes of Ferrous Metals	Tempering or Drawing		X	*		400-1200	(204-649)	Exogas[4, 7]
Carburizing Steels	Gas Carburizing	X			*	1400-1800	(760-982)	Endogas[3]
Low Carbon Ferrous Metals	Reduction & Sintering		X	*		1800-2050	(982-1121)	Endogas
High Carbon & Alloy Ferrous Metals	Reduction & Sintering		X			1800-2050	(982-1121)	Endogas Ammogas
Non-Ferrous Metals	Reduction & Sintering		X			1400-1800	(760-982)	Endogas Ammogas
Low Carbon Steels	Normalizing	X	X			1600-1850	(871-1010)	Exogas[4, 7] Endogas
High Carbon & Alloy Steels	Normalizing (no Decarb)	X	X			1500-2000	(816-1093)	Endogas

(1) Time cycle is “long” if over two hours.

(2) Rich or lean gas atmosphere, depending on individual applications.

(3) Exothermic gas atmosphere may be used as a carrier.

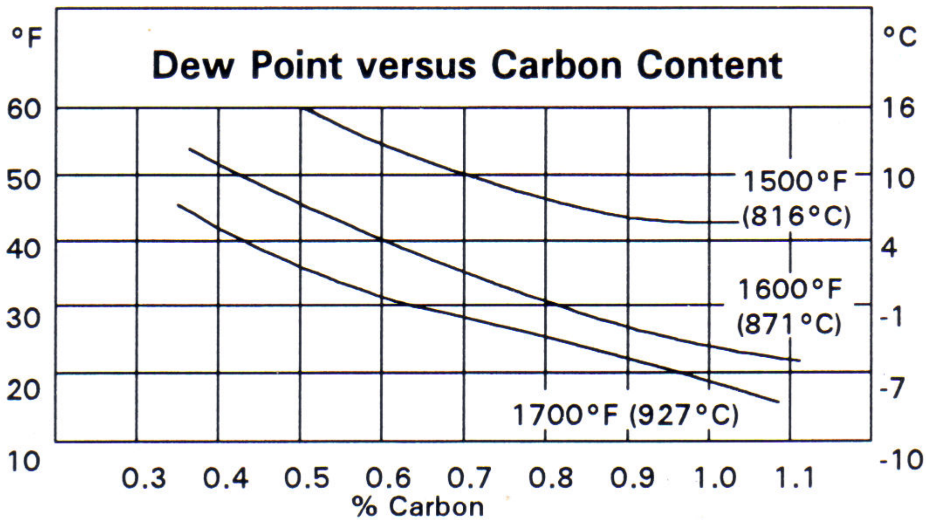
(4) Rich gas atmosphere.

(5) Lean gas atmosphere.

(6) Medium rich gas atmosphere.

(7) (+40°F) (4.4°C) Dewpoint gas atmosphere.

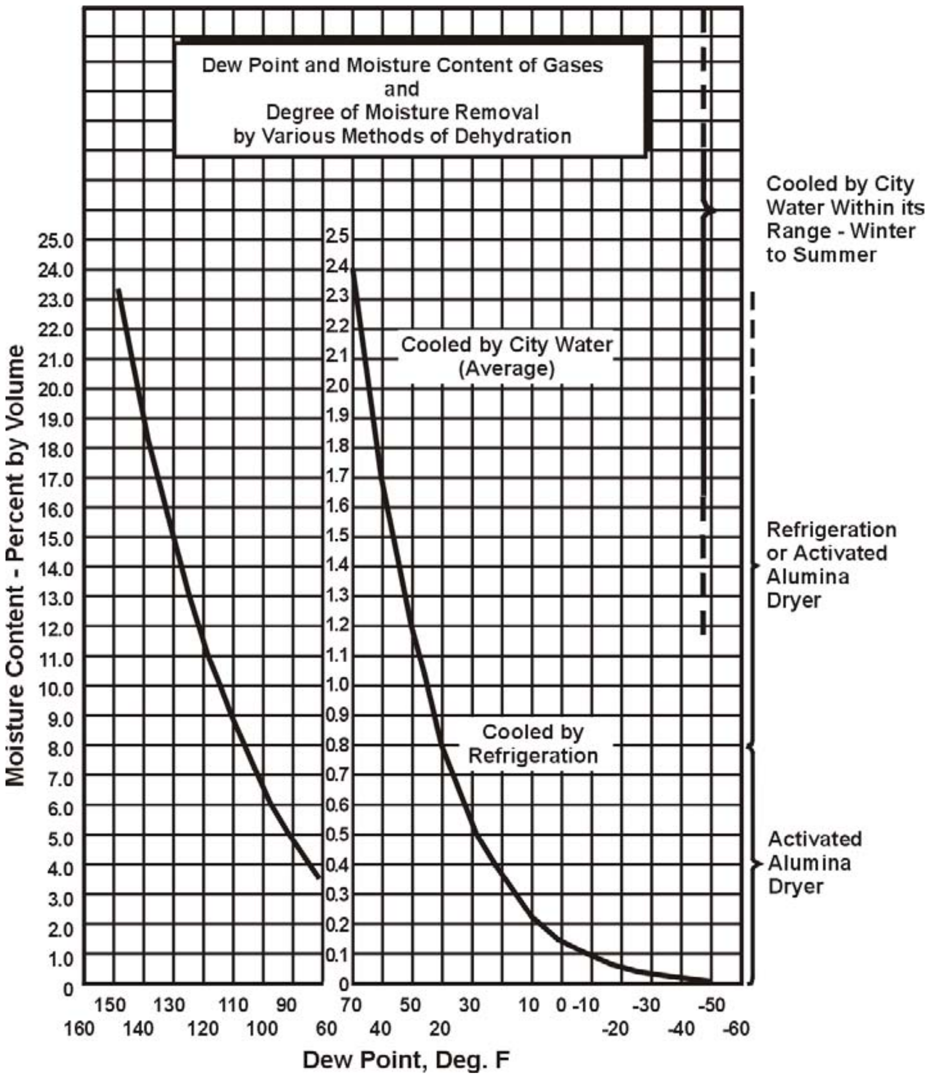
DEWPOINT VERSUS CARBON CONTENT



Typical relationship in neutral hardening application between carbon content of a steel and dew point of endothermic atmosphere at various temperatures.

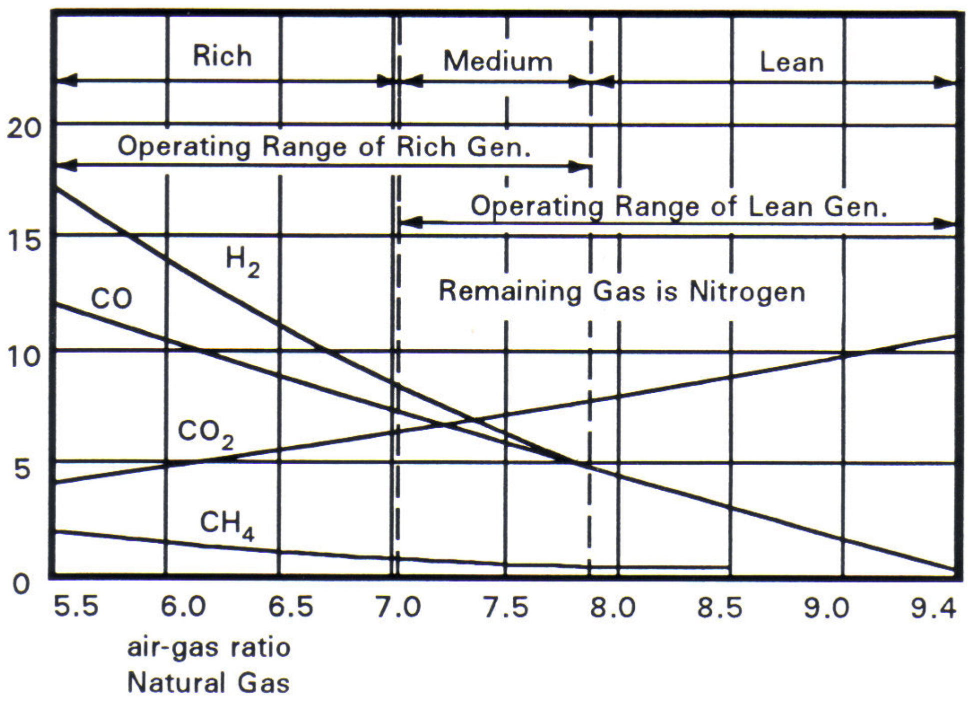
Link to more information on Endothermic Generators:
http://www.secowarwick.com/thermal/bulletins/EndothermicGenerator.pdf

DEWPOINT AND MOISTURE CONTENT OF GASES



Exothermic atmosphere from natural gas

(90% CH_4, C_2H_6, 5% N_2)



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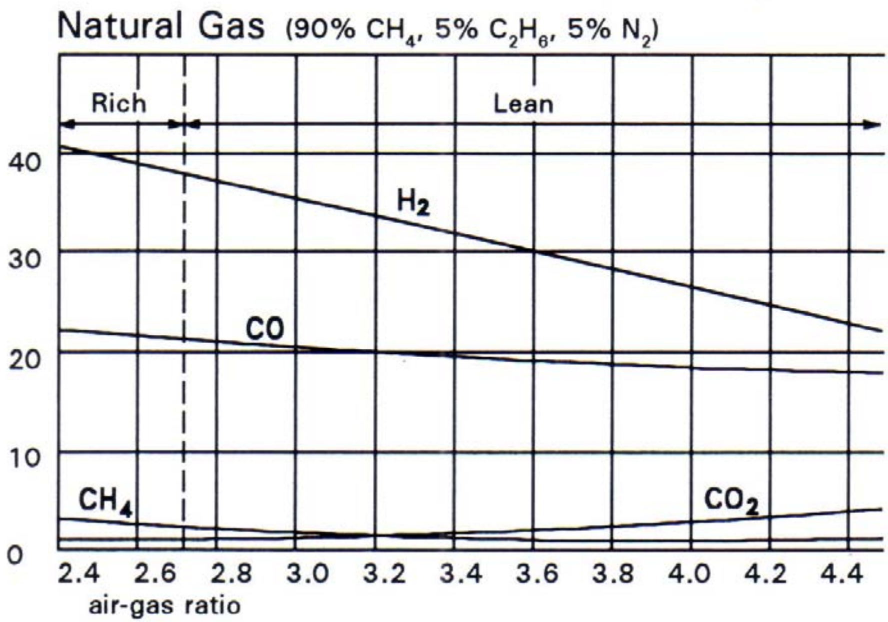

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http://www.secowarwick.com/thermal/bulletins/EndothermicGenerator.pdf

TABLE 1 - CASE HARDENING GRADES OF CARBON STEELS

SAE Steels[1]	Carbon Temp F	Cooling Method	Reheat Temp F	Cooling Medium	Carbonitriding Temp F[2]	Cooling Method	Temper, F[3]
1010	-	-	-	-	1450-1650	Oil	250-400
1015	-	-	-	-	1450-1650	Oil	250-400
1016	1650-1700	Water or Caustic	-	-	1450-1650	Oil	250-400
1018	1650-1700	Water or Caustic	1450	Water or Caustic[4]	1450-1650	Oil	250-400
1019	1650-1700	Water or Caustic	1450	Water or Caustic[4]	1450-1650	Oil	250-400
1020	1650-1700	Water or Caustic	1450	Water or Caustic[4]	1450-1650	Oil	250-400
1022	1650-1700	Water or Caustic	1450	Water or Caustic[4]	1450-1650	Oil	250-400
1026	1650-1700	Water or Caustic	1450	Water or Caustic[4]	1450-1650	Oil	250-400
1030	1650-1700	Water or Caustic	1450	Water or Caustic[4]	1450-1650	Oil	250-400
1109	1650-1700	Water or Oil	1400-1450	Water or Caustic[4]	-	-	250-400
1117	1650-1700	Water or Oil	1450-1600	Water or Caustic[4]	1450-1650	Oil	250-400
1118	1650-1700	Oil	1450-1600	Oil	-	-	250-400
1513	1650-1700	Oil	1450	Oil	-	-	250-400
1518	-	-	-	-	-	-	-
1522	1650-1700	Oil	1450	Oil	-	-	250-400
1524 (1024)	1650-1700	Oil	1450	Oil	-	-	250-400
1525	1650-1700	Oil	1450	Oil	-	-	250-400
1526	1650-1700	Oil	1450	Oil	-	-	250-400
1527 (1027)	1650-1700	Oil	1450	Oil	-	-	250-400

See notes on following page

(1) Generally, it is not necessary to normalize the carbon grades for fulfilling either dimensional or machinability requirements of parts made from the steel grades listed in the table, although where dimension is of vital importance normalizing temperatures of at least 50°F above the carburizing temperatures are sometimes required.
(2) The higher manganese steels such as 1118 and the 1500 series are not usually carbonitrided. If carbonitriding is performed, care must be taken to limit the nitrogen content because high nitrogen will increase their tendency to retain austenite.
(3) Even where recommended draw temperatures are shown, the draw is not mandatory on many applications. Tempering is generally employed for a partial stress relief and improves resistance to cracking from grinding operations. Higher temperatures than those shown may be employed where the hardness specification on the finished parts permits.
(4) 3% sodium hydroxide.

Link to S. A. E. International: http://www.sae.org/

TABLE 2 - HEAT TREATING GRADES OF CARBON STEELS

SAE	**Normalizing**	**Annealing**	**Hardening**	**Quenching**	**Temper**[1]
Steels	**Temp deg F**	**Temp deg F**	**Temp deg F**	**Medium**	
1030	-	-	1575-1600	Water or Caustic	To desired hardness
1035	-	-	1550-1600	Water or Caustic	To desired hardness
1037	-	-	1525-1575	Water or Caustic	To desired hardness
1038[2]	-	-	1525-1575	Water or Caustic	To desired hardness
1039[2]	-	-	1525-1575	Water or Caustic	To desired hardness
1040[2]	-	-	1525-1575	Water or Caustic	To desired hardness
1042	-	-	1500-1550	Water or Caustic	To desired hardness
1043[2]	-	-	1500-1550	Water or Caustic	To desired hardness
1045[2]	-	-	1500-1550	Water or Caustic	To desired hardness
1046[2]	-	-	1500-1550	Water or Caustic	To desired hardness
1050[2]	1600-1700	-	1500-1550	Water or Caustic	To desired hardness
1053	1600-1700	-	1500-1550	Water or Caustic	To desired hardness
1060	1600-1700	1400-1500	1575-1625	Oil	To desired hardness
1074	1550-1650	1400-1500	1575-1625	Oil	To desired hardness
1080	1550-1650	1400-1500[3]	1575-1625	Oil[4]	To desired hardness
1084	1550-1650	1400-1500[3]	1575-1625	Oil[4]	To desired hardness
1085	1550-1650	1400-1500[3]	1575-1625	Oil[4]	To desired hardness
1090	1550-1650	1400-1500[3]	1575-1625	Oil[4]	To desired hardness
1095	1550-1650	1400-1500[3]	1575-1625	Water or Oil	To desired hardness
1137	-	-	1550-1600	Oil	To desired hardness
1141	-	1400-1500	1500-1550	Oil	To desired hardness
1144	1600-1700	1400-1500	1500-1550	Oil	To desired hardness
1145	-	-	1475-1500	Water or Oil	To desired hardness
1146	-	-	1475-1500	Water or Oil	To desired hardness
1151	1600-1700	-	1475-1500	Water or Oil	To desired hardness
1536	1600-1700	-	1500-1550	Water or Oil	To desired hardness
1541	1600-1700	1400-1500	1500-1550	Water or Oil	To desired hardness

(1041)					
1548 (1048)	1600-1700	-	1500-1550	Oil	To desired hardness
1552 (1052)	1600-1700	-	1500-1550	Oil	To desired hardness
1566 (1066)	1600-1700	-	1575-1625	Oil	To desired hardness

(1) Even where recommended draw temperatures are shown, the draw is not mandatory on many applications. Tempering is generally employed for a partial stress relief and improves resistance to cracking from grinding operations. Higher temperatures than those shown may be employed where the hardness specification on the finished parts permits.
(2) Commonly used on parts where induction hardening is employed. However, all steels from SAE 1030 up may have induction hardening applications.
(3) Spheroidal structures are often required for machining purposes and should be cooled very slowly or be isothermally transformed to produce the desired structure.
(4) May be water or brine quenched by special techniques such as partial immersion or time quenched; otherwise they are subject to quench cracking.

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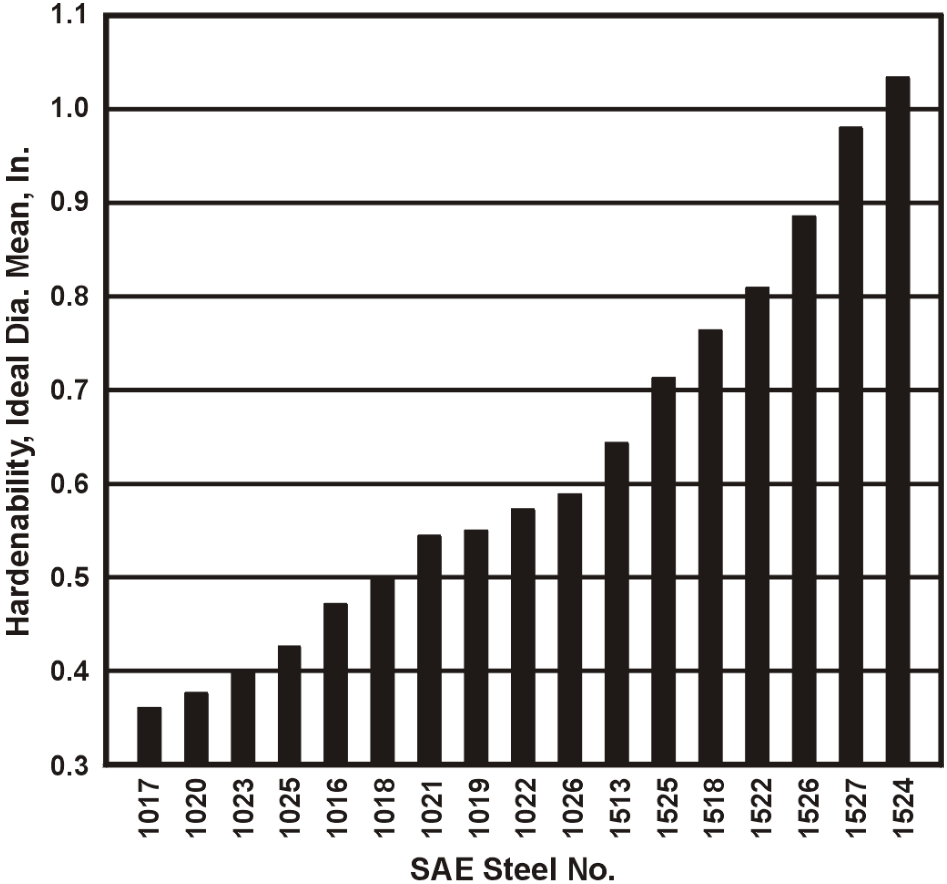
HARDENABILITY CHART



Basis of Calculation:
No. 7 Grain Size
Mean Carbon of Grade
Mean Manganese of Grade

Fig. 1 - Selection of Carbonizing Grades of Carbon Steel on Relative Hardenability Basis

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TABLE 3 - CARBURIZING GRADES OF ALLOY STEELS

SAE Steels[1]	Pretreatments			Carburizing Temp[5] F	Cooling Method	Reheat Temp F	Quenching Medium	Tempering[4] Temp deg F
	Normalize[2]	Normalize & Temper[3]	Cycle Anneal[4]					
4012	Yes	-	-	1650-1700				
4023	Yes	-	-	1650-1700				
4024	Yes	-	-	1650-1700				
4027	Yes	-	-	1650-1700	Quench in Oil[7]	-	-	250-350
4028	Yes	-	-	1650-1700				
4032	Yes	-	-	1650-1700				
4118	Yes	-	-	1650-1700	Quench in Oil[7]	-	-	250-350
4320	Yes	-	Yes	1650-1700	Quench in Oil[7]	-	-	
				1650-1700	Cool Slowly	1525-1550[9]	Oil	250-350
4419	Yes	-	Yes	1650-1700				
4422	Yes	-	Yes	1650-1700	Quench in Oil[7]	-	-	250-350
4427	Yes	-	Yes	1650-1700				
4615	Yes	-	Yes	1650-1700				
4617	Yes	-	Yes	1650-1700	Quench in Oil[7]	-	-	250-350
4620	Yes	-	Yes	1650-1700	Cool Slowly	1525-1550[9]	Oil	250-350
4621	Yes	-	Yes	1650-1700	Quench in Oil	1525-1550[8]	Oil	250-350
4626	Yes	-	Yes	1650-1700				
4718	Yes	-	Yes	1650-1700				
4720	Yes	-	Yes	1650-1700	Quench in Oil	1500-1550[8]	Oil	250-350
4815	-	Yes	Yes	1650-1700	Quench in Oil[7]	-	-	250-325
4817	-	Yes	Yes	1650-1700	Cool Slowly	1475-1525	Oil	250-325
4820	-	Yes	Yes	1650-1700	Quench in Oil	1475-1525	Oil	250-325
5015	Yes	-	Yes	1650-1700				
5115	Yes	-	Yes	1650-1700	Quench in Oil[7]	-	-	250-350
5120	Yes	-	Yes	1650-1700				
6118	Yes	-	-	1650	Quench in Oil[7]	-	-	325
8115	Yes	-	-	1650-1700				

8615	Yes	-	-	1650-1700				
8617	Yes	-	-	1650-1700				
8620	Yes	-	-	1650-1700	Quench in Oil[7]	-	-	250-350
8622	Yes	-	-	1650-1700	Cool Slowly	1500-1600[9]	Oil	250-350
8625	Yes	-	-	1650-1700	Quench in Oil	1500-1600[8]	Oil	250-350
8627	Yes	-	-	1650-1700				
8720	Yes	-	-	1650-1700				
8822	Yes	-	-	1650-1700				
9310	-	Yes	-	1600-1700	Quench in Oil	1450-1525[8]		
					Cool Slowly	1450-1525[9]	Oil	250-325
94B15	Yes	-	-	1650-1700	Quench in Oil[7]	-	-	250-350
94B17	Yes	-	-	1650-1700	Quench in Oil[7]	-	-	250-350

(1) These steels are fine grain. Heat treatments are not necessarily correct for coarse grain.
(2) Normalizing temperature should be at least as high as the carburizing temperature followed by air cooling.
(3) After normalizing, reheat to temperature of 1100-1200°F and hold at temperature approximately 1 hr. per in. of maximum section or 4 hr. minimum time.
(4) Where cycle annealing is desired, heat to at least as high as the carburizing temperature, hold for uniformity, cool rapidly to 1000-1250°F, hold 1 to 3 hrs, then air cool or furnace cool to obtain a structure suitable for machining and finish.
(5) It is general practice to reduce carburizing temperatures to approximately 1550°F before quenching to minimize distortion and retain austenite. For 4800 series steels, the carburizing temperature is reduced to approximately 1500°F before quenching.
(6) Tempering treatment is optional. Tempering is generally employed for partial stress relief and improved resistance to cracking for grinding operations. Temperatures higher than those shown are used in some instances where application requires.
(7) This treatment is most commonly used and generally produces a minimum of distortion.
(8) This treatment is used where the maximum grain refinement is required and/or where parts are subsequently ground on critical dimensions. A combination of good case and core properties is secured with somewhat greater distortion than is obtained by a single quench from the carburizing treatment.
(9) In this treatment the parts are slowly cooled, preferably under a protective atmosphere. They are then reheated and oil quenched. A tempering operation follows as required. This treatment is used when machining must be done between carburizing and hardening or when facilities for quenching form the carburizing cycle are not available. Distortion is least equal to that obtained by a single quench form the carburizing cycle, as described in note 5.

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TABLE 4 - DIRECTLY HARDENABLE GRADES OF ALLOY STEELS

SAE Steels[1]	**Normalizing**[2] **Temp F**	**Annealing**[4] **Temp F**	**Hardening**[5] **Temp F**	**Quenching Medium**	**Temper**
1330	1600-1700	1550-1650	1525-1575	Water or Oil	To desired hardness
1335	1600-1700	1550-1650	1500-1550	Oil	To desired hardness
1340	1600-1700	1550-1650	1500-1550	Oil	To desired hardness
1345	1600-1700	1550-1650	1500-1550	Oil	To desired hardness
4037	-	1500-1575	1525-1575	Oil	To desired hardness
4042	-	1500-1575	1525-1575	Oil	To desired hardness
4047	-	1450-1550	1500-1575	Oil	To desired hardness
4130	1600-1700	1450-1550	1500-1600	Water or Oil	To desired hardness
4135	-	1450-1550	1550-1600	Oil	To desired hardness
4137	-	1450-1550	1550-1600	Oil	To desired hardness
4140	-	1450-1550	1550-1600	Oil	To desired hardness
4142	-	1450-1550	1550-1600	Oil	To desired hardness
4145	-	1450-1550	1500-1550	Oil	To desired hardness
4147	-	1450-1550	1500-1550	Oil	To desired hardness
4150	-	1450-1550	1500-1550	Oil	To desired hardness
4161	-	1450-1550	1500-1550	Oil	To desired hardness, 700 F, min
4340	1600-1700	1450-1550	1500-1550	Oil	To desired hardness
50B40	1600-1700	1500-1600	1500-1550	Oil	To desired hardness
50B44	1600-1700	1500-1600	1500-1550	Oil	To desired hardness
5046	1600-1700	1500-1600	1500-1550	Oil	To desired hardness
50B46	1600-1700	1500-1600	1500-1550	Oil	To desired hardness
50B50	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
5060	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
50B60	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
5130	1600-1700	1450-1550	1525-1575	Water, Caustic Solution, or Oil	To desired hardness
5132	1600-1700	1450-1550	1525-1575	Water, Caustic Solution, or Oil	To desired hardness
5135	1600-1700	1500-1600	1500-1550	Oil	To desired hardness
5140	1600-1700	1500-1600	1500-1550	Oil	To desired hardness
5147	1600-1700	1500-1600	1475-1550	Oil	To desired hardness

5150	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
5155	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
5160	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
51B60	1600-1700	1500-1600	1475-1550	Oil	To desired hardness
50100	-	1350-1450	1425-1475	Water	To desired hardness
51100	-	1350-1450	1500-1600	Oil	To desired hardness
52100	-	1350-1450			To desired hardness
6150	-	1550-1650	1550-1625	Oil	To desired hardness
61B45	1600-1700	1550-1650	1500-1575	Oil	To desired hardness
8630	1600-1700	1450-1550	1525-1600	Water or Oil	To desired hardness
8637	-	1500-1600	1525-1575	Oil	To desired hardness
8640	-	1500-1600	1525-1575	Oil	To desired hardness
8642	-	1500-1600	1500-1575	Oil	To desired hardness
8645	-	1500-1600	1500-1575	Oil	To desired hardness
86B45	-	1500-1600	1500-1575	Oil	To desired hardness
8650	-	1500-1600	1500-1575	Oil	To desired hardness
8655	-	1500-1600	1475-1550	Oil	To desired hardness
8660	-	1500-1600	1475-1550	Oil	To desired hardness
8740	-	1500-1600	1525-1575	Oil	To desired hardness
9254	-	-	1500-1650	Oil	To desired hardness
9260	-	-	1500-1650	Oil	To desired hardness
94B30	1600-1700	1450-1550	1550-1625	Oil	To desired hardness

(1) These steels are fine grain unless otherwise specified.
(2) These steels should be either normalized or annealed for optimum machinability.
(3) Temper at 110-1225.
(4) The specific annealing cycle is dependent upon the alloy content of the steel, the type of subsequent machining operations and desired surface finish.
(5) Frequently, these steels, with the exception of 4340, 50100, 51100, and 52100, are hardened and tempered to a final machinable hardness without preliminary heat treatment.

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MEAN CARBON CONTENT OF SAE SPECIFICATION, %

Mean Carbon Content of SAE Specification, %	Common Applications
0.30-0.37	Heat treated parts requiring moderate strength and great toughness.
0.40-0.42	Heat treated parts requiring higher strength and good toughness.
0.45-0.50	Heat treated parts requiring fairly high hardness and strength with moderate toughness.
0.50-0.60	Springs and hand tools.
1.02	Ball and roller bearings.

TABLE 5 - GRADES OF CHROMIUM-NICKEL AUSTENITIC STEELS NOT HARDENABLE BY THERMAL TREATMENT

UNS Designation	AISI #	Treatment #	Normalizing Temp F	Annealing[1] Temp F	Hardening Temp F	Quenching Medium	Temper
S20100	201	1	-	1850-2050	-	Water or Air	-
S20200	202	1	-	1850-2050	-	Water or Air	-
S30100	301	1	-	1800-2100	-	Water or Air	-
S30200	302	1	-	1800-2100	-	Water or Air	-
S30300	303	1	-	1800-2100	-	Water or Air	-
S30400	304	1	-	1800-2100	-	Water or Air	-
S30500	305	1	-	1800-2100	-	Water or Air	-
S30900	309	1	-	1800-2100	-	Water or Air	-
S31000	310	1	-	1800-2100	-	Water or Air	-
S31600	316	1	-	1800-2100	-	Water or Air	-
S31700	317	1	-	1800-2100	-	Water or Air	-
S32100	321	1	-	1800-2100	-	Water or Air	-
N08330	330	1	-	2050-2250	-	Air	-
S34700	347	1	-	1800-2100		Water or Air	-

(1) Quench to produce full austenitic structure using water or air in accordance with thickness of section. Annealing temperatures given cover process and full annealing as already established and used by industry, the lower end of the range being used for process annealing.

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TABLE 6 - STAINLESS CHROMIUM STEELS

SAE Steels	AISI	Treatment	Normal-izing	Subcritical Annealing	Full Annealing[1]	Hardening	Quenching	
	#	#	Temp F	Temp F	Temp F	Temp F	Medium	Temper
S40900	409	1	-	-	1550-1650	-	Air	-
S41000	410	1	-	1300-1350[2]	1550-1650	-	Oil or Air	To desired hardness
		2	-	-	-	1750-1850		
S41400	414	1	-	1200-1250[2]	-	-	Oil or Air	To desired hardness
		2	-	-	-	1750-1850		
S41600	416	1	-	1300-1350[2]	1550-1650	-	Oil or Air	To desired hardness
		2	-	-	-	1750-1850		
S42000	420	1	-	1350-1450[2]	1550-1650	-	Oil or Air	To desired hardness
		2	-	-	-	1800-1850		
S42020	420F	1	-	1350-1450[2]	1550-1650	-	Oil or Air	To desired hardness
		2	-	-	-	1800-1850		
S43000	430	1	-	1400-1500[4]	-	-	-	-
S43020	430F	1	-	1250-1500[4]	-	-	-	-
S43100	431	1	-	1150-1225[2]	-	1800-1900	Oil or Air	To desired hardness
S43400	434							
S43600	436	1	-	1400-1500[4]	-	-	-	-
S44002	440A							
S44003	440B							
S44004	440C[3]		-	1350-1440[2]	1550-1650	1850-1950	Oil or Air	To desired hardness
S44200	442	1	-	1440-1500[4]	-	-	-	-
S44600	446	1	-	1500-1650[2]	-	-	-	-
51501	501		-	1325-1375[4]	1525-1600	1600-1700	Oil or Air	To desired hardness

(1) Cool slowly in furnace.
(2) Usually air-cooled but may be furnace cooled.
(3) Suffixes A, B, and C denote three types of steel differing only in carbon content. Suffix F denotes a free machining steel
(4) Cool rapidly in air.
Link to S. A. E. International: http://www.sae.org/

TABLE 7 - WROUGHT STAINLESS STEELS OF SPECIAL MACHINABILITY

Proprietary Designation	Treatment #	Subcritical Annealing Temp F	Full Annealing Temp F	Hardening Temp F	Quenching Medium	Temper
203-EZ	1	-	1850-2050[1]	-	Water or Air	-
303 Ma	1	-	1850-2050[1]	-	Water or Air	-
303 Pb	1	-	1850-2050[1]	-	Water or Air	-
303 Cu	1	-	1850-2050[1]	-	Water or Air	-
303 Plus X	1	1300-1350[2]	1550-1650[3]	-	-	-
416 Plus X	11	-	-	1750-1850	Oil or Air	To desired hardness

(1) Quench to produce full austentic structure using water or air in accordance with thickness of section. Annealing temperatures given cover process and full annealing as already established and used by industry, the lower end of the range being used for process annealing.

(2) Usually air-cooled but may be furnace-cooled.

(3) Cool slowly in furnace.

Link to S. A. E. International: http://www.sae.org/

Steel		Normalizing treatment temperature (a)		Annealing (b)				
				Temperature		Rate of cooling , max		Hardness
Type	°C		°F	°C	°F	°C /h	°F /h	HB
Molybdenum high-speed steels								
M1, M10		Do not normalize		815-970	1500-1600	22	40	207-235
M2		Do not normalize		870-900	1600-1650	22	40	212-241
M3, M4		Do not normalize		870-900	1600-1650	22	40	223-255
M6		Do not normalize		870	1600	22	40	248-277
M7		Do not normalize		815-870	1500-1600	22	40	217-255
M30, M33, M34, M36, M41, M42, M46, M47		Do not normalize		870-900	1600-1650	22	40	235-269
M43		Do not normalize		870-900	1600-1650	22	40	248-269
M44		Do not normalize		870-900	1600-1650	22	40	248-293
Tungsten high-speed steels								
T1		Do not normalize		870-900	1600-1650	22	40	217-255
T2		Do not normalize		870-900	1600-1650	22	40	223-255
T4		Do not normalize		870-900	1600-1650	22	40	229-269
T5		Do not normalize		870-900	1600-1650	22	40	235-277
T6		Do not normalize		870-900	1600-1650	22	40	248-293
T8		Do not normalize		870-900	1600-1650	22	40	229-255
T15		Do not normalize		870-900	1600-1650	22	40	241-277
Chromium hot work steels								
H10, H11, H12, H13		Do not normalize		845-900	1550-1650	22	40	192-229
H14		Do not normalize		870-900	1600-1650	22	40	207-235
H19		Do not normalize		870-900	1600-1650	22	40	207-241
Tungsten hot work steels								
H21, H22, H25		Do not normalize		870-900	1600-1650	22	40	207-235
H23		Do not normalize		870-900	1600-1650	22	40	212-255
H24, H26		Do not normalize		870-900	1600-1650	22	40	217-241
Molybdenum hot work steels								
H41, H43		Do not normalize		815-870	1500-1600	22	40	207-235
H42		Do not normalize		845-900	1550-1650	22	40	207-235
High-carbon high chromium cold work steels								
D2, D3, D4		Do not normalize		870-900	1600-1650	22	40	217-255
D5		Do not normalize		870-900	1600-1650	22	40	223-255
D7		Do not normalize		870-900	1600-1650	22	40	235-262
Medium-alloy air-hardening cold work steels								
A2		Do not normalize		845-870	1550-1600	22	40	201-229
A3		Do not normalize		845-870	1550-1600	22	40	207-229
A4		Do not normalize		740-760	1360-1400	14	25	200-241
A6		Do not normalize		730-745	1350-1375	14	25	217-248
A7		Do not normalize		870-900	1600-1650	14	25	235-262

A8		Do not normalize		845-870	1550-1600	22	40	192-223
A9		Do not normalize		845-870	1550-1600	14	25	212-248
A10	790		1450	765-795	1410-1460	8	15	235-269
Oil-hardening cold work steels								
O1	870		1600	760-790	1400-1450	22	40	183-212
O2	845		1550	745-775	1375-1425	22	40	183-212
O6	870		1600	765-790	1410-1450	11	20	183-217
O7	900		1650	790-815	1450-1500	22	40	192-217
Shock-resisting steels								
S1		Do not normalize		790-815	1450-1500	22	40	183-229(c)
S2		Do not normalize		760-790	1400-1450	22	40	192-217
S5		Do not normalize		775-800	1425-1475	14	25	192-229
S7		Do not normalize		815-845	1500-1550	14	25	187-223
Mold steels								
P2		Not required		730	1350-1500	22	40	103-123
P3		Not required		815	1350-1500	22	40	109-137
P4		Do not normalize		870-900	1600-1650	14	25	116-128
P5		Not required		845-870	1550-1600	22	40	105-116
P6		Not required		845	1550	8	15	183-217
P20	900		1650	760-790	1400-1450	22	40	149-179
P21	900		1650	Do not anneal				
Low-alloy special-purpose steels								
L2	870-900		1600-1650	760-790	1400-1450	22	40	163-197
L3	900		1650	790-815	1450-1500	22	40	174-201
L6	870		1600	760-790	1400-1450	22	40	183-212
Carbon-tungsten special-purpose steels								
F1	900		1650	760-800	1400-1475	22	40	183-207
F2	900		1650	790-815	1450-1500	22	40	207-235
Water-hardening steels								
W1, W2	790-925(d)		1450-1700(d)	740-790(e)	1360-1450(e)	22	40	156-201
W5	870-925		1600-1700	760-790	1400-1450	22	40	163-201

(a) Time held at temperature varies from 15 min for small sections to 1 h for large sizes. Cooling is done in still air. Normalizing should not be confused with low-temperature annealing.
(b) The upper limit of ranges should be used for large sections and the lower limit for smaller sections. Time held at temperature varies from 1 h for light sections to 4 h for heavy sections and large furnace charges of high alloy steel.
(c) For 0.25 Si type 183 to 207 HB; for 1.00 Si type, 207 to 229 HB.
(d) Temperature varies with carbon content: 0.60 to 0.75°C, 815°C (1500°F); 0.75 to 0.90 °C, 790°C (1450°F); 0.90 to 1.10°C, 870°C (1600°F); 1.10 to 1.40 °C, 870 to 925°F (1600 to 1700°F).
(e) Temperature varies with carbon content: 0.60 to 0.90 °C, 740 to 790°C (1360 to 1450°F); 0.90 to 1.40 °C, 760 to 790°C (1400 to 1450°F).

Source: ASM Handbook Vol. 4, page 715, table 2. http://products.asminternational.org/hbk/index.jsp

		Hardening							
		Preheat temperature		Hardening temperature		Time at Quenching		Tempering temperature	
Type	**Rate of heating**	**°C**	**°F**	**°C**	**°F**	**temp, min**	**medium (a)**	**°C**	**°F**
Molybdenum high-speed steels									
M1,M7, M10	Rapidly from preheat	730-845	1350-1550	1175-1220	2150-2225(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
M2	Rapidly from preheat	730-845	1350-1550	1190-1230	2175-2250(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
M3, M4, M30, M33, M34	Rapidly from preheat	730-845	1350-1550	1205-1230(b)	2200-2250(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
M6	Rapidly from preheat	790	1450	1175-1205(b)	2150-2200(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
M36	Rapidly from preheat	730-845	1350-1550	1200-1245(b)	2225-2275(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
M41	Rapidly from preheat	730-845	1350-1550	1190-1215(b)	2175-2220(b)	2-5	O, A or S	540-595(c)	1000-1100(d)
M42	Rapidly from preheat	730-845	1350-1550	1190-1210(b)	2175-2210(b)	2-5	O, A or S	510-595(d)	950-1100(d)
M43	Rapidly from preheat	730-845	1350-1550	1190-1215(b)	2175-2220(b)	2-5	O, A or S	510-595(d)	950-1100(d)
M44	Rapidly from preheat	730-845	1350-1550	1200-1225(b)	2190-2240(b)	2-5	O, A or S	540-625(d)	1000-1160(d)
M46	Rapidly from preheat	730-845	1350-1550	1190-1220(b)	2175-2225(b)	2-5	O, A or S	525-565(d)	975-1050(d)
M47	Rapidly from preheat	730-845	1350-1550	1180-1205(b)	2150-2200(b)	2-5	O, A or S	525-595(d)	975-1100(d)
Tungsten high-speed steels									
T1, T2, T4,T8	Rapidly from preheat	815-870	1500-1600	1260-1300(b)	2300-2375(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
T5, T6	Rapidly from preheat	815-870	1500-1600	1275-1300(b)	2325-2375(b)	2-5	O, A or S	540-595(c)	1000-1100(c)
T15	Rapidly from preheat	815-870	1500-1600	1205-1260(b)	2200-2300(b)	2-5	O, A or S	540-650(d)	1000-1200(d)
Chromium hot-work steels									
H10	Moderately from preheat	815	1500	1010-1040	1850-1900	15-40(e)	A	540-650	1000-1200
H11, H12	Moderately from preheat	815	1500	995-1025	1825-1875	15-40(e)	A	540-650	1000-1200
H13	Moderately from preheat	815	1500	995-1040	1825-1900	15-40(e)	A	540-650	1000-1200
H14	Moderately from preheat	815	1500	1010-1065	1850-1950	15-40(e)	A	540-650	1000-1200
H19	Moderately from preheat	815	1500	1095-1205	2000-2200	2-5	A or O	540-705	1000-1300

Molybdenum hot work steels									
H41, H43	Rapidly from preheat	730-845	1350-1550	1095-1190	2000-2175	2-5	O, A or S	565-650	1050-1200
H42	Rapidly from preheat	730-845	1350-1550	1120-1220	2050-2225	2-5	O, A or S	565-650	1050-1200
Tungsten hot work steels									
H21, H22	Rapidly from preheat	815	1500	1095-1205	2000-2200	2-5	A or O	595-675	1100-1250
H23	Rapidly from preheat	845	1550	1205-1260	2200-2300	2-5	O, A or S	650-815	1200-1500
H24	Rapidly from preheat	815	1500	1095-1230	2000-2250	2-5	O, A or S	565-650	1050-1200
H25	Rapidly from preheat	815	1500	1150-1260	2100-2300	2-5	A or O	565-675	1050-1250
H26	Rapidly from preheat	870	1600	1175-1260	2150-2300	2-5	O, A or S	565-675	1050-1250
Medium-alloy air-hardening cold work steels									
A2	Slowly	790	1450	925-980	1700-1800	20-45	A	175-540	350-1000
A3	Slowly	790	1450	955-980	1750-1800	25-60	A	175-540	350-1000
A4	Slowly	675	1250	815-870	1500-1600	20-45	A	175-425	350-800
A6	Slowly	650	1200	830-870	1525-1600	20-45	A	150-425	300-800
A7	Very slowly	815	1500	955-980	1750-1800	30-60	A	150-540	300-1000
A8	Slowly	790	1450	980-1010	1800-1850	20-45	A	175-595	350-1100
A9	Slowly	790	1450	980-1025	1800-1875	20-45	A	510-620	950-1150
A10	Slowly	650	1200	790-815	1450-1500	30-60	A	175-425	350-800
Oil-hardening cold work steels									
O1	Slowly	650	1200	790-815	1450-1500	10-30	O	175-260	350-500
O2	Slowly	650	1200	760-800	1400-1475	5-20	O	175-260	350-500
O6	Slowly	-	-	790-815	1450-1500	10-30	O	175-315	350-600
O7	Slowly	650	1200	790-830	1450-1525	10-30	O or W	175-290	350-550
				845-885	1550-1625				
Shock-resisting steels									
S1	Slowly	-	-	900-955	1650-1750	15-45	O	205-650	400-1200
S2	Slowly	650(f)	1200(f)	845-900	1550-1650	5-20	B or W	175-425	350-800
S5	Slowly	760	1400	870-925	1600-1700	5-20	O	175-425	350-800

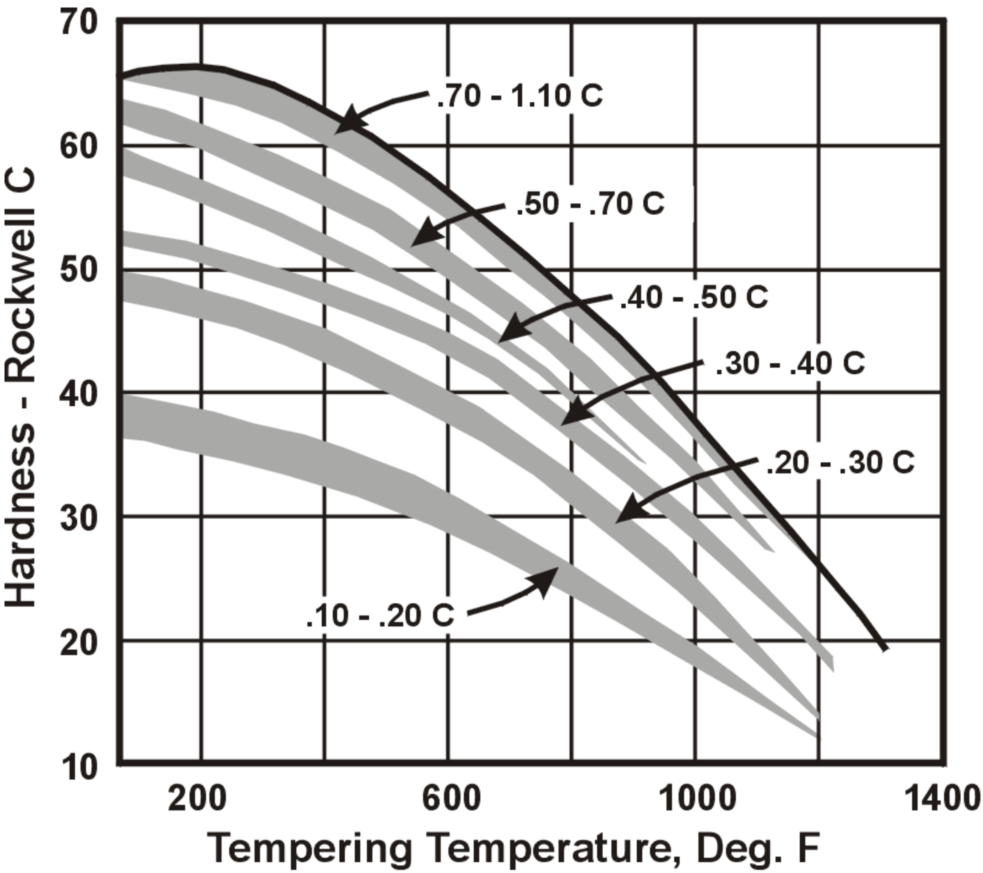
S7	Slowly	650-705	1200-1300	925-955	1700-1750	15-45	A or O	205-620	400-1150
Mold steels									
P2	-	900-925(g)	1650-1700(g)	830-845(h)	1525-1550(h)	15	O	175-260	350-500
P3	-	900-925(g)	1650-1700(g)	800-830(h)	1475-1525(h)	15	O	175-260	350-500
P4	-	900-925(g)	1775-1825(g)	970-995(h)	1775-1825(h)	15	A or O	175-480	350-900
P5	-	900-925(g)	1650-1700(g)	845-870(h)	1550-1600(h)	15	O or W	175-260	350-500
P6	-	900-925(g)	1650-1700(g)	790-815(h)	1450-1500(h)	15	A or O	175-230	350-450
P20	-	870-900(h)	1600-1650(h)	815-870	1500-1600	15	O	480-595(i)	900-1100(i)
P21(j)	Slowly	Do not preheat		705-730	1300-1350	60-180	A or O	510-550	950-1025
Low-alloy special-purpose steels									
L2	Slowly	-	-	W: 790-845	W: 1450-1550	10-30	O or W	175-540	350-1000
				O: 845-925	O: 1550-1700				
L3	Slowly	-	-	W: 775-815	W: 1425-1500	10-30	O or W	175-315	350-600
				O: 815-870	O: 1500-1600				
L6	Slowly	-	-	790-845	1450-1550	10-30	O	175-540	350-1000
Carbon-tungsten special-purpose steels									
F1, F2	Slowly	650	1200	790-870	1450-1600	15	W or B	175-260	350-500
Water-hardening steels									
W1, W2, W3	Slowly	565-650(k)	1050-1200(k)	760-815	1400-1550	10-30	B or W	175-345	350-650
High-carbon, high-chromium cold work steels									
D1, D5	Very Slowly	815	1500	980-1025	1800-1875	15-45	A	205-540	400-1000
D3	Very Slowly	815	1500	925-980	1700-1800	15-45	O	205-540	400-1000
D4	Very Slowly	815	1500	970-1010	1775-1850	15-45	A	205-540	400-1000
D7	Very Slowly	815	1500	1010-1065	1850-1950	30-60	A	150-540	300-1000

See notes next page

(a) O, oil quench; A, air cool; S, salt bath quench; W, water quench; B, brine quench.

(b) When the high-temperature heating is carried out in a salt bath, the range of temperatures should be about 15°C (25°F) lower than given in this line.
(c) Double tempering recommended for not less than 1 h at temperature each time.
(d) Triple tempering recommended for not less than 1 h at temperature each time.
(e) Times apply to open-furnace heat treatment. For pack hardening, a common rule is to heat 1.2 min/mm (30 min/in.) of cross section of the pack.
(f) Preferable for large tools to minimize decarburization.
(g) Carburizing temperature.
(h) After carburizing.
(i) Carburized case hardness.
(j) P21 is a precipitation-hardening steel having a thermal treatment that involves solution treating and aging rather than hardening and tempering.
(k) Recommended for large tools and tools with intricate sections.

Source: ASM Handbook Vol. 4, page 716-717, table 3.
http://products.asminternational.org/hbk/index.jsp



The effect of carbon content on the hardness of tempered carbon steel

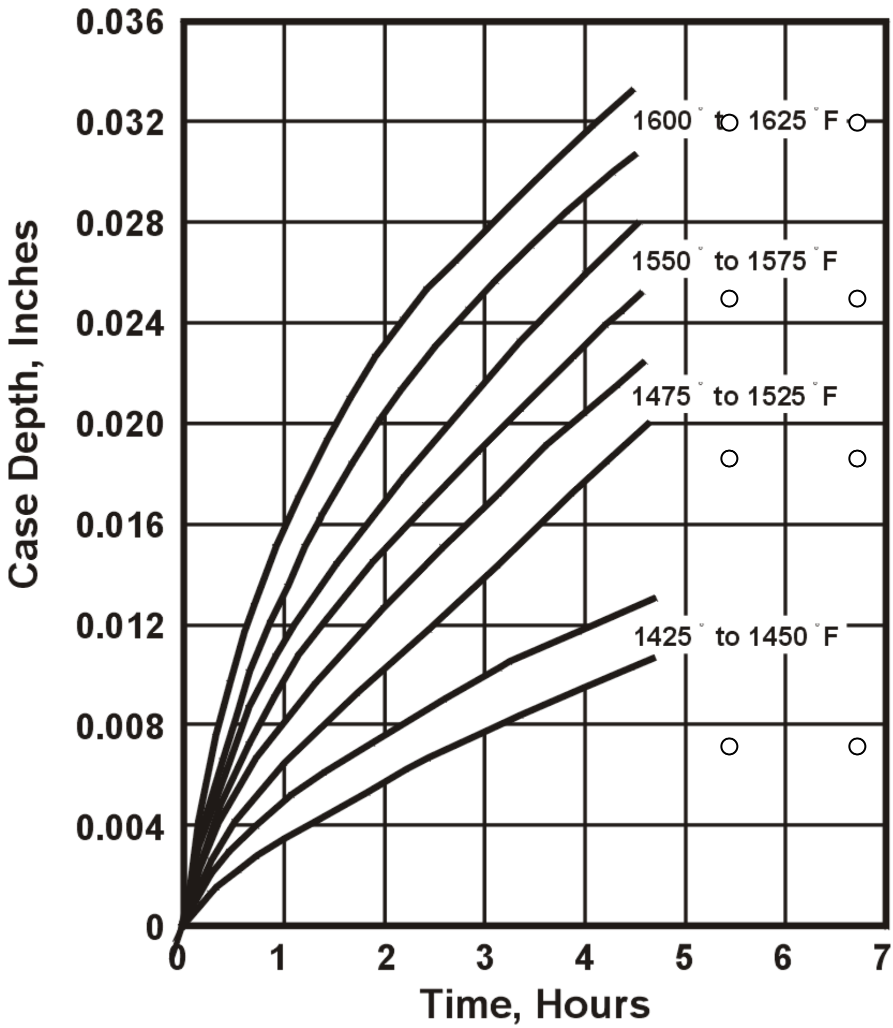
Reprinted from Metals Engineering Institute
“Heat Treatment of Steel,” 1957

CARBURIZING TIMES AND TEMPERATURES

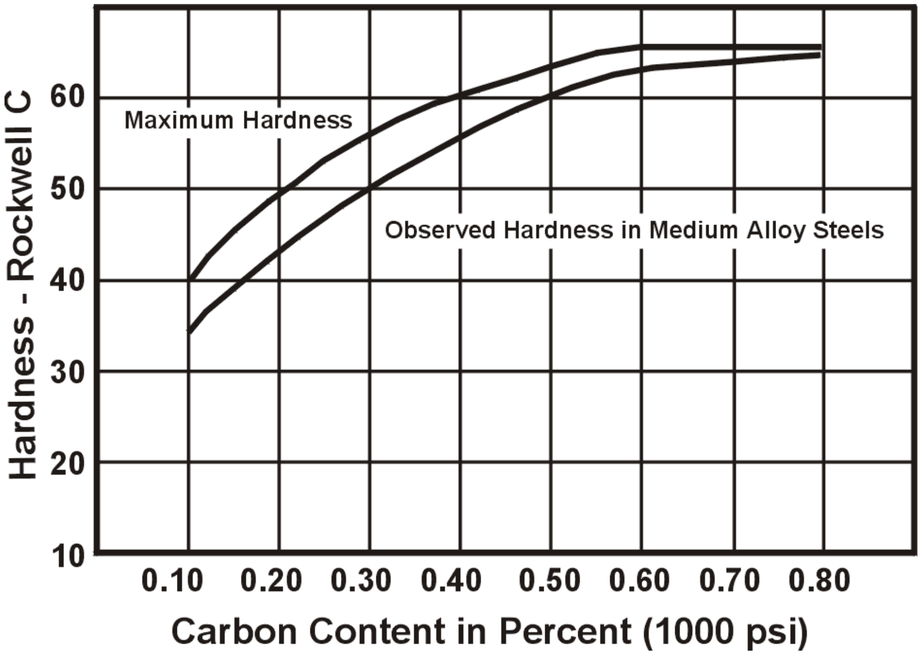
Time in Hours	Temperature, °F									
	1400	**1450**	**1500**	**1550**	**1600**	**1650**	**1700**	**1750**	**1800**	**1850**
1	0.008	0.010	0.012	0.015	0.018	0.021	0.025	0.029	0.034	0.040
2	0.011	0.014	0.017	0.021	0.025	0.030	0.035	0.041	0.048	0.056
3	0.014	0.017	0.021	0.025	0.031	0.037	0.043	0.051	0.059	0.069
4	0.016	0.020	0.024	0.029	0.035	0.042	0.050	0.059	0.069	0.079
5	0.018	0.022	0.027	0.033	0.040	0.047	0.056	0.066	0.077	0.089
6	0.019	0.024	0.030	0.036	0.043	0.052	0.061	0.072	0.084	0.097
7	0.021	0.026	0.032	0.039	0.047	0.056	0.066	0.078	0.091	0.105
8	0.022	0.028	0.034	0.041	0.050	0.060	0.071	0.083	0.097	0.112
9	0.024	0.029	0.036	0.044	0.053	0.063	0.075	0.088	0.103	0.119
10	0.025	0.031	0.038	0.046	0.056	0.067	0.079	0.093	0.108	0.126
11	0.026	0.033	0.040	0.048	0.059	0.070	0.083	0.097	0.113	0.132
12	0.027	0.034	0.042	0.051	0.061	0.073	0.087	0.102	0.119	0.138
13	0.028	0.035	0.043	0.053	0.064	0.076	0.090	0.106	0.123	0.143
14	0.029	0.037	0.045	0.055	0.066	0.079	0.094	0.110	0.128	0.149
15	0.031	0.039	0.047	0.057	0.068	0.082	0.097	0.114	0.133	0.154
16	0.032	0.039	0.048	0.059	0.071	0.084	0.100	0.117	0.137	0.159
17	0.033	0.040	0.050	0.060	0.073	0.087	0.103	0.121	0.141	0.164
18	0.033	0.042	0.051	0.062	0.075	0.090	0.106	0.125	0.145	0.169
19	0.034	0.043	0.053	0.064	0.077	0.092	0.109	0.128	0.149	0.173
20	0.035	0.044	0.054	0.066	0.079	0.094	0.112	0.131	0.153	0.178
21	0.036	0.045	0.055	0.067	0.081	0.097	0.114	0.134	0.157	0.182
22	0.037	0.046	0.056	0.069	0.083	0.099	0.117	0.138	0.161	0.186
23	0.038	0.047	0.058	0.070	0.085	0.101	0.120	0.141	0.164	0.190
24	0.039	0.048	0.059	0.072	0.086	0.103	0.122	0.144	0.168	0.195
25	0.039	0.049	0.060	0.073	0.088	0.106	0.125	0.147	0.171	0.199
26	0.040	0.050	0.061	0.075	0.090	0.108	0.127	0.150	0.175	0.203
27	0.041	0.051	0.063	0.076	0.092	0.110	0.130	0.153	0.178	0.206
28	0.042	0.052	0.064	0.078	0.094	0.112	0.132	0.155	0.181	0.210
29	0.042	0.053	0.065	0.079	0.095	0.114	0.134	0.158	0.185	0.214
30	0.043	0.054	0.066	0.080	0.097	0.116	0.137	0.161	0.188	0.217

For Example: 4320 carburized at 1700°F for 11 hours at temperature would attain "case depth" of 0.083 inches. If 0.100 inches were specified it would require 16 hours. Source: Metal Progress, August 1943.

CARBONITRIDING CHART



Courtesy Armour Ammonia Division
Armour and Company



The hardness of martensite (untempered) as a function of carbon content

Courtesy of The United States Steel Corporation

Chapter 5 - Vacuum Heat Treatment

INTRODUCTION

The development of commercial vacuum furnace equipment for industry began in the 1950's. Metallurgical processes such as annealing, hardening, sintering, tempering, brazing, and diffusion bonding can be carried out in vacuum. Vacuum may also be used to purge a chamber prior to introduction of a controlled atmosphere. As new applications for vacuum heat treating are discovered, the market for equipment continues to expand.

Any substance exposed to the atmosphere will adsorb and absorb molecules of air, microscopic dust, water, and chemical vapors and bacteria. Over time, this material will react chemically with the main body substance to produce oxides, nitrides, or complex organic coatings, which may be undesirable and are considered contaminants or impurities. Thermal processing in standard heat treating equipment under oxidizing or reducing atmosphere removes or changes these contaminants through chemical reaction. The reduction of oxides with hydrogen and resultant formation of water vapor is a good example.

A primary difference in this oxide reduction between vacuum heat treating and conventional heat treating (protective atmosphere) is the kind of reaction that takes place. Here, dissociation pressures of compounds govern instead of chemical reaction rates between elements and gas atmospheres. These concepts are no more difficult than the chemical reactions of prepared atmospheres, but they are perhaps a little less familiar. Many of the common oxides that are present break down spontaneously by dissociation in vacuum, at moderate temperatures without the use of a reducing agent.

This effect of vacuum processing can be compared to processing in an atmosphere furnace at a specific moisture content or dewpoint. Dewpoint versus vacuum level is not a true comparison of environment, but is useful for comparing processes, particularly those requiring dry hydrogen for bright annealing, hardening, and brazing of stainless steels. If a process requires -100°F dewpoint hydrogen, a vacuum level of 1×10^{-3} Torr may suffice to provide a bright surface. The cleaning ability and protection afforded by vacuum without the requirement of expensive or combustible process gases make it attractive.

Vacuum equipment is generally cool, clean, quiet, and efficient. Vacuum processing is flexible, adaptable, reliable, and economical, and environmentally friendly.

Degrees of Vacuum

Degrees of vacuum level are expressed opposite to the absolute pressure levels. Therefore, high vacuum means low pressure. In common usage, the levels shown in Table I correspond to the recommendation of the A.V.S. Standards Committee.

DEGREES OF VACUUM		
Rough or low vacuum		**Atmosphere -1 Torr**
Fine or medium vacuum	-	1 Torr - 10^{-3} Torr
High vacuum	-	10^{-3} Torr - 10^{-6} Torr
Very high vacuum	-	10^{-6} Torr - 10^{-9} Torr
Ultra high vacuum	-	10^{-9} Torr and below

GAS QUENCHING TECHNOLOGY

Advances in gas quenching technology and equipment have been made to address the growing number of parts and materials requiring vacuum heat treatment. Solution or austenizing treatments for tools steel, oil-hardening alloy steels and Ni - and - Co -base alloys have been traditionally processed in the molten salts and quench oils. These traditional processes in addition to potential cracking and distortion problems require post heat treatment cleaning. SECO/WARWICK has developed a family of high pressure quench furnaces that combine convection heating and high pressure quenching at pressures of up to 20 bar fill the gap of cooling between atmospheric gas quenching and oil quenching. There are three commercial varieties of gas quenching vacuum furnaces applicable, depending on the steel alloy and cross section of the process parts: 2 bar, 6 bar and 10/20 bar.

6, 10, and 20 Bar Furnace Applications

6 Bar N_2 - *Loosely packed load*

λ = 1.0 - 3.0 for appropriate cross sections in 1" (25 mm) – 4" (100 mm) range

- High speed steels (e.g. M2 [AISI] up to cross section 3" (70 mm) – 4" (100 mm)
- High alloy hot working tool steels (H11/H13 [AISI] etc.)
- High alloy cold working tool steels (1.2080 [DIN] to 80 mm/100 mm)

- Oil quenched alloy steels of small cross sections (e.g. 1.2842 [DIN] - cross sections to 25 mm/40 mm; 1.2550, according to DIN to 20 mm)
- Martensitic stainless steels of limited cross sections
- Solution heat treating of austentic steels type 18/8

10 Bar N_2 - *Densely packed load*

λ = 8.0 - 2.0 for appropriate cross sections in 1" (25 mm) – 4" (100 mm) range (load density 30/40% higher compared to 6 bar)

- High speed steels - no restrictions on cross section and density of loads
- High, medium, and low alloy hot work tool steels
- High and medium alloy structure steels of limited cross-sections (e.g. O1, O2, O6, O7, 4140, 4340 according to AISI and other steels for toughening: also after ion carburizing of 1.4140 [AISI] steel)

20 Bar He - He/N_2 - *Dense and tightly packed load*

λ = 0.4 - 1.0 for appropriate cross sections in 1" (25 mm) – 4" (100 mm) range (load density 80/150% higher than at 6 bar)

- High speed steels
- High, medium, and low alloy hot working tool steels
- High, medium, and low alloy cold working tool steels
- Oil quenched alloy steels for toughening, including quenching after ion carburizing and nitro-carburizing

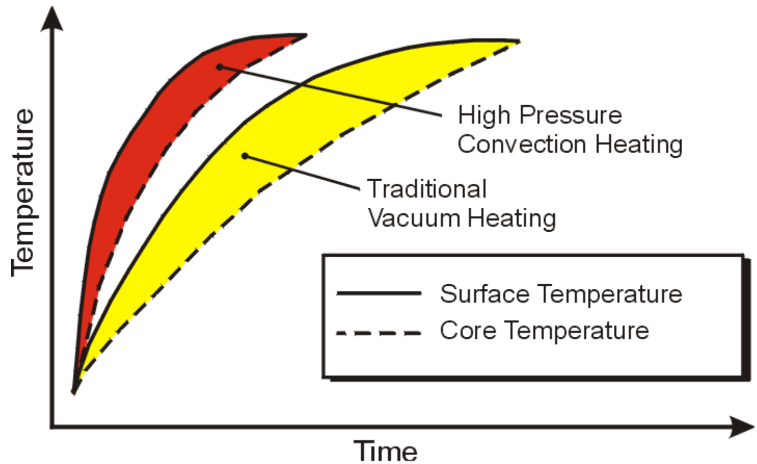
The parameter λ defines the time for the temperature in the center of the load to fall from 800° C to 500° C. By knowing λ for different quenching conditions, it is possible to use a TTT diagram to predict the hardness at the center of the load. Table I shows the hardness of several alloy steels in relation to different quenching gas pressure.

TABLE I - HARDNESS OF VARIOUS ALLOY STEELS IN 6, 10 AND 20 BAR QUENCH VACUUM FURNACE

Material	Cooling 6/10/20 bar	HRC
6 Bar	10 Bar / 20 Bar	
1.2721- (similar to L6)		59
1.2767- 6F7		56
1.2510 *01*		64
1.2550 *S1*		60
1.2842 *02*		63
1.2363 *A2*		63
1.2080 *D3*		64
1.2436 (similar to L6)		65
1.2379 *D2*		63
1.2713 *L6*		56
1.2714 (imilar to L6)		57

1.2343 H11 1.2344 *H13*											54
1.2365 *H10*											50
1.2083 *420*											56
1.2316 (similar to 422)											50
1.3343 *M2*											66
Thickness (mm) (in)	20 3/4	40 1 1/2	60 2 1/4	80 3	100 4	120 4 3/4	140 5 1/2	160 6 1/4	180 7	200 7 3/4	

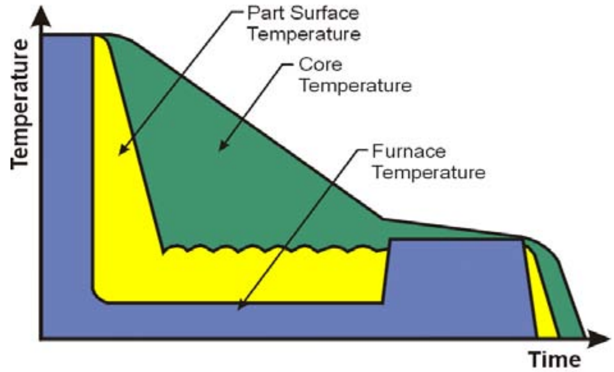
The transfer of heat under vacuum takes place through radiation, however, it transfers efficiently only at the temperature above 1400°F. In order to carry out heating uniformly and quickly in the lower temperature, inner gas is used for convective heat transfer.



For the uniformity and quick convection heating, the hot zone must be thermally insulated. Convection heating effectively breaks down stresses that are present in the heated parts. The stresses in the part are caused by machining or poor steel quality prior to heat treatment. Convection heating is a pre-requirement for low distortion during the heating up cycle. The advantages of convection heating are:

- Uniform heating and low distortion of the parts
- Shorten heating cycle for hardening and tempering; The cycle can be 50% shorter with convection heating as compared to tempering with conventional vacuum furnace
- Better uniformity in a low temperature range
- Higher loading capacity into the furnace
- Tempering and annealing in the same furnace and better utilization of the furnace

Isothermal Quench – Marquench



The furnace and control system are designed to perform an automatic isothermal quench (marquenching). The intensity of high pressure quenching leads to the possibility of part cracking and distortion. The problems mainly arise in parts with wide cross sections. A controlled cooling cycle results in better microstructure after hardening, for certain loads, reducing the number of tempering cycles to single one. The better microstructure influences the durability of the process tool steels, particular hot working dies. For example, isothermal hardening of 450 x 450 x 80 mm dies of H-13 yielded a hardness of 57 HRC after tempering at 550°C, where as the maximum hardness achieved without isothermal hardening cycle with constant cooling and tempering at 550°C was only 54 HRC.6

At the end of austenitenizing time, the cooling begins with maximum pressure and maximum gas circulation. One of the thermocouples is located on the part surface and the other in the part core. As the temperature of the part surface approaches the marquenching temperature (Ms) the quenching pressure is reduced. The circulation speed of the gas is reduced to a lower range to allow for temperature equalization between the surface and core temperatures. Stable surface temperature is maintained with veritable gas blower speed controlled by the motor inverter. In order to attain a gradual equalization between the core and surface of the part, the convection fan could be also switched on. The convection heating prevents the surface temperature from falling below the marquenching (Ms) temperature. As a result, no martensite formation takes place on the surface or inside the part until surface and core temperature equalize.

Finally, when the temperature of the surface and the core of the part reach a preprogram difference; ΔT the entire workload is further cooled to unloading temperature.

Considering upstream and downstream costs, vacuum carburizing provides a total reduction of processing costs and is a natural fit in a lean manufacturing cell.

There is an increased interest in furnaces for vacuum carburizing due to the demand for products with the best overall metallurgical quality and lowest unit cost. Vacuum carburizing technology produces work with minimum distortion, the direct result of being cooled with gas. The surface metallurgy is superior because the carburization process is carried out in a vacuum environment. Vacuum furnaces systems provide "cold to cold" (cold work going in, cold work coming out) and fully automatic operation that reduces the amount of operator involvement, thus minimizing labor costs.

Vacuum furnace technology is a "green" manufacturing process with no negative impact on the environment.

This technology differs considerably from traditional gas carburizing both in the equipment used and in the process economy. This following presents aspects of vacuum carburizing technology that have an impact on process costs and quality improvements in the final product.

Vacuum carburizing is considerably faster than gas carburizing

Vacuum carburizing is characterized by an extraordinarily high coefficient of carbon transfer at the phase interface, which results in a high carbon transfer. In the initial phase of carburizing, for example, at a temperature of 1740°F (950°C), the carbon stream directed at the charge surface reaches the rate of 250 g/m2h. This means that, in the case of thin carburization layers, the process is considerably faster than the gas carburizing process. The advantage is smaller in the case of thick layers that exceed for example, .00315 inches (0.8 mm), where the carbon transfer is much more dependant on the diffusion coefficient (DC).

The vacuum carburizing process may easily be carried out even at temperatures of up to 1900°F (1050°C), within the natural temperature range of a vacuum furnace. The process temperature increases to 1700-1800°F (950-980°C), compared to traditional gas carburizing processes that typically operate within a temperature range of 1600-1700°F (880-930°C). Operating at higher temperatures results in shorter carburizing cycles due to the considerable increase of the diffusion coefficient (DC). Both the increased amount of carbon in the carburizing atmosphere, and faster diffusion (Dc) are responsible for the increase in vacuum carburizing efficiency when compared to the traditional gas carburizing.

Reduction of the processing time and energy-related factors

Vacuum carburizing technology differs considerably from gas carburizing in the method of delivering the carbon stream to the charge surface, process regulation, and in the completion of the entire cycle. More differences are found in the furnace construction, the results of heat and chemical treatment, and in the consumption of energy, and therefore, the process costs. The new technology consistently reduces and/or eliminates deformations, eliminates internal oxidation, and reduces the exhaust gas emission into the atmosphere.

It is commonly believed that shortening the cycle period according to this method will reduce the process cost. But, the reduction of the process duration is higher for the same temperature, in the case of thin carburized layers than thicker layers, where the impact of the diffusion coefficient is dominant. For thin layers, especially those manufactured at high temperatures in the steel grades with higher hardening capacity, the vacuum cycles will be very competitive compared to gas carburizing. The implementation examples below illustrate the efficiency of vacuum carburizing.

The vacuum carburizing method allows a uniform carburized layer to be easily produced in openings of small diameter, considerable depth and no internal oxidation

A good example of this is found in elements of diesel injectors made of EN32B, 18CrNiMo7-6 (17HNM). The vacuum carburizing cycle, usually operating in a temperature range of 1540-1690°F (840-920oC), requires 11 minutes of carburizing for a .01969inches (0.5 mm) layer, and 120 minutes of diffusion. A similar cycle performed in an atmosphere furnace required the process to be carried out at a temperature range of 1540-1560°F (840-850oC) took three times as long to obtain comparable quality. The conspicuous impact of no internal oxidation is shown in (fig. 1).

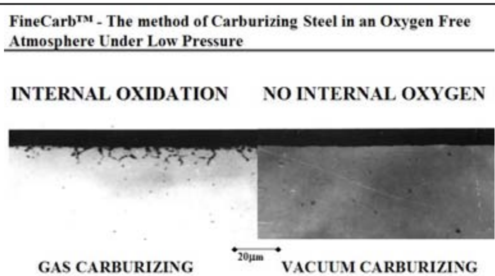


Figure 1 Comparison of carburizing processes

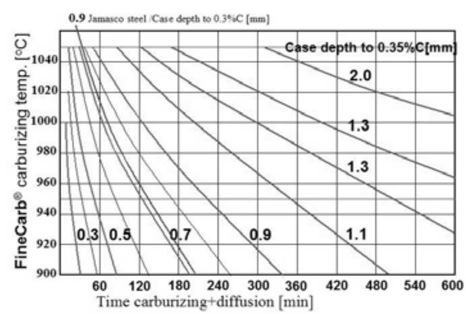


Figure 2 Approximate duration of vacuum carburizing process for 16MnCr5 steels, correlated to the temperature and the required thickness of the A HT layer

A comparison of gas carburizing and FineCarb® vacuum carburizing was conducted to demonstrate the differences in the process cycle for typical carburized materials.

The tests were carried out for a net charge of 770 pounds (350 kg), consisting of 16MnCr5 and 15CrNi6 steels. The tests of 16MnCr5 steel were carried out in a Casemaster® integral quench furnace with a 24 inch x 24 inch x 36 inch load capacity and in a double-chamber SECO/WARWICK NVPT 24 inch x 24 inch x 36 inch (600mm x 600mm x 900 mm) furnace, while the tests of 15CrNi6 steel were carried out in the same Casemaster IQ furnace and in a single-chamber SECO/WARWICK VPT 4035/36 vacuum furnace. The comparison was performed for two layer thickness values: .02362 and .04724 inch (0.6 and 1.2mm). The process of gas carburizing is usually carried out at temperatures of up to 1690-1700°F (920-930°C), while the process of vacuum carburizing is normally carried out at temperatures of up to 1760-1800°F (960-980°C). Therefore, the comparison was carried out for the temperatures of 1690°F (920°C) and 1760°F (960°C), respectively. Moreover, the time of heat up to carburization temperature for a given charge is assumed to be 50 minutes, and the time of burn-in after cool-down for hardening is assumed to be 30 minutes. The results are presented in the following tables.

16MnCr5 (16HG) steel

EHT[mm]	Total cycle [minutes]	(N+D) cycle [minutes]
Gas carburizing		
0.6	315	176
1.2	660	520
FineCarb vacuum carburizing		
0.6	210	63 (carburizing: 13 minutes)
1.2	525	380 (carburizing: 27 minutes)

15CrNi6 (15HN) steel

EHT	Total cycle	(N+D) cycle
Gas carburizing		
0.6mm	250	109
1.2mm	495	352
FineCarb vacuum carburizing		
0.6mm	220	50 (carburizing: 9 minutes)
1.2mm	450	280(carburizing: 19 minutes)

The above results confirm the claimed efficiency, especially in the case of thin layers using general cycle time estimates for the FineCarb process – at a high temperature range, easy to obtain in a vacuum furnace – for 16MnCr5 steel and the most common layer thickness values.

The economic competitiveness of the process (installation cost excluded) is a separate question. Theses cycle times have considerable impact on the consumption of energy-related factors. While disregarding detailed list of components of the very process (i.e. the stop time, the time of maintaining the furnace during weekends, etc.), the energy consumption for a 15CrNi6 charge and 0.6 mm and 1.2 mm layers is presented below.

Gas carburizing	FineCarb vacuum carburizing
0.6 mm: 200 kWh, which includes charge heating - 65kWh	0.6 mm: 180 kWh, which includes charge heating - 65kWh
1.2mm: 290 kWh	1.2 mm: 315kWh

The table shows the vacuum carburizing method to be competitive in the case of thin layers, while gas carburizing is slightly more profitable in the case of thicker layers, which is due to larger heat loss of the insulation of the heating chamber in a vacuum furnace. Vacuum carburizing is more competitive when compared to the consumption of the process atmosphere. The atmosphere consumption for both 0.6mm and 1.2mm layers is presented below.

Gas carburizing	FineCarb vacuum carburizing
Feeding time aprox. 4.5 h - Endo atmosphere consumption 35 Nm3 (1,236 ft3) per cycle	Feeding time approx. 9 minutes – gas consumption (ethylene/acetylene/hydrogen) – 0.45 Nm3 (15 ft3) per cycle
Feeding time approx. 8.5h - 65Nm3 (2,295 ft3)	Feeding time: 19 minutes – 0.95Nm3 (33.5 ft3)

The post-processing gas emission is considerably lower in the vacuum carburizing technology, specifically toxic CO and CO_2. The vacuum carburizing technology also involves the consumption of cooling gas used in the gas hardening cycle (the cost of about 0.4 PLN/Nm3 x the volume of the cooling chamber x the process pressure). In the case of 15CrNi6 steel hardened in VPT 4035/36 furnace at the pressure of 10 bars, the cost of used Nitrogen is about \$6.30 (€5.30) per cycle (Prices based on 4th quarter 2005 costs in Eastern Europe). When module furnaces are used and the demand for the cooling gas is much higher, a recycling system can be designed to improve the efficiency to 98%, which further reduces costs.

The trials were performed in a vacuum carburizing furnace updated with the latest measurement technology. These modifications allowed the chemical composition of output gasses to be constantly registered on the run. As the proportions of the atmosphere feed were known, it was possible to determine the most probable directions of chemical reactions occurring during the process, and to determine their kinetics

Pre-nitriding for low pressure carburizing, PreNitLPC®, expands the FineCarb® LPC Vacuum Carburizing Technology family of applications to include higher carburizing temperatures and a wider range of steel grades

Low pressure carburizing technology is in common use in many industries, successfully replacing many traditional technologies. A new process approach is the addition of nitrogen together with carbon into the surface layer. This leads to the improvement of the layers' functional properties and economic effects.

Pre-nitriding for low pressure carburizing, PreNitLPC®, expands the FineCarb® LPC Vacuum Carburizing Technology family of applications to include higher carburizing temperatures and a wider range of steel grades. This technology has been developed at the Institute of Materials & Engineering Science at Technical University of Lodz (Poland) in conjunction with SECO/WARWICK S.A., and is currently in commercial use.

Technically, the process is based on dosing the ammonia gas into the vacuum furnace chamber during heat-up ramp of charge at the temperature interval from 400°C up to 700°C. As a result, the carburized layers performed at the higher temperatures do not demonstrate the grain growth. Due to the higher temperature of the process, (even 1100°C), it can be run for a shorter time without any negative impacts on the microstructure and mechanical properties.

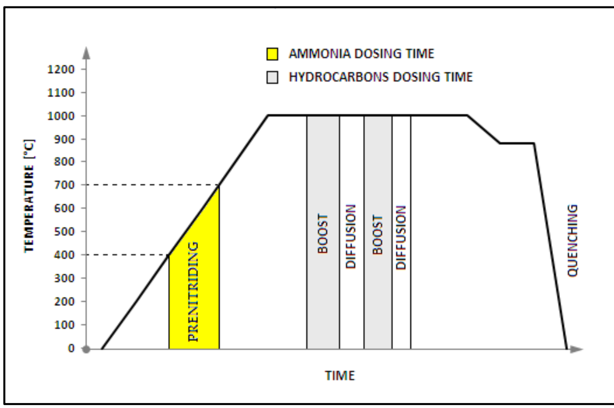


Fig. 1 Process flow chart acc. To PreNitLPC® technology.

PreNitLPC® is a modern, fast and economical option for low pressure carburizing, that which significantly improves process efficiency.

Performance

A series of processes were performed at different temperatures in order to compare the structure and the properties of layers created by standard low pressure carburizing – LPC and low pressure carburizing aided by pre-nitriding – PreNitLPC® technologies. In addition, the conventional process was performed in order to compare both methods.

Two types of steel were carburized, the 16MnCr5 (5115 acc. to AISI) and 17CrNi6-6 (1.5918 acc. to DIN).

Type of carburizing method	Conventional	LPC	PreNitLPC®		
Process Temperature	920[°C]	920[°C]	950[°C]	980[°C]	1000[°C]
Case depth (criterion 0,4% C)	0,6 [mm]				
Surface concentration	0,8[%C]				

Table 1. Carburizing process conditions

An ammonia gas and the carburizing atmosphere were dosed into the furnace chamber, according to the procedures described in the patent [4] and patent [5], respectively. The process parameters are shown in the Table 1.

Results

Carburizing time reduction

The higher temperature of carburizing, the higher carbon diffusion coefficient (exponential dependence), resulted in a significant reduction of the process time. The results for different conditions are illustrated in the Table 2 and on the Figure 1.

Type of carburizing method	Conventional	LPC	PreNitLPC®		
Case depth (criterion 0,4% C)	0,6 [mm]				
Temperature	920[°C]	920[°C]	950[°C]	980[°C]	1000[°C]
Carburizing (boost) time	167min	23min	17min	13min	11min
Diffusion time		1h 52min	1h 24min	58min	43min
Total time	2h 47min	2h 15min	1h 41min	1h 11min	54 min

Table 2. Processes time obtained for different carburizing conditions.

The shortest total time of process was obtained for the process of carburizing with pre-nitriding at the highest temperature of 1000°C. The 0.6 mm case was created just after 54 min of treatment. Such a short time is up to 68% less than the obtained according to conventional carburizing and up to 60% shorter in comparison to LPC at 920°C (Fig. 2).

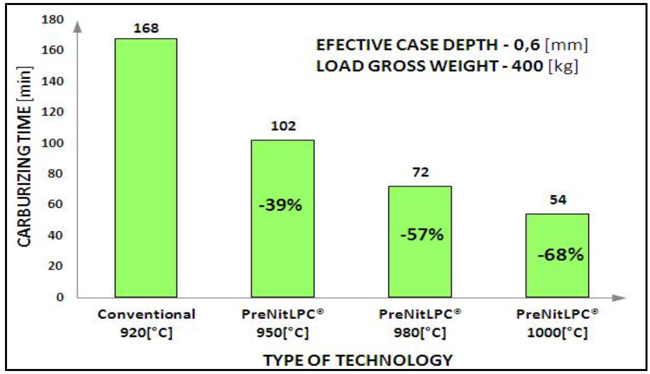


Fig. 2 The comparison of total processes time for different types of treatment.

Microstructure

The structure of created layers at different carburizing processes and grain size of austenite are shown in figure 3. As shown, the grain size is significant lower where the PreNitLPC® was used. Additionally, the size was even smaller when the process was run at 1000°C, in comparison to the carburizing at 920°C without pre-nitriding option.

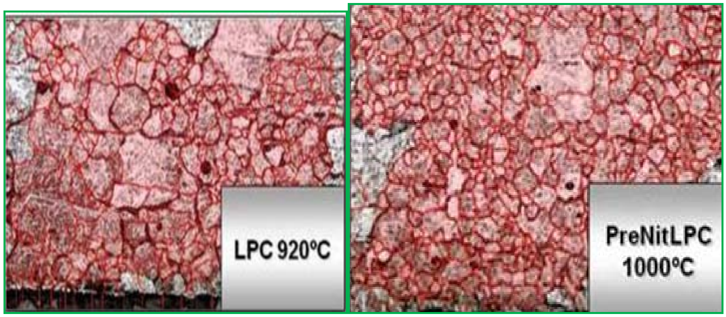


Fig.3 Surface layer of 16MnCr5 depending on applied technology:

a) LPC, Low pressure carburizing at 920°C,

b) PreNitLPC®, pre-nitriding with low pressure carburizing at 1000°C.

The influence of the temperature on the grain size of the core was also established. As it was predicted, the grain diameter of the core was greater, at the PreNitLPC® process temperature of 1000°C, than those performed acc. to LPC at 920°C, and it equals 19.2 μm (No 8,1 acc. to ASTM) and 12.2 μm (No 9,4 acc. to ASTM), respectively for the 16MnCr5 steel. This was the result of the nitrogen presence only in the surface layer, which was added at the heat-up stage.

To summarize, the pre-nitriding option reduced the total process time when the temperature is higher, while the grain growth in the surface layer is eliminated.

The combination of even more fine-grained, hard, wear-resistant layer and a relatively flexible core has allowed to obtain, a very satisfactory mechanical and tribological properties of treated parts.

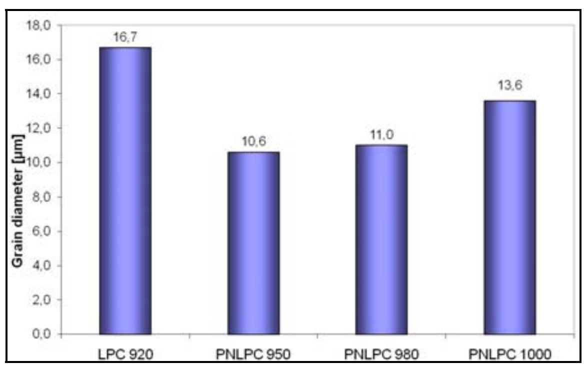


Fig. 4 Comparison of the surface layer grain size of 16MnCr5 steel for different types of treatment.

Strength properties

It was crucial to determine the mechanical properties of obtained layers in order to establish the potential of applications of the PreNitLPC® technology in comparison to other carburizing methods.

It appeared that the hardness profile in the surface layer of 16MnCr5 steel was comparable to the results of LPC technology.

The fatigue strength for bending was measured. The calculated Wöhler's curves within limited and unlimited range of fatigue strength for processes LPC 920°C and PreNitLPC® 1000°C are shown in figure 5.

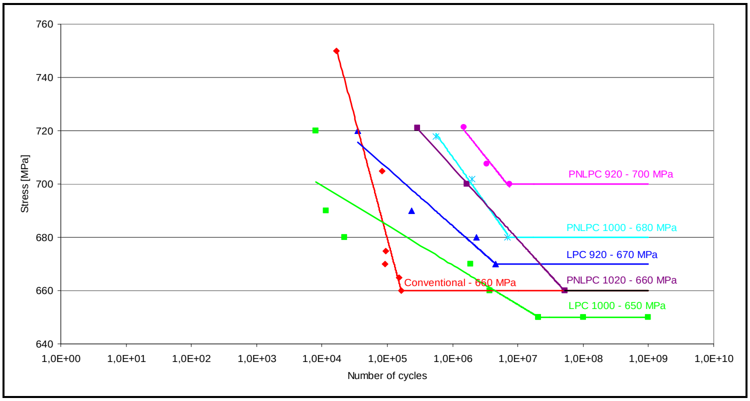


Fig. 5 Wöhler's curves within limited and unlimited range of fatigue strength for different types of treatment,17CrNi6-6 steel.

It appeared that the fatigue strength for bending was higher after PreNitLPC® for 17CrNi6-6 steel.

The fatigue strength for pitting was also determined according to the British Standard IP 300/82. No matter how carburizing method has been applied, the results were comparable in the case of 16MnCr5 steel and the average value was in the range of 1,46 – 1,61 x 10+6 cycles.

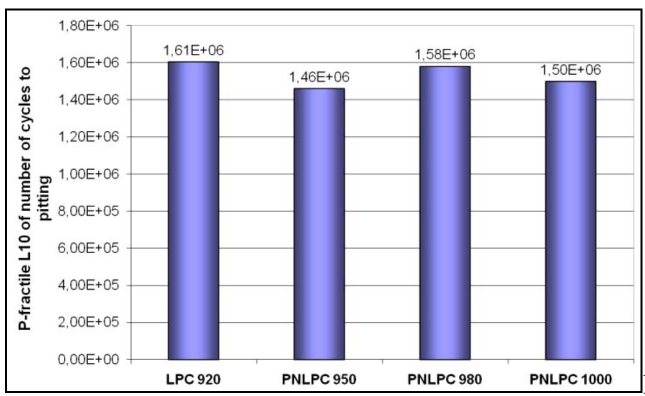


Fig. 6 Fatigue strength for pitting for 16MnCr5 steel depending on applied technology

In addition, the impact fracture resistance tests were performed on samples sized 10x10x55 mm with a U shaped notch. The samples of the thermo-chemical treatment have been tested according to the Charpy's test and the results are shown on the figure 7.

All measurements exceed the value 150 J/cm2 of notched impact strength. Those performed acc. to PreNitLPC® are even higher and increase within the rise of the temperature from 155 J/cm2 at 920oC up to 168 J/cm2 at 1020oC.

However, the differences are not significant and almost comparable for all methods.

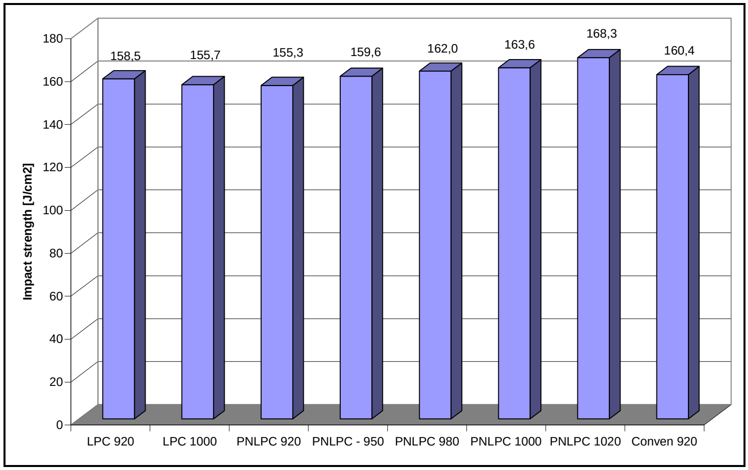


Fig. 7 Notched impact strength acc. to Charpy's test for 16MnCr5 steel depending on applied technology

Summary

The layers, having been produced using the PreNitLPC® process at higher temperatures during the pre-nitriding phase, demonstrate the strength properties similar to work that has been conventionally carburized at lower temperatures.

This technology saves process costs by reducing the carburizing cycle time and reducing the consumption of process gases (C_2H_2, C_2H_4, H_2, NH_3) as measured in liters and not, as in the case of conventional technologies, in cubic meters per hour.

PreNitLPC®, the latest advance in the FineCarb® family of technology, is a unique process offering total value in both cost of operation and process efficiency:

- Reduce Carburizing Cycle Time
- Lower Process Cost
- No Internal Oxidation
- Excellent Uniformity
- Optimum carbon penetration
- No CO2 emissions
- Environmentally-friendly

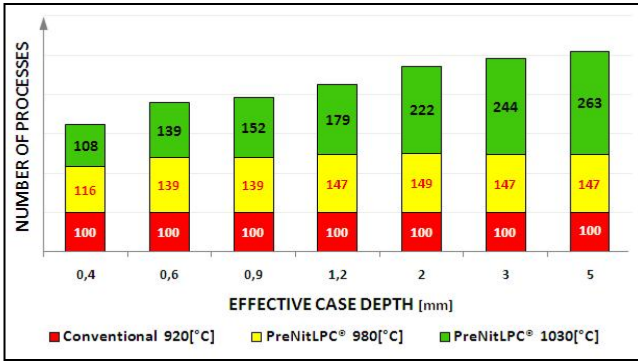


Fig. 7 Efficiency increase depending on Effective Case Depth

For every 100 processes (i.e. for 0,6mm ECD) according to traditional carburizing methods (Fig. 8), PreNitLPC® technology can offer you up to 40% in increased process efficiency.

Optimum carbon penetration allows for the efficient heat treatment of complex shapes and the densely packed loads with superior case uniformity. This technology is adaptable to both new and existing furnaces equipped with FineCarb® technology and may be equipped with either an oil or gas quench.

ROCKWELL SCALE - HARDENED STEEL AND HARD ALLOYS

							Dph	**Khn***	**Bhn**	**Tensile Strength**
C	A	D	15N	30N	45N	G	10kg	500g & over	300kg	10^3psi (approx.)
80	92.0	86.5	96.5	92.0	87.0	-	1865	-	-	-
79	91.5	85.5	-	91.5	86.5	-	1787	-	-	-
78	91.0	84.5	96.0	91.0	85.5	-	1710	-	-	-
77	90.5	84.0	-	90.5	84.5	-	1633	-	-	-
76	90.0	83.0	95.5	90.0	93.5	-	1556	-	-	-
75	89.5	82.5	-	89.0	82.5	-	1478	-	-	-
74	89.0	81.5	95.0	88.5	81.5	-	1400	-	-	-
73	88.5	81.0	-	88.0	80.5	-	1323	-	-	-
72	88.0	80.0	94.5	87.0	79.5	-	1245	-	-	-
71	87.0	79.5	-	86.5	78.5	-	1160	-	-	-
70	86.5	78.5	94.0	86.0	77.5	-	1076	972	-	-
69	86.0	78.0	93.5	85.0	76.5	-	1004	946	-	-
68	85.5	77.0	-	84.5	75.5	-	942	920	-	-
67	85.0	76.0	93.0	83.5	74.5	-	894	895	-	-
66	84.5	75.5	92.5	83.0	73.0	-	854	870	-	-
65	84.0	74.5	92.0	82.0	72.0	-	820	846	-	-
64	83.5	74.0	-	81.0	71.0	-	789	822	-	-
63	83.0	73.0	91.5	80.0	70.0	-	763	799	-	-
62	82.5	72.5	91.0	79.0	69.0	-	739	776	-	-
61	81.5	71.5	90.5	78.5	67.5	-	716	754	-	-
60	81.0	71.0	90.0	77.5	66.5	-	695	732	614	-
59	80.5	70.0	89.5	76.5	65.5	-	675	710	600	-
58	80.0	69.0	-	75.5	64.0	-	655	690	587	-
57	79.5	68.5	89.0	75.0	63.0	-	636	670	573	-
56	79.0	67.5	88.5	74.0	62.0	-	617	650	560	-
55	78.5	67.0	88.0	73.0	61.0	-	598	630	547	301
54	78.0	66.0	87.5	72.0	59.5	-	580	612	534	291
53	77.5	65.5	87.0	71.0	58.5	-	562	594	522	282
52	77.0	64.5	86.5	70.5	57.5	-	545	576	509	273
51	76.5	64.0	86.0	69.5	56.0	-	528	558	496	264
50	76.0	63.0	85.5	68.5	55.0	-	513	542	484	255
49	75.5	62.0	85.0	67.5	54.0	-	498	526	472	246
48	74.5	61.5	84.5	66.5	52.5	-	485	510	460	237
47	74.0	60.5	84.0	66.0	51.5	-	471	495	448	229
46	73.5	60.0	83.5	65.0	50.0	-	458	480	437	221
45	73.0	59.0	83.0	64.0	49.0	-	446	466	437	214
44	72.5	58.5	82.5	63.0	48.0	-	435	452	426	207

43	72.0	57.5	82.0	62.0	46.5	-	424	438	415	200
42	71.5	57.0	81.5	61.5	45.5	-	413	426	404	194
41	71.0	56.0	81.0	60.5	44.5	-	403	414	393	188
40	70.5	55.5	80.5	59.5	43.0	-	393	402	382	182
39	70.0	54.5	80.0	58.5	42.0	-	383	391	372	177
38	69.5	54.0	79.5	57.5	41.0	-	373	380	362	171
37	69.0	53.0	79.0	56.5	39.5	-	363	370	342	166
36	68.5	52.5	78.5	56.0	38.5	-	353	360	332	162
35	68.0	51.5	78.0	55.0	37.0	-	343	351	322	157
34	67.5	50.5	77.0	54.0	36.0	-	334	342	313	153
33	67.0	50.0	76.5	53.0	35.0	-	325	334	305	148
32	66.5	49.0	76.0	52.0	33.5	-	317	326	297	144
31	66.0	48.5	75.5	51.5	32.5	-	309	318	290	140
30	65.5	47.5	75.0	50.5	31.5	92.0	301	311	283	136
29	65.0	47.0	74.5	49.5	30.0	91.0	293	304	276	132
28	64.5	46.0	74.0	48.5	29.0	90.0	285	297	270	129
27	64.0	45.5	73.5	47.5	28.0	89.0	278	290	265	126
26	63.5	44.5	72.5	47.0	26.5	88.0	271	284	260	123
25	63.0	44.0	72.0	46.0	25.5	87.0	264	278	255	120
24	62.5	43.0	71.5	45.0	24.0	86.0	257	272	250	117
23	62.0	42.5	71.0	44.0	23.0	84.5	251	266	245	115
22	61.5	41.5	70.5	43.0	22.0	83.5	246	261	240	112
21	61.0	41.0	70.0	42.5	20.0	82.5	241	256	235	110
20	60.5	40.0	69.5	41.5	19.5	81.0	236	251	230	108

ROCKWELL SCALE - SOFT STEEL, GRAY AND MALLEABLE CAST IRON, AND MOST NONFERROUS METALS

B	F	G	15T	30T	45T	E	H	K	A	Khn*	Bhn 500 kg	Bhn 3000 kg	Tensile Strength
										500g & over	(10mm ball)	& Dph, 10kg	103 psi approx.
100	-	82.5	93.0	82.0	72.0	-	-	-	61.5	251	201	240	116
99	-	81.0	92.5	81.5	71.0	-	-	-	61.0	246	195	234	112
98	-	79.0	-	81.0	70.0	-	-	-	60.0	241	189	228	109
97	-	77.5	92.0	80.5	69.0	-	-	-	59.5	236	184	222	106
96	-	76.0	-	80.0	68.0	-	-	-	59.0	231	179	216	103
95	-	74.0	91.5	79.0	67.0	-	-	-	58.0	226	175	210	101
94	-	72.5	-	78.5	66.0	-	-	-	57.5	221	171	205	98
93	-	71.0	91.0	78.0	65.5	-	-	-	57.0	216	167	200	96
92	-	69.0	90.5	77.5	64.5	-	-	100.0	56.5	211	163	195	93
91	-	67.5	-	77.0	63.5	-	-	99.5	56.0	206	160	190	91
90	-	66.0	90.0	76.0	62.5	-	-	98.5	55.5	201	157	185	89
89	-	64.0	89.5	75.5	61.5	-	-	98.0	55.0	196	154	180	87
88	-	62.5	-	75.0	60.5	-	-	97.0	54.0	192	151	176	85
87	-	61.0	89.0	74.5	59.5	-	-	96.5	53.5	188	148	172	83
86	-	59.0	88.5	74.0	58.5	-	-	95.5	53.0	184	145	169	81
85	-	57.5	-	73.5	58.0	-	-	94.5	52.5	180	142	165	80
84	-	56.0	88.0	73.0	57.0	-	-	94.0	52.0	176	140	162	78
83	-	54.0	87.5	72.0	56.0	-	-	93.0	51.0	173	137	159	77
82	-	52.5	-	71.5	55.0	-	-	92.0	50.5	170	135	156	75
81	-	51.0	87.0	71.0	54.0	-	-	91.0	50.0	167	133	153	74
80	-	49.0	86.5	70.0	53.0	-	-	90.5	49.5	164	130	150	72
79	-	47.5	-	69.5	52.0	-	-	89.5	49.0	161	128	147	-
78	-	46.0	86.0	69.0	51.0	-	-	88.5	48.5	158	126	144	-
77	-	44.0	85.5	68.0	50.0	-	-	88.0	48.0	155	124	141	-
76	-	42.5	-	67.5	49.0	-	-	87.0	47.0	152	122	139	-
75	99.5	41.0	85.0	67.0	48.5	-	-	86.0	46.5	150	120	137	-
74	99.0	39.0	-	66.0	47.5	-	-	85.0	46.0	147	118	135	-
73	98.5	37.5	84.5	65.5	46.5	-	-	84.5	45.5	145	116	132	-
72	98.0	36.0	84.0	65.0	45.5	-	-	83.5	45.0	143	114	130	-
71	97.5	34.5	-	64.0	44.5	100.0	-	82.5	44.5	141	112	127	-
70	97.0	32.5	83.5	63.5	43.5	99.5	-	81.5	44.0	139	110	125	-
69	96.0	31.0	83.0	62.5	42.5	99.0	-	81.0	43.5	137	109	123	-
68	95.5	29.5	-	62.0	41.5	98.0	-	80.0	43.0	135	107	121	-
67	95.0	28.0	82.5	61.5	40.5	97.5	-	89.0	42.5	133	106	119	-
66	94.5	26.5	82.0	60.5	39.5	97.0	-	78.0	42.0	131	104	117	-
65	94.0	25.0	-	60.0	38.5	96.0	-	77.5	-	129	102	116	-
64	93.5	23.5	81.5	59.5	37.5	95.5	-	76.5	41.5	127	101	114	-
63	93.0	22.0	81.0	58.5	36.5	95.0	-	75.5	41.0	125	99	112	-
62	92.0	20.5	-	58.0	35.5	94.5	-	74.5	40.5	124	98	110	-
61	91.5	19.0	80.5	57.0	34.5	93.5	-	74.0	40.0	122	96	108	-

60	91.0	17.5	-	56.5	33.5	93.0	-	73.0	39.5	120	95	107	-
59	90.5	16.0	80.0	56.0	32.0	92.5	-	72.0	39.0	118	94	106	-
58	90.0	14.5	79.5	55.0	31.0	92.0	-	71.0	38.5	117	92	104	-
57	89.5	13.0	-	54.5	30.0	91.0	-	70.5	38.0	115	91	103	-
56	89.0	11.5	79.0	54.0	29.0	90.5	-	69.5	-	114	90	101	-
55	88.0	10.0	78.5	53.0	28.0	90.0	-	68.5	37.5	112	89	100	-
54	87.5	8.5	-	52.5	27.0	89.5	-	68.0	37.0	111	87	-	-
53	87.0	7.0	78.0	51.5	26.0	89.0	-	67.0	36.5	110	86	-	-
52	86.5	5.5	77.5	51.0	25.0	88.0	-	66.0	36.0	109	85	-	-
51	86.0	4.0	-	50.5	24.0	87.5	-	65.0	35.5	108	84	-	-
50	85.5	2.5	77.0	49.5	23.0	87.0	-	64.5	35.0	107	83	-	-
49	85.0	-	76.5	49.0	22.0	86.5	-	63.5	-	106	82	-	-
48	84.5	-	-	48.5	20.5	85.5	-	62.5	34.5	105	81	-	-
47	84.0	-	76.0	47.5	19.5	85.0	-	61.5	34.0	104	80	-	-
46	83.0	-	75.5	47.0	18.5	84.5	-	61.0	33.5	103	-	-	-
45	82.5	-	-	46.0	17.5	84.0	-	60.0	33.0	102	79	-	-
44	82.0	-	75.0	45.5	16.5	83.5	-	59.0	32.5	101	78	-	-
43	81.5	-	74.5	45.0	15.5	82.5	-	58.0	32.0	100	77	-	-
42	81.0	-	-	44.0	14.5	82.0	-	57.5	31.5	99	76	-	-
41	80.5	-	74.0	43.5	13.5	81.5	-	56.5	31.0	98	75	-	-
40	79.5	-	73.5	43.0	12.5	81.0	-	55.5	-	97	-	-	-
39	79.0	-	-	42.0	11.0	80.0	-	54.5	30.5	96	74	-	-
38	78.5	-	73.0	41.5	10.0	79.5	-	54.0	30.0	95	73	-	-
37	78.0	-	72.5	40.5	9.0	79.0	-	53.0	29.5	94	72	-	-
36	77.5	-	-	40.0	8.0	78.5	100.0	52.0	29.0	93	-	-	-
35	77.0	-	72.0	39.5	7.0	78.0	99.5	51.5	28.5	92	71	-	-
34	76.5	-	71.5	38.5	6.0	77.0	99.0	50.5	28.0	91	70	-	-
33	75.5	-	-	38.0	5.0	76.5	-	49.5	-	90	69	-	-
32	75.0	-	71.0	37.5	4.0	76.0	98.5	48.5	27.5	89	-	-	-
31	74.5	-	-	36.5	3.0	75.5	98.0	48.0	27.0	88	68	-	-
30	74.0	-	70.5	36.0	2.0	75.0	-	47.0	26.5	-	67	-	-
29	73.5	-	70.0	35.5	1.0	74.0	97.5	46.0	26.0	-	-	-	-
28	73.0	-	-	34.5	-	73.5	97.0	45.0	25.5	-	66	-	-
27	72.5	-	69.5	34.0	-	73.0	96.5	44.5	25.0	85	-	-	-
26	72.0	-	69.0	33.0	-	72.5	-	43.5	24.5	-	65	-	-
25	71.0	-	-	32.5	-	72.0	96.0	42.5	-	-	64	-	-
24	70.5	-	68.5	32.0	-	71.0	95.5	41.5	24.0	-	-	-	-
23	70.0	-	68.0	31.0	-	70.5	-	41.0	23.5	82	63	-	-
22	69.5	-	-	30.5	-	70.0	95.0	40.0	23.0	-	-	-	-
21	69.0	-	67.5	29.5	-	69.5	94.5	39.0	22.5	-	62	-	-
20	68.5	-	-	29.0	-	68.5	-	38.0	22.0	-	-	-	-
19	68.0	-	67.0	28.5	-	68.0	94.0	37.5	21.5	79	61	-	-
18	67.0	-	66.5	27.5	-	67.5	93.5	36.5	-	-	-	-	-
17	66.5	-	-	27	-	67.0	93.0	35.5	21.0	-	60	-	-
16	66.0	-	66.0	26	-	66.5	-	35.0	20.5	-	-	-	-
15	65.5	-	65.5	25.5	-	65.5	92.5	34.0	20.0	76	59	-	-
14	65.0	-	-	25	-	65.0	92.0	33.0	-	-	-	-	-
13	64.5	-	65.0	24.0	-	64.5	-	32.0	-	-	58	-	-
12	64.0	-	64.5	23.5	-	64.0	91.5	31.5	-	-	-	-	-
11	63.5	-	-	23.0	-	63.5	91.0	30.5	-	73	-	-	-

10	63.0	-	64.0	22.0	-	62.5	90.5	29.5	-	-	57	-	-
9	62.0	-	-	21.5	-	62.0	-	29.0	-	-	-	-	-
8	61.5	-	63.5	20.0	-	61.5	90.0	28.0	-	71	-	-	-
7	61.0	-	63.0	20.0	-	61.0	89.5	27.0	-	-	56	-	-
6	60.5	-	-	19.5	-	60.5	-	26.0	-	-	-	-	-
5	60.0	-	62.5	18.5	-	60.0	89.0	25.5	-	69	55	-	-
4	59.5	-	62.0	18.0	-	59.0	88.5	24.5	-	-	-	-	-
3	59.0	-	-	17.0	-	58.5	88.0	23.5	-	-	-	-	-
2	58.0	-	61.5	16.5	-	58.0	-	23.0	-	68	54	-	-
1	57.5	-	61.0	16.0	-	57.5	87.5	22.0	-	-	-	-	-
0	57.0	-	-	15.0	-	57.0	87.0	21.0	-	67	53	-	-

COLORS OF HARDENING AND TEMPERING HEATS

Colors of Hardening Heats		
°F	**°C**	**Color of Heats**
752	400	Red - visible in the dark
885	474	Red - visible in twilight
975	525	Red - visible in daylight
1077	581	Red -visible in sunlight
1292	700	Dull Red
1472	800	Turning to cherry
1652	900	Cherry proper
1832	1000	Bright cherry red
2012	1100	Orange red
2192	1200	Orange yellow
2372	1300	White
2552	1400	Brilliant White
2732	1500	Dazzling White
2912	1600	Bluish White

Colors of Tempering Heats				
Temp. held for 1 hour		**Color of Oxides**	**Temp. held for 8 min.**	
°F	°C		°F	°C
370	188	Faint Yellow	460	238
390	199	Light Straw	510	265
410	210	Dark Straw	560	293
430	221	Brown	610	321
450	232	Purple	640	337
490	254	Dark Blue	660	349
510	265	Light Blue	710	376

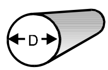
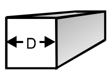
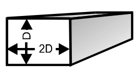
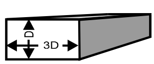
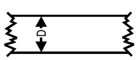
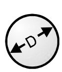
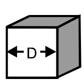
WEIGHTS AND MELTING POINTS

Metal	Weight per Cu. in. lbs.	Weight per Cu. ft. lbs.	Melting Point °F	Mean specific Heat 60 to Melting Point BTU per lb. per °F
Aluminum		166.7	1215	0.248
Antimony		418.7	1166	0.054
Bismuth		611.5	418	0.033
Brass		536.6	1700-1850	0.104
Bronze		522.2	1675	0.095
Cadmium		536.6	610	0.058
Copper		550.4	1981	0.104
Gold		1205.6	1945	0.033
Iron (cast)	0.2600	449.2	2100-2300	0.150
Lead	0.4105	709.5	621	0.032
Magnesium	0.0628	108.6	1204	0.272
Nickel	0.3177	556	2646	0.134
Platinum	0.8184	1416.6	3191	0.032
Silver	0.3802	657.1	1761	0.063
Solder	0.3325	585.6	450	0.040
Steel	0.2816	486.7	2500	0.165
Tin	0.2632	454.8	449	0.069
Zinc	0.2581	446.1	787	0.107

According to tests made by the Carpenter Steel Company in the Service Bulletin, Volume 2, the center and surface of work reach the furnace temperature at the same time and accordingly the best method of determining time required to heat for hardening is by visual observation of the work actually coming up to heat, observing the following precautions:

1. Place the thermocouple directly behind the largest section of the work.
2. Judge temperature of actual work, not loose scale or corners, by looking through the slightly open door of the furnace, not the peephole.
3. Allow approximately 5 minutes per inch of section for uniform heating after work and thermocouple are apparently at heat (1400° to 1500°).

For a rough rule for calculating heating time, figure approximately on a heat penetration at the rate of 1/8" per 5 minutes or about 20 minutes per inch on round bars. For high speed steels in hardening temperature, total time is allowed at 4 to 6 minutes per inch of thickness but never long enough to "blister". This table gives approximate rates for other shapes:

	Shapes	Speed Factor
	Long cylinder (dia. = D)	1
	Long square (D x D)	1
	Long rectangle (D x 2D)	.7
	Long rectangle (D x 3D)	.6
	Infinite plate (very wide, thickness = D)	.5
	Sphere (dia. = D)	1.5
	Cube (D x D x D)	1.5

TIME REQUIRED (per inch) TO REACH FURNACE TEMERATURE

Per inch of diameter or thickness, with furnace maintained steadily at T max. Steel having dark or scaled surface[1].

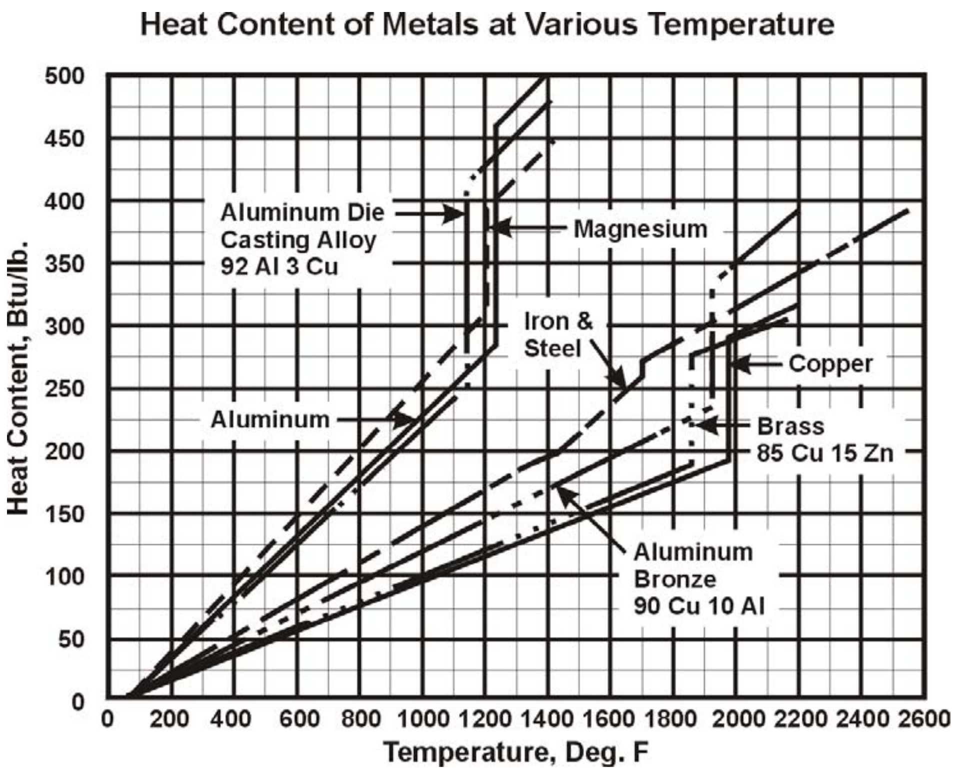
Tempering	In a hot air oven, w/out circulation			In circulating air oven, or oil bath[2]		
Temp.	**Cubes or Spheres**	**Squares or Cylinders**	**Average Flats**	**Cubes or Spheres**	**Squares or Cylinders**	**Average Flats**
250°F	30 min.	55 min.	80 min.	15 min.	20 min.	30 min.
300°	30	50	75	15	20	30
350°	30	50	70	15	20	30
400°	25	45	65	15	20	30
500°	25	40	60	15	20	30
600°	25	40	55	15	20	30
700°	20	35	50	15	20	30
800°	20	30	45	15	20	30
900°	20	30	40	15	20	30

NOTE: Temperatures above 900°F are visible - watch the color.

(1) The above figures apply to a dark or scale surface on the tool. If the tool surface is finish ground, or otherwise brightened, allow double time in a still hot air oven. No extra allowance need be made or bright surfaces in a circulating oven, or in an oil bath.

(2) An oil bath can be used only at the lower temperatures.

Source: Carpenter Service Bulletin Vol. 2, No. 9.


Heat Content of Metals at Various Temperature
Heat Content, Btu/lb.
Temperature, Deg. F
0
50
100
150
200
250
300
350
400
450
500
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Aluminum Die Casting Alloy 92 Al 3 Cu
Magnesium
Iron & Steel
Aluminum
Copper
Brass 85 Cu 15 Zn
Aluminum Bronze 90 Cu 10 Al

Hardenability is a term used to designate that property of steel which determines the depth and distribution of hardness induced by quenching from the austenitizing temperature. Whereas the as-quenched surface hardness of a steel part is dependent primarily on carbon content and cooling rate, the depth to which a certain hardness level is maintained with given quenching conditions is a function of its hardenability. Hardenability is largely determined by the percentage of alloying elements present in the steel. Austenitic grain size, time and temperature during austenitizing, and prior microstructure also can have significant effects.

Hardenablility, determined by standard procedures described below, is constant for a given composition; whereas hardness will vary with the cooling rate. Thus, for a given composition, the hardness obtained at any location in a part will depend not only on carbon content and hardenability but also on the size and configuration of the part and the quenchant and quenching conditions used.

The hardenability required for a particular part depends on many factors, including size, design, and service stresses. For highly stressed parts, particularly those loaded principally in tension, the best combination of strength and toughness is attained by through hardening to a martensitic structure followed by adequate tempering. Quenching such parts to a minimum of 80% martensite is generally considered adequate. Carbon steel can be used for thin sections, but as section size increases, alloy steels of increasing hardenability are required. Where only moderate stresses are involved, quenching to a minimum of 50% martensite is sometimes appropriate.

In order to satisfy the stress loading requirements of a particular application, a carbon or alloy steel having the required hardenability must be selected. The usual practice is to select the most economical grade which can consistently meet the desired properties.

There are many applications where through-hardening is not necessary, or even desirable. For example, for parts which are stressed principally at or near the surface, or in which wear-resistance or resistance to shock loading are primary considerations, shallow-hardening steels or surface hardening treatments, as discussed below may be appropriate.

End-Quench Hardenability Testing

The most commonly used method of determining hardenability is the end-quench test developed by Jominy and Boegehold[1].

In conducting the test, a 1-inch-round specimen 4 inches long is first normalized to eliminate the variable of prior microstructure, then heated uniformly to a standard austenitizing temperature.

The specimen is removed from the furnace, placed in a jig, and immediately end-quenched by a jet of water maintained at room temperature. The water contacts the end-face of the specimen without wetting the sides, and quenching is continued until the entire specimen has cooled.

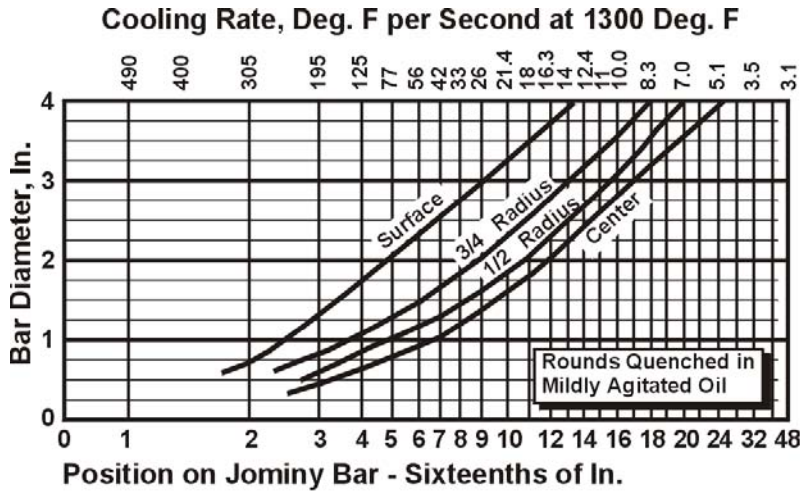
Longitudinal flat surfaces are ground on opposite sides of the quenched specimen, and Rockwell C scale readings are taken at 16th-inch intervals for the first inch from the quenched end, and at greater intervals beyond that point until a hardness level of HRC 20 or a distance of 2 inches from the quenched end is reached.

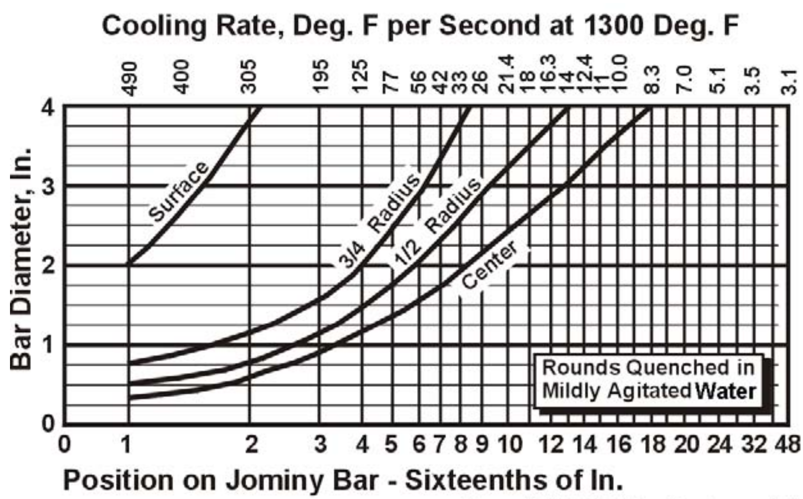
A hardenability curve is usually plotted using Rockwell C readings as ordinates and distances from the quenched end as abscissas. Representative data have been accumulated for a variety of standard grades and are published by SAE and AISI as H-bands. These show graphically and in tabular form the high and low limits applicable to each grade. Steels specified to these limits are designated as H-grades.

(1) For a complete description of this test see the SAE Handbook or ASTM Designation A255.

ASTM: http://www.astm.org/BOOKSTORE/PUBS/1377.htm

SAE Handbook: http://www.sae.org/pubs/





(From 1959 *SAE* Handbook, pg. 55)

SAE Handbook: http://www.sae.org/pubs/

Since only the end of the specimen is quenched in this test, it is obvious that the cooling rate along the surface of the specimen decreases as the distance from the quenched end increases. Experiments have confirmed that the cooling rate at a given point along the bar can be correlated with the cooling rate at various locations on rounds of various sizes.

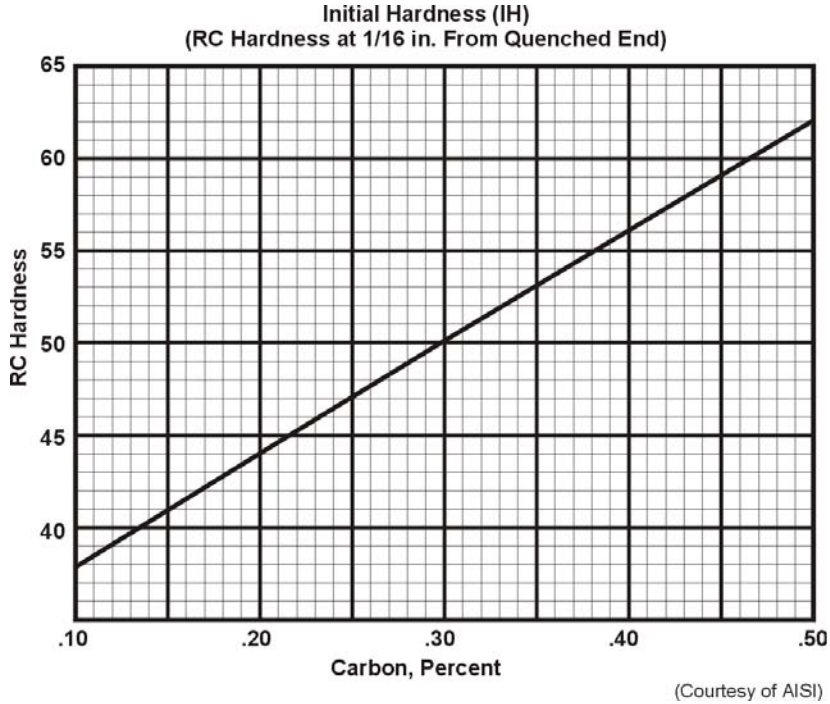
The following graphs show this correlation for surface, ¾ radius, ½ radius and center locations for rounds up to 4 inches in diameter quenched in mildly agitated oil and in mildly agitated water. Similar data are shown at the top of each H-Band as published by SAE and AISI. These values are not absolute, but are useful in determining the grades which may achieve a particular hardness at a specified location in a given section.

Calculation of End-Quench Hardenability Based on Analysis

It is sometimes desirable to predict the end-quench hardenability curve of a proposed analysis or of a commercial steel not available for testing.

The method[1] described here affords a reasonably accurate means of calculating hardness at any Jominy location on a section of steel of known analysis and grain size. To illustrate this method, consider a heat of 8640 having a grain size of No. 8 at the quenching temperature and the analysis shown in step II, below.

STEP I. Determine the initial hardness (IH). This is the hardness at 1/16 inch on the end-quench specimen and is a function of the carbon content as illustrated by the graph below. The IH for .39% carbon is HRC 55.5.



(1) Based on the work of M.A. Grossman, AIME, February 1942, and J. Field, Metal Progress, March 1943.

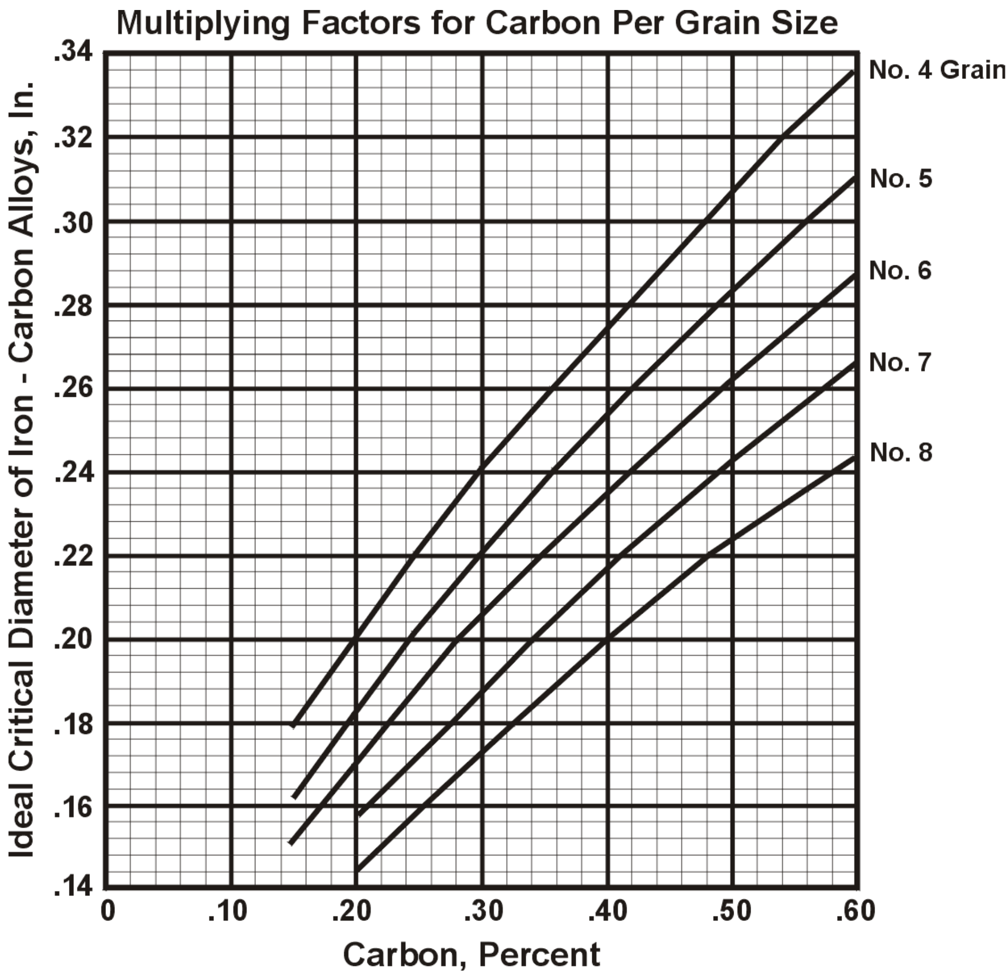
MULTIPLYING FACTORS FOR CARBON PER GRAIN SIZE

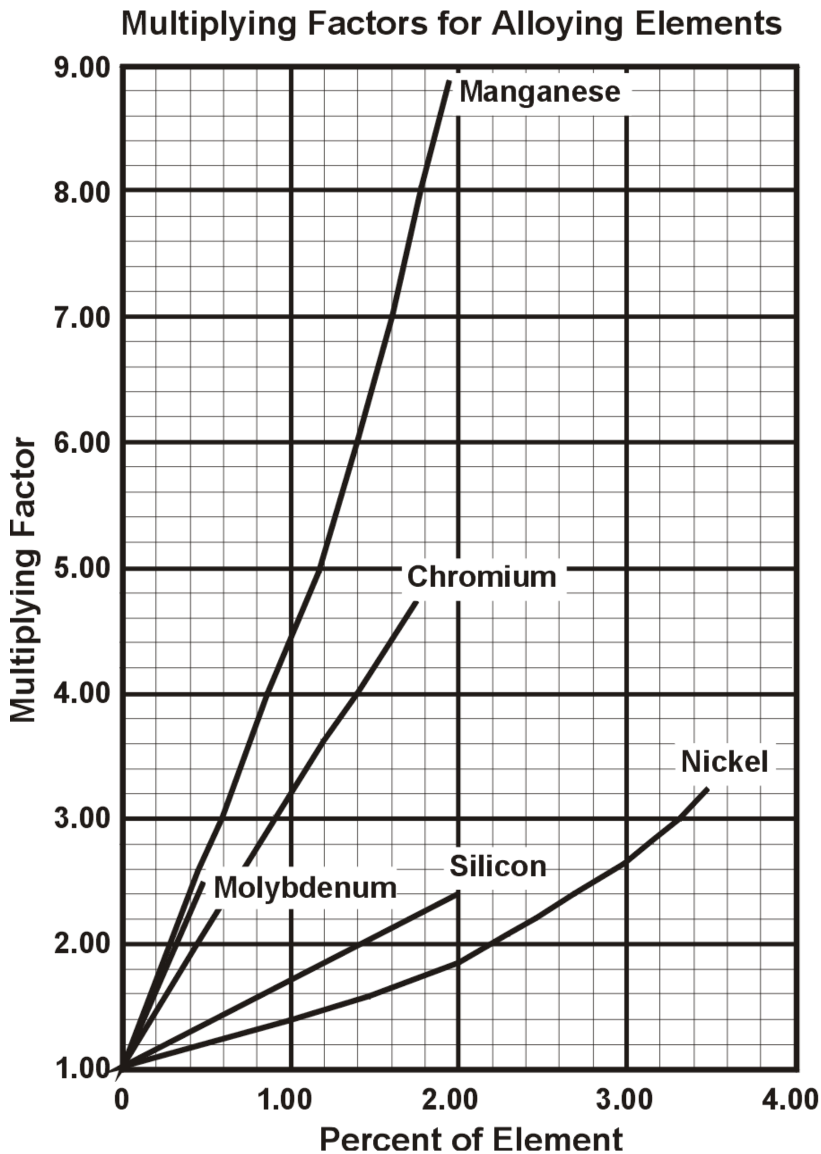
STEP II. Calculate the ideal critical diameter (DI). This is the diameter of the largest round of the given analysis which will harden to 50% martensite at the center during an ideal quench. The DI is the product of the multiplying factors representing each element.

From the graphs below, find the multiplying factors for carbon at No. 8 grain size, and for the other elements:

	C	Mn	Si	Ni	Cr	Mo
Heat Analysis (%)	.39	.91	.25	.54	.56	.20
Multiplying Factor	.195	4.03	1.18	1.20	2.21	1.60

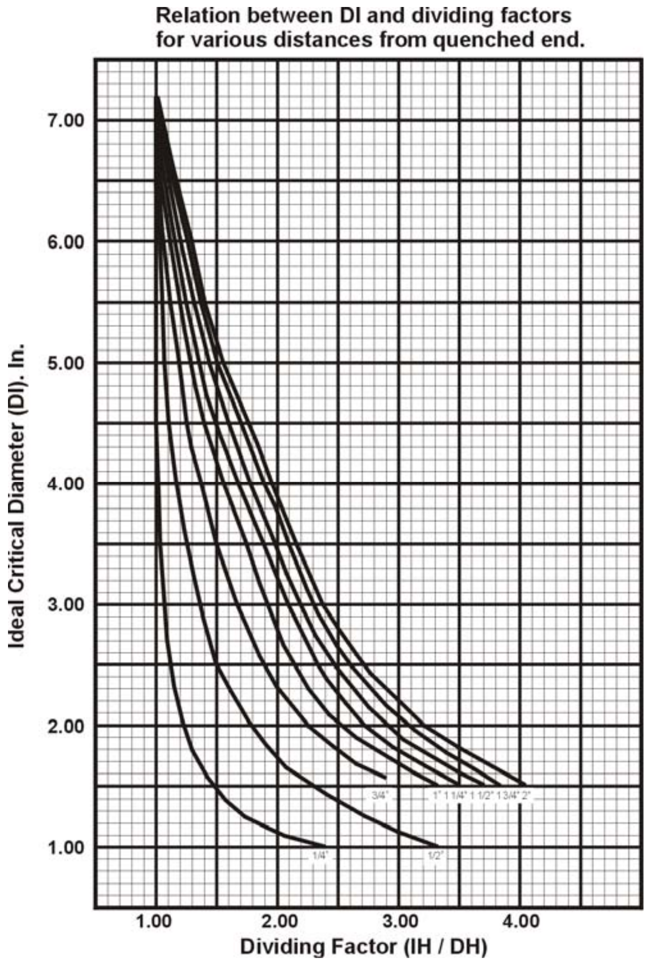
The product of these factors is 3.93 DI.


Multiplying Factors for Carbon Per Grain Size
Ideal Critical Diameter of Iron - Carbon Alloys, In.
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
0
.10
.20
.30
.40
.50
.60
Carbon, Percent
No. 4 Grain
No. 5
No. 6
No. 7
No. 8


Multiplying Factors for Alloying Elements
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Multiplying Factor
Manganese
Chromium
Nickel
Silicon
Molybdenum
0
1.00
2.00
3.00
4.00
Percent of Element

RELATION BETWEEN DI AND DIVIDING FACTORS FOR VARIOUS DISTRANCES FROM QUENCHED END

STEP III. Determine the IH/DH ratios corresponding to each Jominy distance for a DI of 3.93. The IH/DH ratio is based on the observation that with a DI 7.30 or greater, an end-quench curve approximating a straight line out to 2 inches is obtained, and that a DI less than 7.30 will produce a falling curve. The drop in hardness at any point on the curve may be conveniently expressed as a ratio of the maximum hardness attainable (IH) to the hardness actually obtained (DH). The IH/DH ratios, or dividing factors, are plotted on the following graph:



STEP IV. Calculate the Rockwell C hardness for each distance by dividing the IH (55.5) by each respective dividing factor:

Distance, in:	Dividing Factor	Calculated HRC
1/16	-	55.5
¼	1.03	54
½	1.21	46
¾	1.41	39.5
1	1.61	34.5
1 ¼	1.75	32
1 ½	1.84	30
1 ¾	1.92	29
2	1.96	28.5

Source: Bethlehem Steel Co., "Modern Steels and Their Properties," Seventh Edition.

If the effect of various contained elements is known, it is possible to anticipate approximately the response of steel to heat treatment under identical conditions. Aside from the chemistry, the other characteristics of the steel developed by melting practice, rolling temperatures, etc., must be similar when comparing steels by this method.

Values which may be used for the various elements are:

Carbon…………0.01% = 30	Chromium……...0.01%= 5
Manganese……..0.01% = 8	Vanadium………0.01%= 20
Phosphorus…….0.001% = 4	Molybdenum…...0.01%= 16
Sulfur…………..0.001% = 1	Tungsten………..0.01%= 4
Silicon…………0.01% = 5	Copper…………0.01%= 4
Nickel…………0.01% = 4	

These factor figures have been found useful in comparing heats of steel containing the same elements. They however, are not infallible when comparing one type of steel with another, since the value of any of these alloying elements varies, depending on whether the effect is of a single element or the combined effect of several elements. This applies more particularly to alloy steels.

As an example of the application of this quick method, compare the hardness factors of AISI C1030 and AISI C1132 using the mean of the analysis range.

AISI C1030		**AISIx1132**	
Carbon…….30x30=	900	Carbon……….30x30=	900
Manganese….75x8=	600	Manganese….150x8=	1200
Phosphorus…..23x4=	92	Phosphorus…..23x4=	92
Sulfur……….27x1=	27	Sulfur………112x1=	112
Silicon……....20x5=	100	Silicon…..…….20x5=	100
Hardness Factor =	1719	Hardness Factor =	2404

An arithmetical method for obtaining the approximate tensile strength of rolled carbon steel:

T.S. = C x 650 + M x 90 + M x C x 4 + P x 1000 + 38800

Source: Bethlehem Steel Co. Catalog 107.

NOTE: A more theoretical description of Hardening may be found in ASM Handbook, Vol. 4.
http://products.asminternational.org/hbk/index.jsp

QUENCHING NOTES

As proper quenching is recognized as one of the most important steps in heat treating, the following is condensed from the Carpenter Service Bulletin on this important subject.

A still, fresh water quenching bath is not an ideal quenching medium because of the large quantity of gas dissolved which settles in the form of bubbles on the surface of the tool, especially in holes or recesses, forming soft spots which are quite likely to crack or badly weaken the tool.

A still, brine quenching bath is much better than fresh water as the salt dissolved in the water prevents the water from dissolving atmospheric gases and accordingly the brine "takes hold" and "wets" the tool all over immediately, so that quenching proceeds uniformly. Brine also throws scale better than fresh water and usually yields cleaner tools. Ordinarily the most satisfactory brine bath will contain between 5% and 10% of salt.

A still, 5% caustic soda quenching solution is one of the fastest and most efficient quenching solution is one of the fastest and most efficient quenching baths except that it is corrosive to clothing and hands and is rarely necessary for most heat treating work. Bath temperatures should be between 70° and 100°F.

Oil for quenching should have a high flash-point, low viscosity, constant composition and should be maintained at temperatures from 140°F. to 160°F.

In flush-quenching, water is just as good as brine as gas pockets cannot form on the work.

TEMPERATURE CONVERSIONS OF ºF AND ºC SCALES

Albert Sauveur type of table. Look up reading in middle column; if in degrees Centigrade, read Fahrenheit equivalent in right-hand column: if in degrees Fahrenheit, read Centigrade equivalent in Left-hand column. Values as printed in "Bethlehem Alloy Steels".

-459.0 to 0			0 to 100						100 to 1000					
ºC		ºF	ºC		ºF	ºC		ºF	ºC		ºF	ºC		ºF
-273	-459.4		-17.8	0	32	10.0	50	122.0	38	100	212	260	500	932
-268	-450		-17.2	1	33.8	10.6	51	123.8	43	110	230	266	510	950
-262	-440		-16.7	2	35.6	11.1	52	125.6	49	120	248	271	520	968
-257	-430		-16.1	3	37.4	11.7	53	127.4	54	130	266	277	530	986
-251	-420		-15.6	4	39.2	12.2	54	129.2	60	140	284	282	540	1004
-246	-410		-15.0	5	41.0	12.8	55	131.0	66	150	302	288	550	1022
-240	-400		-14.4	6	42.8	13.3	56	132.8	71	160	320	293	560	1040
-234	-390		-13.9	7	44.6	13.9	57	134.6	77	170	338	299	570	1058
-229	-380		-13.3	8	46.4	14.4	58	136.4	82	180	356	304	580	1076
-223	-370		-12.8	9	48.2	15.0	59	138.2	88	190	374	310	590	1094
-218	-360		-12.2	10	50.0	15.6	60	140.0	93	200	392	316	600	1112
-212	-350		-11.7	11	51.8	16.1	61	141.8	99	210	410	321	610	1130
-207	-340		-11.1	12	53.6	16.7	62	143.6	100	212	413.6	327	620	1148
-201	-330		-10.6	13	55.4	17.2	63	145.4	104	220	428	332	630	1166
-196	-320		-10.0	14	57.2	17.8	64	147.2	110	230	446	338	640	1184
-190	-310		-9.4	15	59.0	18.3	65	149.0	116	240	464	343	650	1202
-184	-300		-8.9	16	60.8	18.9	66	150.8	121	250	482	349	660	1220
-179	-290		-8.3	17	62.6	19.4	67	152.6	127	260	500	354	670	1238
-173	-280		-7.8	18	64.4	20.0	68	154.4	132	270	518	360	680	1256
-169	-273	-459.4	-7.2	19	66.2	20.6	69	156.2	138	280	536	366	690	1274
-168	-270	-454	-6.7	20	68.0	21.1	70	158.0	143	290	554	371	700	1292
-162	-260	-436	-6.1	21	69.8	21.7	71	159.8	149	300	572	377	710	1310
-157	-250	-418	-5.6	22	71.6	22.2	72	161.6	154	310	590	382	720	1328
-151	-240	-400	-5.0	23	73.4	22.8	73	163.4	160	320	608	388	730	1346
-146	-230	-382	-4.4	24	75.2	23.3	74	165.2	166	330	626	393	740	1364
-140	-220	-364	-3.9	25	77.0	23.9	75	167.0	171	340	644	399	750	1382
-134	-210	-346	-3.3	26	78.8	24.4	76	168.8	177	350	662	404	760	1400
-129	-200	-328	-2.8	27	80.6	25.0	77	170.6	182	360	680	410	770	1418
-123	-190	-310	-2.2	28	82.4	25.6	78	172.4	188	370	698	416	780	1436
-118	-180	-292	-1.7	29	84.2	26.1	79	174.2	193	380	716	421	790	1454
-112	-170	-274	-1.1	30	86.0	26.7	80	176.0	199	390	734	427	800	1472
-107	-160	-256	-0.6	31	87.8	27.2	81	177.8	204	400	752	432	810	1490
-101	-150	-238	0	32	89.6	27.8	82	179.6	210	410	770	438	820	1508
-96	-140	-220	0.6	33	91.4	28.3	83	181.4	216	420	788	443	830	1526
-90	-130	-202	1.1	34	93.2	28.9	84	183.2	221	430	806	449	840	1544
-84	-120	-184	1.7	35	95.0	29.4	85	185.0	27	440	824	454	850	1562
-79	-110	-166	2.2	36	96.8	30.0	86	186.4	232	450	842	460	860	1580
-73	-100	-148	2.8	37	98.6	30.6	87	188.6	238	460	860	466	870	1598
-68	-90	-130	3.3	38	100.4	31.1	88	190.4	243	470	878	471	880	1616

-62	-80	-112	3.9	39	102.2	31.7	89	192.2	249	480	896	477	890	1634
-57	-70	-94	4.4	40	104.0	32.2	90	194.0	254	490	914	482	900	1652
-51	-60	-76	5.0	41	105.8	32.8	91	195.8				488	910	1670
-46	-50	-58	5.6	42	107.6	32.3	92	197.6				493	920	1688
-40	-40	-40	6.1	43	109.4	33.9	93	199.4				499	930	1706
-34	-30	-22	6.7	44	111.2	34.4	94	201.2				504	940	1724
-29	-20	-4	7.2	45	113.0	35.0	95	203.0				510	950	1742
-23	-10	14	7.8	46	114.8	35.6	96	204.8				516	960	1760
-17.8	0	32	8.3	47	116.6	36.1	97	206.6				521	970	1778
			8.9	48	118.4	36.7	98	208.4				527	980	1796
			9.4	49	120.2	37.2	99	210.2				532	990	1814
						37.8	100	212.0				538	1000	1832

1000 to 2000						**2000 to 3000**					
ºC		**ºF**	**ºC**		**ºF**	**ºC**		**ºF**	**ºC**		**ºF**
538	1000	1832	816	1500	2732	1093	2000	3632	1371	2500	4532
543	1010	1850	821	1510	2750	1099	2010	3650	1377	2510	4550
549	1020	1868	827	1520	2768	1104	2020	3668	1382	2520	4568
554	1030	1886	832	1530	2786	1110	2030	3686	1388	2530	4586
560	1040	1904	838	1540	2804	1116	2040	3704	1393	2540	4604
566	1050	1922	843	1550	2822	1121	2050	3722	1399	2550	4622
571	1060	1940	849	1560	2840	1127	2060	3740	1404	2560	4640
577	1070	1958	854	1570	2858	1132	2070	3758	1410	2570	4658
582	1080	1976	860	1580	2876	1138	2080	3776	1416	2580	4676
588	1090	1994	866	1590	2894	1143	2090	3794	1421	2590	4694
593	1100	2012	871	1600	2912	1149	2100	3812	1427	2600	4712
599	1110	2030	877	1610	2930	1154	2110	3830	1432	2610	4730
604	1120	2048	882	1620	2948	1160	2120	3848	1438	2620	4748
640	1130	2066	888	1630	2966	1166	2130	3866	1443	2630	4766
616	1140	2084	893	1640	2984	1171	2140	3884	1449	2640	4784
621	1150	2102	899	1650	3002	1177	2150	3902	1454	2650	4802
627	1160	2120	904	1660	3020	1182	2160	3920	1460	2660	4820
632	1170	2138	910	1670	3038	1188	2170	3938	1466	2670	4838
638	1180	2156	916	1680	3056	1193	2180	3958	1471	2680	4856
643	1190	2174	921	1690	3074	1199	2190	3974	1477	2690	4874
649	1200	2192	927	1700	3092	1204	2200	3992	1482	2700	4892
654	1210	2210	932	1710	3110	1210	2210	4010	1488	2710	4910
660	1220	2228	938	1720	3128	1216	2220	4028	1493	2720	4928
666	1230	2246	943	1730	3146	1221	2230	4046	1499	2730	4946
671	1240	2264	949	1740	3164	1227	2240	4064	1504	2740	4964
677	1250	2282	954	1750	3182	1232	2250	4082	1510	2750	4982
682	1260	2300	960	1760	3200	1238	2260	4100	1516	2760	5000
688	1270	2318	966	1770	3218	1243	2270	4118	1521	2770	5018
693	1280	2336	971	1780	3236	1249	2280	4136	1527	2780	5036
699	1290	2354	977	1790	3254	1254	2290	4154	1532	2790	5054
704	1300	2372	982	1800	3272	1260	2300	4172	1538	2800	5072
710	1310	2390	988	1810	3290	1266	2310	4190	1543	2810	5090
716	1320	2408	993	1820	3308	1271	2320	4208	1549	2820	5108
721	1330	2426	999	1830	3326	1277	2330	4226	1554	2830	5126

727	1340	2444	1004	1840	3344	1282	2340	4244	1560	2840	5144
732	1350	2462	1010	1850	3362	1288	2350	4262	1566	2850	5162
738	1360	2480	1016	1860	3380	1293	2360	4280	1571	2860	5180
743	1370	2498	1021	1870	3398	1299	2370	4298	1577	2870	5198
749	1380	2516	1027	1880	3416	1304	2380	4316	1582	2880	5216
754	1390	2534	1032	1890	3434	1310	2390	4334	1588	2890	5234
760	1400	2552	1038	1900	3452	1316	2400	4352	1593	2900	5252
766	1410	2570	1043	1910	3470	1321	2410	4370	1599	2910	5270
771	1420	2588	1049	1920	488	1327	2420	4388	1604	2920	5288
777	1430	2606	1054	1930	3506	1332	2430	4406	1610	2930	5306
782	1440	2624	1060	1940	3524	1338	2440	4424	1616	2940	5324
788	1450	2642	1066	1950	3542	1343	2450	4442	1621	2950	5342
793	1460	2660	1071	1960	3560	1349	2460	4460	1627	2960	5360
799	1470	2678	1077	1970	3578	1354	2470	4478	1632	2970	5378
804	1480	2696	1082	1980	3596	1360	2480	4496	1638	2980	5396
810	1490	2714	1088	1990	3614	1366	2490	4514	1643	2990	5414
			1093	2000	3632				1649	3000	5432

PRESSURE CONVERSION FACTORS

1 in. water = .07355 in. mercury
.036 lbs./sq. in.
576 oz./sq. in.

1 in. mercury = 13.596 in. water
1.133 ft. water
.489 lbs./sq. in.
7.855 oz./sq. in.

1 lb. pressure = 27.78 in. water
2.43 in. mercury

1 oz. pressure = 1.736 in. water
127 in. mercury

1 ft. water = 883 in. mercury
.432 lbs./sq. in.

1 inch = 2.540 centimeter

1 centimeter = 0.3937 inch

1 cubic inch = 16.387 cubic centimeters

1 cubic centimeter = 0.06102 cubic inch

1 gram = 0.0022 pounds avoirdupois

1 ft. = 30.480 cm.

1 gal. = 231 cubic inches

Figure 1

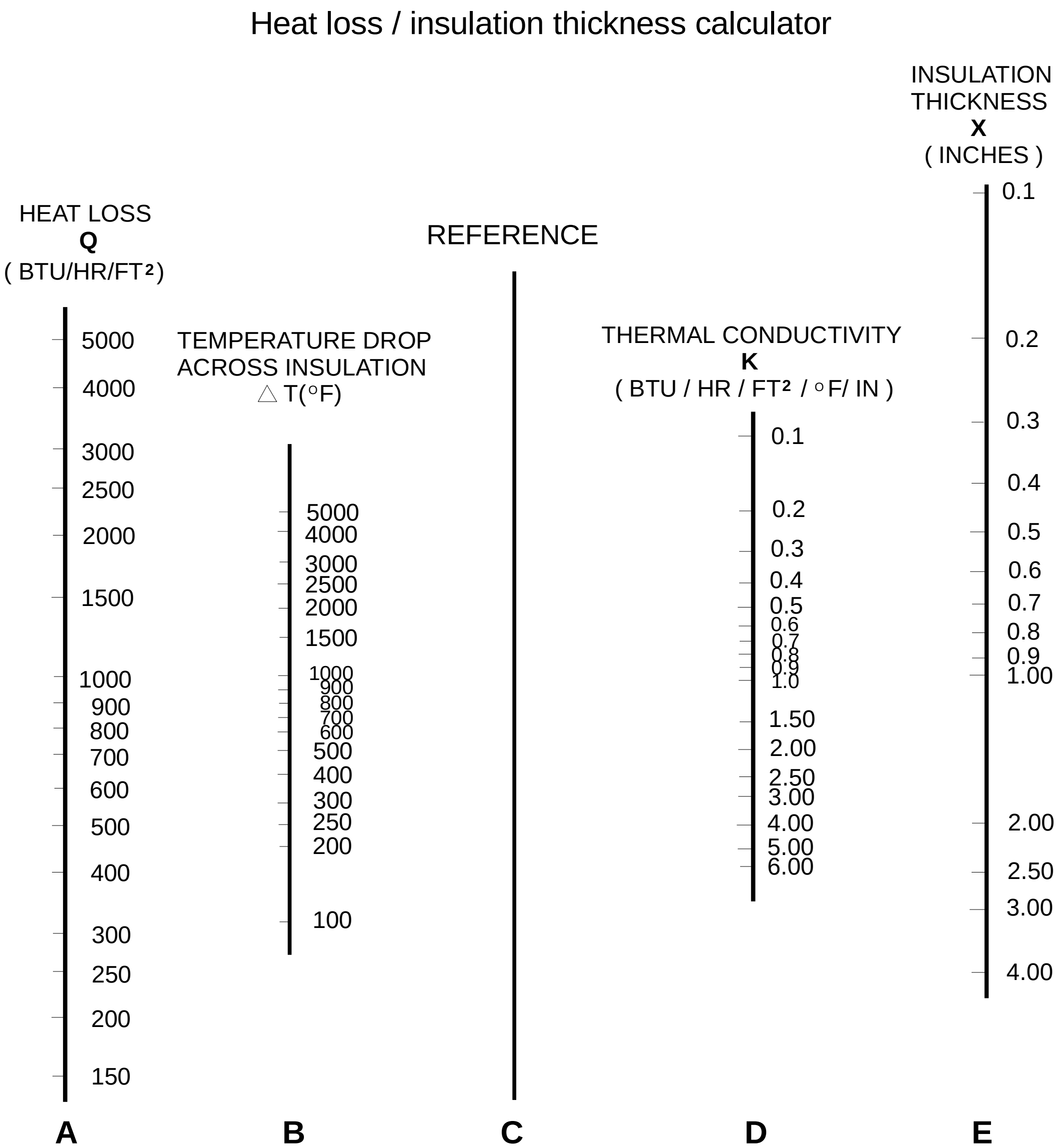
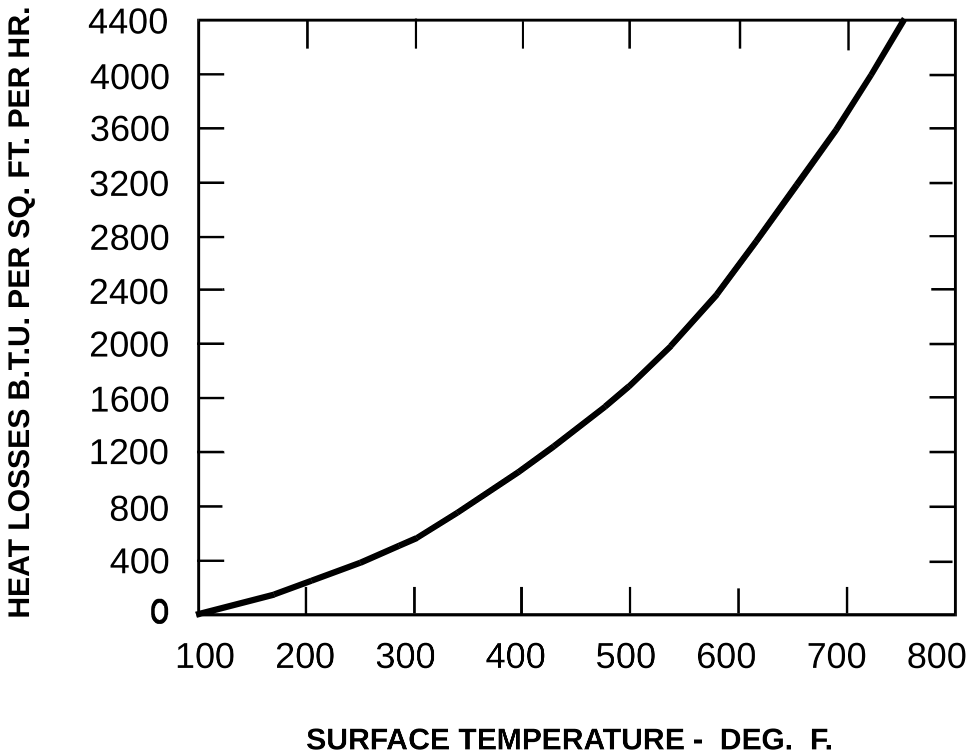


Figure 2



(1) Select: the desired outside wall temperature and estimate the heat loss from figure 1, or

(1a) Determine: the heat loss from the heat flow or heat input available.

(2) Determine: the temperature drop from the desired inside and outside wall temperatures.

(3) Obtain: the mean thermal conductivity at the average temperature from the data sheets.

(4) Connect: the heat loss (Q) on line A with the temperature difference (Δ T) on line B and extend to reference line C and mark intersections.

(5) Connect: the intersection of line C with the thermal conductivity (K) on line D and read the required insulation thickness on line E.

(6) The same procedure will enable determination of the heat loss (Q), temperature drop (Δ T) thermal conductivity (K) - knowing any three of the variables.

Simplified method of determining combustion air required to completely burn a given amount of fuel.

$$\text{CFH Air} = \frac{\text{Btu/Hr. input}}{100}$$

To correct gas volume from one set of conditions to another

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

P = absolute pressure

= 14.7 + gauge psi.

T = absolute temperature in $^{\circ}R = {^{\circ}F} + 460$

V = Volume in any consistent terms.

Normally useful for determining standard cubic feet of fuel consumed when metering pressure is other than standard i.e., gas passing through a volumetric gas meter at 5 psig., for example. (The heating valve of fuel gases is based on Btu/CF at standard gas conditions.)

Turndown Ratio of Fixed Area Burner.

$$\text{T.D.} = \sqrt{\frac{\text{Maximum Pressure Drop across Burner}}{\text{Minimum Pressure Drop across Burner}}}$$

Where pressure drops are expressed in the same units.

Relationship between flow capacity at a specified pressure drop and C_V factor.

C_V = Flow Factor. Defined as the amount of water @ 60°F in gallons per minute which will flow through a valve in the open position with a pressure drop through the valve of 1 pound per square inch.

For capacity conversion to gases the following formula may be used for pressure ratios less than critical ratios.

$$Q = 1360\, C_V \sqrt{\frac{V(P_1 - P_2)\, P_2}{GT}}$$

Q = SCFH @ 14.7 psia. and 60°F.
P_1 = Inlet pressure, PSIA.
P_2 = Outlet pressure, PSIA.
T = Flowing temperature, °R.
G = Specific gravity of the gas.

ABBREVIATIONS FOR METRIC UNITS

C	degree centigrade
cal	calorie
cm	centimeter
g	gram
j,J	joule
kcal, Kcal	kilogram-calorie
Kg	kilogram
l	liter
m	meter
mm	millimeter

METRIC TO METRIC ONVERSION

Area:	1 sq. m = 10,000 sq. cm = 1,000,000 sq. mm
Heat:	1 kcal = 1000 cal = 4184 joules
Length:	1 m = 100 cm = 1000 mm
Pressure:	1 kg/sq. cm = 10,000 kg/sq. m = 1000 cm H^2O = 735.6 mm Hg = 0.982 bars
Volume:	1 cu m = 1,000,000 cu cm = 999.97 l
Weight:	1 kg = 1000 g

AREA

Metric to English
1 sq. mm = 0.00155 sq. in = 0.00001076 sq. ft
1 sq. cm = 0.15 sq. in = 0.001076 sq. ft
1 sq. m = 1550 sq. in = 10.76 sq. ft

English to Metric
1 sq. in = 645.16 sq. mm = 6.452 sq. cm = 0.0006452 sq. m
1 sq. ft = 92,903 sq. mm = 929.03 sq. cm = 0.0929 sq. m

DENSITY

Metric to English
1 g/cu cm = 0.036 lb./cu in = 62.43 lb./cu ft

English to Metric
1 lb./cu in = 27.68 g/cu cm
1 lb./cu ft = 0.016 g/cu m

HEAT

Metric to English
1 cal = 0.003967 Btu
1 kcal = 3.967 Btu
1 joule = 0.000948 Btu

English to Metric
1 Btu = 251.996 cal = 0.252 kcal = 1054.35 joules

HEAT CONTENT

Metric to English
1cal/g = 1.8 Btu/lb.
1 cal/g - °C = 1 Btu/lb.-°F
1 cal/cu cm = 112.37 Btu/cu ft
1 kcal/cu m = 0.112 Btu/cu ft

English to Metric
1 Btu/lb. = 0.0556 cal/g
1 Btu/lb.-°F = 1 cal/g - °C
1 Btu/cu ft = 0.8898 cal/cu m = 8.898 kcal/cu m

HEAT FLUX

Metric to English
1 cal/hr-sq. cm = 3.687 Btu/hr-sq. ft
1 cal/hr-sq. cm = 1.082 watts/sq. ft

English to Metric
1 Btu/hr-sq. ft = 0.271 cal hr-sq. cm
1 kw/sq. ft = 925 cal/hr-sq. cm

LENGTH

Metric to English
1 mm = 0.03937 in = 0.003281 ft
1 cm = 0.3937 in = 0.03281 ft
1 m = 39.37 in = 3.281 ft

English to Metric
1 in = 25.4 mm = 2.54 cm = 0.0254 m
1 ft = 304.8 mm = 30.48 cm = 0.3048 m

PRESSURE

Metric to English
1 kg/sq. cm = 14.21 lb./ sq. in = 29.0 in Hg = 393.72 in H2O
1 g/sq. cm = 0.01421 lb./sq. in = 0.2274 oz/sq. in = 0.3936 in H2O
1 mm Hg = 1 torr = 0.01933 lb./sq. in

English to Metric
1 lb./sq. in = 0.0703 kg/sq. cm = 70.306 g/sq. cm = 703 mm H2O
1 oz/sq. in = 0.00439 kg/sq. cm = 4.39 g/sq. cm = 44 mm H2O
1 in H2O = 0.00254 kg/sq. cm = 2.54 g/sq. cm
1 in Hg = 0.491 lb./sq. in = 25.4 torrs

THERMAL CONDUCTIVITY

Metric to English

1 cal cm/hr-sq. cm - ^oC = .0672 Btu ft/hr-sq. ft - ^oF
= 0.807 Btu-in/hr-sq. ft - ^oF

English to Metric

1 Btu ft/hr-sq. ft - ^oF = 14.88 cal cm/hr sq. cm - ^oC
1 Btu in/hr-sq. ft - ^oF = 1.24 cal cm/hr-sq. cm - ^oC

VELOCITY

Metric to English

1 cm/sec = 0.393 in/sec
= 0.03281 ft/sec
= 1.9686 ft/min
1 m/sec = 39.37 in/sec
= 3.281 ft/sec
= 196.86 ft/min

English to Metric

1 in/sec = 2.54 cm/sec = 0.0254 m/sec
1 ft/sec = 30.48 cm/sec = 0.3048 m/sec
1 ft/min = 0.508 cm/sec = 0.00508 m/sec

VOLUME

Metric to English

1 cu cm = 0.0610 cu in = 0.034 U.S. fluid oz
1 cu m = 61,020 cu in = 35.31 cu ft = 264.17 U.S. gal
1 l = 61.025 cu in = 0.0353 cu ft = 0.264 U.S. gal

English to Metric

1 cu in = 16.387 cu cm = 0.00001639 cu m = 0.0164 l
1 cu ft = 28,316.8 cu cm = 0.0283 cu m = 28.316 l
1 U.S. gal = 3785.4 cu cm = 0.003785 cu m = 3785 l

WEIGHT

Metric to English

1 g = 0.035 oz avdp
1 kg = 35.27 oz avdp = 2.204 lb. avdp

English to Metric

1 oz avdp = 28.35 g = 0.02835 kg
1 lb. avdp = 453.59 g = 0.4536 kg

TEMPERATURE

$^{o}C = 5/9\ (^{o}F-32)$
$^{o}F = (9/5\ ^{o}C) + 32$
$^{o}K = {^{o}C} + 273.15$
$^{o}R = {^{o}F} + 459.67$

AREA		
MULTIPLY	**BY**	**TO OBTAIN**
square inch	6.4516	square centimeter
	0.0645	square decimeter
	1,273,240	circular mil
square centimeter	0.1550	square inch
	0.0010764	square foot
square decimeter	15.500	square inch
circular mil	0.0000007854	square inch
square foot	0.0929	square meter

MASS		
MULTIPLY	**BY**	**TO OBTAIN**
ounce (Av)	28.3495	gram
gram	0.03527	ounce (Av)
	0.002205	pound (Av)
pound	0.453592	kilogram
kilogram	2.20462	pound (Av)

LENGTH

MULTIPLY	BY	TO OBTAIN
inch	2.540	centimeter
centimeter	0.3937	inch
foot	30.48	centimeter
centimeter	0.0328	foot
yard	0.9144	meter
meter	1.0936	yard
mile	1.6094	kilometer
kilometer	0.6214	mile

SPECIFIC HEAT

MULTIPLY	BY	TO OBTAIN
Btu per pound per °F	1.000	calorie per gram per °C
	4.186	joule per gram per °C
calorie per gram per °C	1.000	Btu per pound per °F
	4.186	joule per gram per °C
joule per gram per °C	0.2389	calorie per gram per °C
	0.2389	Btu per pound per °F
Btu per pound per °F	4186.82	joule per kg per °K
joule per kg per °K	0.0002388	Btu per pound per °F

MISCELLANEOUS

MULTIPLY	BY	TO OBTAIN
gallon of water (62°F)	8.337	pound of water
cubic foot of water (62°F)	62.369	pound of water
inch of water (39.1°F)	0.036127	pound per square inch
foot of water (39.1°F)	0.43352	pound per square inch

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