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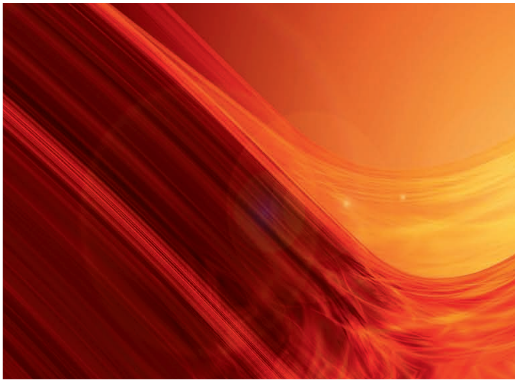

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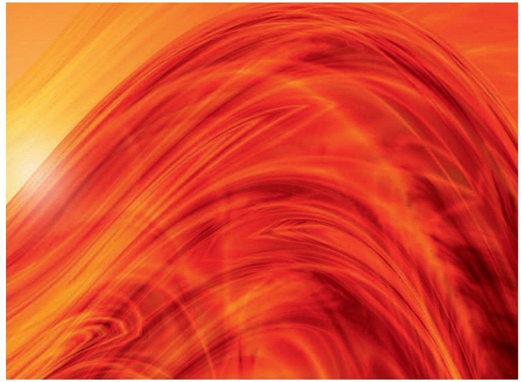

Practical Data for Metallurgists

Practical Data for Metallurgists

Sixteenth Edition

Welcome to the Practical Data for Metallurgists, the guide that technical experts, operations managers and engineering personnel have turned to for more than 50 years for the latest metallurgical information. Our guide—which conforms with information published by AISI and SAE—includes an updated listing of standard steels and their chemical compositions, hardening abilities and tolerances.

At Timken, we use a combination of materials science, application engineering and processing capabilities to add value and improve the performance of our customers. Providing you with the information you need to make informed decisions about your alloy steel needs is just one way we help you reach your fullest potential.

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STANDARD CARBON STEELS
Chemical Composition Ranges and Limits

SAE No.	C	Mn	P Max	S Max
1005	.06 max	.35 max	.040	.050
1006	.08 max	.25/.40	.040	.050
1008	.10 max	.30/.50	.040	.050
1010	.08/.13	.30/.60	.040	.050
1011	.08/.14	.60/.90	.040	.050
1012	.10/.15	.30/.60	.040	.050
1013	.11/.16	.30/.60	.030	.050
1015	.13/.18	.30/.60	.040	.050
1016	.13/.18	.60/.90	.040	.050
1017	.15/.20	.30/.60	.040	.050
1018	.15/.20	.60/.90	.040	.050
1020	.18/.23	.30/.60	.040	.050
1021	.18/.23	.60/.90	.040	.050
1022	.18/.23	.70/1.00	.040	.050
1023	.20/.25	.30/.60	.040	.050
1025	.22/.28	.30/.60	.040	.050
1026	.22/.28	.60/.90	.040	.050
1029	.25/.31	.60/.90	.040	.050
1030	.28/.34	.60/.90	.040	.050
1035	.32/.38	.60/.90	.040	.050
1038	.35/.42	.60/.90	.040	.050
1039	.37/.44	.70/1.00	.040	.050
1040	.37/.44	.60/.90	.040	.050
1042	.40/.47	.60/.90	.040	.050
1043	.40/.47	.70/1.00	.040	.050
1044	.43/.50	.30/.60	.040	.050
1045	.43/.50	.60/.90	.040	.050
1046	.43/.50	.70/1.00	.040	.050
1049	.46/.53	.60/.90	.040	.050
1050	.48/.55	.60/.90	.040	.050
1053	.48/.55	.70/1.00	.040	.050
1055	.50/.60	.60/.90	.040	.050
1060	.55/.65	.60/.90	.040	.050
1065	.60/.70	.60/.90	.040	.050
1070	.65/.75	.60/.90	.040	.050
1074	.70/.80	.50/.80	.040	.050
1078	.72/.85	.30/.60	.040	.050
1080	.75/.88	.60/.90	.040	.050
1086	.80/.93	.30/.50	.040	.050
1090	.85/.98	.60/.90	.040	.050
1095	.90/1.03	.30/.50	.040	.050

FREE CUTTING RESULPHURIZED STEELS

Chemical Composition Ranges and Limits

SAE No.	C	Mn	P Max	S
1117	.14/.20	1.00/1.30	.030	.08/.13
1118	.14/.20	1.30/1.60	.030	.08/.13
1126	.23/.29	.70/1.00	.030	.08/.13
1132	.27/.34	1.35/1.65	.030	.08/.13
1137	.32/.39	1.35/1.65	.030	.08/.13
1138	.34/.40	.70/1.00	.030	.08/.13
1140	.37/.44	.70/1.00	.030	.08/.13
1141	.37/.45	1.35/1.65	.030	.08/.13
1144	.40/.48	1.35/1.65	.030	.24/.33
1146	.42/.49	.70/1.00	.030	.08/.13
1151	.48/.55	.70/1.00	.030	.08/.13

FREE CUTTING REPHOSPHORIZED AND RESULPHURIZED STEEL

Chemical Composition Ranges and Limits

SAE No.	C	Mn	P	S
1212	.13 max	.70/1.00	.07/.12	.16/.23
1213	.13 max	.70/1.00	.07/.12	.24/.33
1215	.09 max	.75/1.05	.04/.09	.26/.35

NOTE: 12XX grades are customarily furnished without specified silicon content because of adverse effect on machinability.

HIGH MANGANESE CARBON STEEL

Chemical Composition Ranges and Limits

SAE No.	C	Mn	P Max	S Max
1522	.18/.24	1.10/1.40	.030	.050
1524	.19/.25	1.35/1.65	.030	.050
1526	.22/.29	1.10/1.40	.030	.050
1527	.22/.29	1.20/1.50	.030	.050
1541	.36/.44	1.35/1.65	.030	.050
1547	.43/.51	1.35/1.65	.030	.050
1548	.44/.52	1.10/1.40	.030	.050
1552	.47/.55	1.20/1.50	.030	.050
1566	.60/.71	.85/1.15	.030	.050

STANDARD ALLOY STEELS
Chemical Composition Ranges and Limits

SAE No.	C	Mn	Cr	Ni	Mo	Other
1330	.28/.33	1.60/1.80	....	....	....	....
1335	.33/.38	1.60/1.90	....	....	....	....
1340	.38/.43	1.60/1.90	....	....	....	....
4023	.20/.25	.70/.90	....	....	.20/.30	....
4027	.25/.30	.70/.90	....	....	.20/.30	....
4037	.35/.40	.70/.90	....	....	.20/.30	....
4047	.45/.50	.70/.90	....	....	.20/.30	....
4118	.18/.23	.70/.90	.40/.60	....	.08/.15	....
4120[a]	.18/.23	.90/1.20	.40/.60	....	.13/.20	....
4130	.28/.33	.40/.60	.80/1.10	....	.15/.25	....
4137	.35/.40	.70/.90	.80/1.10	....	.15/.25	....
4140	.38/.43	.75/1.00	.80/1.10	....	.15/.25	....
4142	.40/.45	.75/1.00	.80/1.10	....	.15/.25	....
4145	.43/.48	.75/1.00	.80/1.10	....	.15/.25	....
4150	.48/.53	.75/1.00	.80/1.10	....	.15/.25	....
4320	.17/.22	.45/ .65	.40/.60	1.65/2.00	.20/.30	....
4340	.38/.43	.60/.80	.70/.90	1.65/2.00	.20/.30	....
E4340	.38/.43	.65/.85	.70/.90	1.65/2.00	.20/.30	....
4620	.17/.22	.45/.65	....	1.65/2.00	.20/.30	....
4820	.18/.23	.50/.70	....	3.25/3.75	.20/.30	....
50B46§	.44/.49	.75/1.00	.20/.35	....	....	....
5120	.17/.22	.70/.90	.70/.90	....	....	....
5130	.28/.33	.70/.90	.80/1.10	....	....	....
5132	.30/.35	.60/.80	.75/1.00	....	....	....
5140	.38/.43	.70/.90	.70/.90	....	....	....
5150	.48/.53	.70/.90	.70/.90	....	....	....
5160	.56/.64	.75/1.00	.70/.90	....	....	....
51B60§	.56/.64	.75/1.00	.70/.90	....	....	....
51100	.98/1.10	.25/.45	.90/1.15	....	....	....
E52100	.98/1.10	.25/.45	1.30/1.60	....	....	P = .025 S = .025
52100	.93/1.05	.25/.45	1.35/1.60	....	....	P = .025 S = .015

SAE No.	C	Mn	Cr	Ni	Mo	Other
						V
6150	.48/.53	.70/.90	.80/1.10	....	....	.15 min
8615	.13/.18	.70/.90	.40/.60	.40/.70	.15/.25	....
8617	.15/.20	.70/.90	.40/.60	.40/.70	.15/.25	....
8620	.18/.23	.70/.90	.40/.60	.40/.70	.15/.25	....
8622	.20/.25	.70/.90	.40/.60	.40/.70	.15/.25	....
8630	.28/.33	.70/.90	.40/.60	.40/.70	.15/.25	....
8640	.38/.43	.75/1.00	.40/.60	.40/.70	.15/.25	....
8645	.43/.48	.75/1.00	.40/.60	.40/.70	.15/.25	....
8720	.18/.23	.70/.90	.40/.60	.40/.70	.20/.30	....
8822	.20/.25	.75/1.00	.40/.60	.40/.70	.30/.40	....
						Si
9259	.56/.64	.75/1.00	.45/.65	....	....	.70/1.10
9260	.56/.64	.75/1.00	....	....	....	1.80/2.20

§B = .0005/.003 [a] Formerly PS 15

Unless specified:
Si = .15/.35, P = .035 max (SAE J1268), S = .040 max, Ni = .25 max, Cr = .20 max, Mo = .06 max

These standard grades can have modifications in chemistry when agreed upon by user and supplier.

PS GRADES (Formerly EX Grades)

Chemical Composition Ranges and Limits

PS No.	C	Mn	Cr	Ni	Mo	Other
10	.19/.24	.95/1.25	.25/.40	.20/.40	.05/.10	....
16	.20/.25	.90/1.20	.40/.60	....	.13/.20	....
17	.23/.28	.90/1.20	.40/.60	....	.13/.20	....
18	.25/.30	.90/1.20	.40/.60	....	.13/.20	**B**
19	.18/.23	.90/1.20	.40/.60	....	.08/.15	.0005-.003
20	.13/.18	.90/1.20	.40/.60	....	.13/.20	....
21	.15/.20	.90/1.20	.40/.60	....	.13/.20	....
31	.15/.20	.70/.90	.45/.65	.70/1.00	.45/.60	....
32	.18/.23	.70/.90	.45/.65	.70/1.00	.45/.60	....
33	.17/.24	.85/1.25	.20 min	.20 min	.05 min	....
34	.28/.33	.90/1.20	.40/.60	....	.13/.20	....
36	.38/.43	.90/1.20	.45/.65	....	.13/.20	....
38	.43/.48	.90/1.20	.45/.65	....	.13/.20	....
39	.48/.53	.90/1.20	.45/.65	....	.13/.20	....
40	.51/.59	.90/1.20	.45/.65	....	.13/.20	....
54	.19/.25	.70/1.05	.40/.70	....	.05 min	....
55	.15/.20	.70/1.00	.45/.65	1.65/2.00	.65/.80	....
56	.08/.13	.70/1.00	.45/.65	1.65/2.00	.65/.80	....
57†	.08 max	1.25 max	17.00/19.00	....	1.75/2.25	....
58	.16/.21	1.00/1.30	.45/.65	....	....	....
59	.18/.23	1.00/1.30	.70/.90	....	....	....
61	.23/.28	1.00/1.30	.70/.90	....	....	**B**
63	.31/.38	.75/1.10	.45/.65	....	....	.0005-.003
64	.16/.21	1.00/1.30	.70/.90	....	....	....
65	.21/.26	1.00/1.30	.70/.90	....	....	**V**
66	.16/.21	.40/.70	.45/.75	1.65/2.00	.08/.15	.10/.15
67	.42/.49	.80/1.20	.85/ 1.20	....	.25/.35	....

Unless Specified:
Si = .15/.35, P = .035 max, S = .040 max

† P = .040 max, S = .15/.35, Si = 1.00 max

Note: PS Nos. 15, 24 and 30 are now standard grades.
(See SAE Nos. 4120, 4121 and 4715)

STANDARD H STEELS
Chemical Composition Ranges

SAE No.	C	Mn	Cr	Ni	Mo	Other
1330 H	.27/.33	1.45/2.05	....	....	....	....
1335 H	.32/.38	1.45/2.05	....	....	....	....
1340 H	.37/.44	1.45/2.05	....	....	....	....
1345 H	.42/.49	1.45/2.05	....	....	....	....
4027 H	.24/.30	.60/1.00	....	....	.20/.30	....
4028 H[a]	.24/.30	.60/1.00	....	....	.20/.30	....
4032 H	.29/.35	.60/1.00	....	....	.20/.30	....
4037 H	.34/.41	.60/1.00	....	....	.20/.30	....
4042 H	.39/.46	.60/1.00	....	....	.20/.30	....
4047 H	.44/.51	.60/1.00	....	....	.20/.30	....
4118 H	.17/.23	.60/1.00	.30/.70	....	.08/.15	....
4130 H	.27/.33	.30/.70	.75/1.20	....	.15/.25	....
4135 H	.32/.38	.60/1.00	.75/1.20	....	.15/.25	....
4137 H	.34/.41	.60/1.00	.75/1.20	....	.15/.25	....
4140 H	.37/.44	.65/1.10	.75/1.20	....	.15/.25	....
4142 H	.39/.46	.65/1.10	.75/1.20	....	.15/.25	....
4145 H	.42/.49	.65/1.10	.75/1.20	....	.15/.25	....
4147 H	.44/.51	.65/1.10	.75/1.20	....	.15/.25	....
4150 H	.47/.54	.65/1.10	.75/1.20	....	.15/.25	....
4161 H	.55/.65	.65/1.10	.65/.95	....	.25/.35	....
4320 H	.17/.23	.40/.70	.35/.65	1.55/2.00	.20/.30	....
4340 H	.37/.44	.55/.90	.65/.95	1.55/2.00	.20/.30	....
E4340 H	.37/.44	.60/.95	.65/.95	1.55/2.00	.20/.30	....
4620 H	.17/.23	.35/.75	....	1.55/2.00	.20/.30	....
4718 H	.15/.21	.60/.95	.30/.60	.85/1.25	.30/.40	....
4720 H	.17/.23	.45/.75	.30/.60	.85/1.25	.15/.25	....
4815 H	.12/.18	.30/.70	....	3.20/3.80	.20/.30	....
4817 H	.14/.20	.30/.70	....	3.20/3.80	.20/.30	....
4820 H	.17/.23	.40/.80	....	3.20/3.80	.20/.30	....
50B40 H[b]	.37/.44	.65/1.10	.30/.70	....	....	....
50B44 H[b]	.42/.49	.65/1.10	.30/.70	....	....	....
5046 H	.43/.50	.65/1.10	.13/.43	....	....	....
50B46 H[b]	.43/.50	.65/1.10	.13/.43	....	....	....
50B50 H[b]	.47/.54	.65/1.10	.30/.70	....	....	....
50B60 H[b]	.55/.65	.65/1.10	.30/.70	....	....	....

[a] S = .035/.050
[b] B = .0005/.003

STANDARD H STEELS – continued

SAE No.	C	Mn	Cr	Ni	Mo	Other
5120 H	.17/.23	.60/1.00	.60/1.00	....	....	....
5130 H	.27/.33	.60/1.00	.75/1.20	....	....	....
5132 H	.29/.35	.50/.90	.65/1.10	....	....	....
5135 H	.32/.38	.50/.90	.70/1.15	....	....	....
5140 H	.37/.44	.60/1.00	.60/1.00	....	....	....
5147 H	.45/.52	.60/1.05	.80/1.25	....	....	....
5150 H	.47/.54	.60/1.00	.60/1.00	....	....	....
5155 H	.50/.60	.60/1.00	.60/1.00	....	....	....
5160 H	.55/.65	.65/1.10	.60/1.00	....	....	....
51B60H[b]	.55/.65	.65/1.10	.60/1.00	....	....	....
						V
6118 H	.15/.21	.40/.80	.40/.80	....	....	.10/.15
6150 H	.47/.54	.60/1.00	.75/1.20	....	....	.15 min.
81B45 H[b]	.42/.49	.70/1.05	.30/.60	.15/.45	.08/.15	....
8617 H	.14/.20	.60/.95	.35/.65	.35/.75	.15/.25	....
8620 H	.17/.23	.60/.95	.35/.65	.35/.75	.15/.25	....
8622 H	.19/.25	.60/.95	.35/.65	.35/.75	.15/.25	....
8625 H	.22/.28	.60/.95	.35/.65	.35/.75	.15/.25	....
8627 H	.24/.30	.60/.95	.35/.65	.35/.75	.15/.25	....
8630 H	.27/.33	.60/.95	.35/.65	.35/.75	.15/.25	....
86B30 H[b]	.27/.33	.60/.95	.35/.65	.35/.75	.15/.25	....
8637 H	.34/.41	.70/1.05	.35/.65	.35/.75	.15/.25	....
8640 H	.37/.44	.70/1.05	.35/.65	.35/.75	.15/.25	....
8642 H	.39/.46	.70/1.05	.35/.65	.35/.75	.15/.25	....
8645 H	.42/.49	.70/1.05	.35/.65	.35/.75	.15/.25	....
86B45 H[b]	.42/.49	.70/1.05	.35/.65	.35/.75	.15/.25	....
8650 H	.47/.54	.70/1.05	.35/.65	.35/.75	.15/.25	....
8655 H	.50/.60	.70/1.05	.35/.65	.35/.75	.15/.25	....
8660 H	.55/.65	.70/1.05	.35/.65	.35/.75	.15/.25	....
8720 H	.17/.23	.60/.95	.35/.65	.35/.75	.20/.30	....
8740 H	.37/.44	.70/1.05	.35/.65	.35/.75	.20/.30	....
8822 H	.19/.25	.70/1.05	.35/.65	.35/.75	.30/.40	....
						Si
9260 H	.55/.65	.65/1.10	....	....	....	1.70/2.20
9310 H	.07/.13	.40/.70	1.00/1.45	2.95/3.55	.08/.15	....
94B15 H[b]	.12/.18	.70/1.05	.25/.55	.25/.65	.08/.15	....
94B17 H[b]	.14/.20	.70/1.05	.25/.55	.25/.65	.08/.15	....
94B30 H[b]	.27/.33	.70/1.05	.25/.55	.25/.65	.08/.15	....

Unless specified:
Si = .15/.35, P = .030 max (SAE J1268), S = .040 max, Cu = .35 max, Ni = .25 max, Cr = .20 max, Mo = .06 max

[b] B = .0005/.003

STANDARD CARBON AND CARBON BORON H STEELS

Chemical Composition Ranges and Limits

SAE No.	C	Mn	P Max	S Max	Si
1038 H	.34/.43	.50/1.00	.030	.050	.15/.35
1045 H	.42/.51	.50/1.00	.030	.050	.15/.35
1522 H	.17/.25	1.00/1.50	.030	.050	.15/.35
1524 H	.18/.26	1.25/1.75	.030	.050	.15/.35
1526 H	.21/.30	1.00/1.50	.030	.050	.15/.35
1541 H	.35/.45	1.25/1.75	.030	.050	.15/.35
15B21*	.17/.24	.70/1.20	.030	.050	.15/.35
15B28H	.25/.34	1.00/1.50	.030	.050	.15/.35
15B30H	.27/.35	.70/1.20	.030	.050	.15/.35
15B35H*	.31/.39	.70/1.20	.030	.050	.15/.35
15B37H*	.30/.39	1.00/1.50	.030	.050	.15/.35
15B41H*	.35/.45	1.25/1.75	.030	.050	.15/.35
15B48H*	.43/.53	1.00/1.50	.030	.050	.15/.35
15B62H*	.54/.67	1.00/1.50	.030	.050	.40/.60

For electric furnace steels P & S = .025 max and the prefix E is added.
*B = .0005/.003

RESTRICTED HARDENABILITY STEELS

Chemical Composition Ranges

SAE No.	C	Mn	Si	Ni	Cr	Mo
15B21RH*	.17/.22	.80/1.10	.15/.35	....	....	....
15B35RH*	.33/.38	.80/1.10	.15/.35	....	....	....
3310RH	.08/.13	.40/.60	.15/.35	3.25/3.75	1.40/1.75	....
4027RH	.25/.30	.70/.90	.15/.35	....	....	.20/.30
4118RH	.18/.23	.70/.90	.15/.35	....	.40/.60	.08/.15
4120RH	.18/.23	.90/1.20	.15/.35	....	.40/.60	.13/.20
4130RH	.28/.33	.40/.60	.15/.35	....	.80/1.10	.15/.25
4140RH	.38/.43	.75/1.00	.15/.35	....	.80/1.10	.15/.25
4145RH	.43/.48	.75/1.00	.15/.35	....	.80/1.10	.15/.25
4161RH	.56/.64	.75/1.00	.15/.35	....	.70/.90	.25/.35
4320RH	.17/.22	.45/.65	.15/.35	1.65/2.00	.40/.60	.20/.30
4620RH	.17/.22	.45/.65	.15/.35	1.65/2.00	....	.20/.30
4820RH	.18/.23	.50/.70	.15/.35	3.25/3.75	....	.20/.30
50B40RH*	.38/.43	.75/1.00	.15/.35	....	.40/.60	....
5130RH	.28/.33	.70/.90	.15/.35	....	.80/1.10	....
5140RH	.38/.43	.70/.90	.15/.35	....	.70/.90	....
5160RH	.56/.64	.75/1.00	.15/.35	....	.70/.90	....
8620RH	.18/.23	.70/.90	.15/.35	.40/.70	.40/.60	.15/.25
8622RH	.20/.25	.70/.90	.15/.35	.40/.70	.40/.60	.15/.25
8720RH	.18/.23	.70/.90	.15/.35	.40/.70	.40/.60	.20/.30
8822RH	.20/.25	.75/1.00	.15/.35	.40/.70	.40/.60	.30/.40
9310RH	.08/.13	.45/.65	.15/.35	3.00/3.50	1.00/1.40	.08/.15

Unless specified: Cu = .35 max, Ni = .25 max, Cr = .20 max, Mo = .06 max
*B = .0005 /.003

FORMERLY STANDARD STEELS

Chemical Composition Ranges and Limits

SAE No.	C	Mn	P Max	S Max
1009	.15 max	.60 max	.040	.050
1033	.30/.36	.70/1.00	.040	.050
1034	.32/.38	.50/.80	.040	.050
1037	.32/.38	.70/1.00	.040	.050
1059	.55/.65	.50/.80	.040	.050
1062	.54/.65	.85/1.15	.040	.050
1064	.60/.70	.50/.80	.040	.050
1069	.65/.75	.40/.70	.040	.050
1075	.70/.80	.40/.70	.040	.050
1084	.80/.93	.60/.90	.040	.050
1085	.80/.93	.70/1.00	.040	.050
1086	.80/.94	.30/.50	.040	.050
1108	.08/.13	.50/.80	.040	.08/.13
1109	.08/.13	.60/.90	.040	.08/.13
1110	.08/.13	.30/.60	.040	.08/.13
1111	.13 max	.60/.90	.07/0.12	.10/.15
1112	.13 max	.70/1.00	.07/0.12	.16/.23
1113	.13 max	.70/1.00	.07/0.12	.24/.33
1114	.10/.16	1.00/1.30	.040	.08/.13
1115	.13/.18	.60/.90	.040	.08/.13
1116	.14/.20	1.10/1.40	.040	.16/.23
1119	.14/.20	1.00/1.30	.040	.24/.33
1120	.18/.23	.70/1.00	.040	.08/.13
1123	.20/.27	1.20/1.50	.040	.06/.09
1139	.35/.43	1.35/1.65	.040	.13/.20
1145	.42/.49	.70/1.00	.040	.04/.07
1152	.48/.55	.70/1.00	.040	.06/.09
1211	.13 max	.60/.90	.07/.12	.10/.15
1320	.18/.23	1.60/1.90	.040	.040
1345	.43/.48	1.60/1.90	.035	.040
1513	.10/.16	1.10/1.40	.030	.050
1518	.15/.21	1.10/1.40	.040	.050
1525	.23/.29	.80/1.10	.040	.050
1533	.30/.37	1.10/1.40	.040	.050
1534	.30/.37	1.20/1.50	.040	.050
1536	.30/.37	1.20/1.50	.040	.050
1544	.40/.47	.80/1.10	.040	.050
1545	.43/.50	.80/1.10	.040	.050
1546	.44/.52	1.00/1.30	.040	.050
1551	.45/.56	.85/1.15	.040	.050
1553	.48/.55	.80/1.10	.040	.050
1561	.55/.65	.75/1.05	.040	.050
1570	.65/.75	.80/1.10	.040	.050
1572	.65/.76	1.00/1.30	.040	.050
1580	.75/.88	.80/1.10	.040	.050
1590	.85/.98	.80/1.10	.040	.050

FORMERLY STANDARD STEELS – continued
Chemical Composition Ranges and Limits

SAE No.	C	Mn	Cr	Ni	Mo	Other
2317	.15/.20	.40/.60	....	3.25/3.75	....	....
2330	.28/.33	.60/.80	....	3.25/3.75	....	....
2340	.38/.43	.70/.90	....	3.25/3.75	....	....
2345	.43/.48	.70/.90	....	3.25/3.75	....	....
2512	.09/.14	.45/.60	....	4.75/5.25	....	....
2515	.12/.17	.40/.60	....	4.75/5.25	....	....
2517	.15/.20	.45/.60	....	4.75/5.25	....	....
3115	.13/.18	.40/.60	.55/.75	1.10/1.40	....	....
3120	.17/.22	.60/.80	.55/.75	1.10/1.40	....	....
3130	.28/.33	.60/.80	.55/.75	1.10/1.40	....	....
3135	.33/.38	.60/.80	.55/.75	1.10/1.40	....	....
X3140	.38/.43	.70/.90	.70/.90	1.10/1.40	....	....
3140	.38/.43	.70/.90	.55/.75	1.10/1.40	....	....
3145	.43/.48	.70/.90	.70/.90	1.10/1.40	....	....
3150	.48/.53	.70/.90	.70/.90	1.10/1.40	....	....
3215	.10/.20	.30/.60	.90/1.25	1.50/2.00	....	....
3220	.15/.25	.30/.60	.90/1.25	1.50/2.00	....	....
3230	.25/.35	.30/.60	.90/1.25	1.50/2.00	....	....
3240	.35/.45	.30/.60	.90/1.25	1.50/2.00	....	....
3245	.40/.50	.30/.60	.90/1.25	1.50/2.00	....	....
3250	.45/.55	.30/.60	.90/1.25	1.50/2.00	....	....
3310	.08/.13	.45/.60	1.40/1.75	3.25/3.75	....	....
3311	.10/.16	.30/.50	1.30/1.60	3.25/3.75	.15 max	....
3312	.08/.13	.45/.60	1.40/1.75	3.25/3.75	....	....
3316	.14/.19	.45/.60	1.40/1.75	3.25/3.75	....	....
3325	.20/.30	.30/.60	1.25/1.75	3.25/3.75	....	....
3335	.30/.40	.30/.60	1.25/1.75	3.25/3.75	....	....
3340	.35/.45	.30/.60	1.25/1.75	3.25/3.75	....	....
3415	.10/.20	.30/.60	.60/.95	2.75/3.25	....	....
3435	.30/.40	.30/.60	.60/.95	2.75/3.25	....	....
3450	.45/.55	.30/.60	.60/.95	2.75/3.25	....	....
4012	.09/.14	.75/1.00	....	....	.15/.25	....
4024[†]	.20/.25	.70/.90	....	....	.20/.30	....
4028[†]	.25/.30	.70/.90	....	....	.20/.30	....
4032	.30/.35	.70/.90	....	....	.20/.30	....
4042	.40/.45	.70/.90	....	....	.20/.30	....
4053	.50/.56	.75/1.00	....	....	.20/.30	....
4063	.60/.67	.75/1.00	....	....	.20/.30	....
4068	.63/.70	.75/1.00	....	....	.20/.30	....
4119	.17/.22	.70/.90	.40/.60	....	.20/.30	....
4121[a]	.18/.23	.75/1.00	.45/.65	....	.20/.30	....
4125	.23/.28	.70/.90	.40/.60	....	.20/.30	....
4131	.28/.33	.50/.70	.90/1.20	....	.15/.25	....
4135	.33/.38	.70/.90	.80/1.10	....	.15/.25	....
4147	.45/.50	.75/1.00	.80/1.10	....	.15/.25	....
4161	.56/.64	.75/1.00	.70/.90	....	.25/.35	....
4317	.15/.20	.45/.65	.40/.60	1.65/2.00	.20/.30	....
4337	.35/.40	.60/.80	.70/.90	1.65/2.00	.20/.30	....
4419	.18/.23	.45/.65	....	....	.45/.60	....

[†] S = .035/.050 [a] Formerly PS 24

FORMERLY STANDARD STEELS – continued
Chemical Composition Ranges and Limits

SAE No.	C	Mn	Cr	Ni	Mo	Other
4419H	.17/.23	.35/.75	....	....	.45/.60	....
4422	.20/.25	.70/.90	....	....	.35/.45	....
4427	.24/.29	.70/.90	....	....	.35/.45	....
4608	.06/.11	.25/.45	....	1.40/1.75	.15/.25	....
46B12*	.10/.15	.45/.65	....	1.65/2.00	.20/.30	....
4615	.13/.18	.45/.65	....	1.65/2.00	.20/.30	....
4617	.15/.20	.45/.65	....	1.65/2.00	.20/.30	....
X4620	.18/.23	.50/.70	....	1.65/2.00	.20/.30	....
4621	.18/.23	.70/.90	....	1.65/2.00	.20/.30	....
4621H	.17/.23	.60/1.00	....	1.55/2.00	.20/.30	....
4626	.24/.29	.45/.65	....	.70/1.00	.15/.25	....
4640	.38/.43	.60/.80	....	1.65/2.00	.20/.30	....
4715[b]	.13/.18	.70/.90	.45/.65	.70/1.00	.45/.60	....
4718	.16/.21	.70/.90	.35/.55	.90/1.20	.30/.40	....
4720	.17/.22	.50/.70	.35/.55	.90/1.20	.15/.25	....
4812	.10/.15	.40/.60	....	3.25/3.75	.20/.30	....
4815	.13/.18	.40/.60	....	3.25/3.75	.20/.30	....
4817	.15/.20	.40/.60	....	3.25/3.75	.20/.30	....
5015	.12/.17	.30/.50	.30/.50	....	....	....
50B40*	.38/.43	.75/1.00	.40/.60	....	....	....
50B44*	.43/.48	.75/1.00	.40/.60	....	....	....
5045	.43/.48	.70/.90	.55/.75	....	....	....
5046	.43/.48	.75/1.00	.20/.35	....	....	....
50B50*	.48/.53	.75/1.00	.40/.60	....	....	....
5060	.56/.64	.75/1.00	.40/.60	....	....	....
50B60*	.56/.64	.75/1.00	.40/.60	....	....	....
5115	.13/.18	.70/.90	.70/.90	....	....	....
5117	.15/.20	.70/.90	.70/.90	....	....	....
5135	.33/.38	.60/.80	.80/1.05	....	....	....
5145	.43/.48	.70/.90	.70/.90	....	....	....
5145H	.42/.49	.60/1.00	.60/1.00	....	....	....
5147	.46/.51	.70/.95	.85/1.15	....	....	....
5152	.48/.55	.70/.90	.90/1.20	....	....	....
5155	.51/.59	.70/.90	.70/.90	....	....	....
50100	.98/1.10	.25/.45	.40/.60	....	....	....
						V
6115	.10/.20	.30/.60	.80/1.10	....	....	.15 min
6117	.15/.20	.70/.90	.70/.90	....	....	.10 min
6118	.16/.21	.50/.70	.50/.70	....	....	.10/.15
6120	.17/.22	.70/.90	.70/.90	....	....	.10 min
6125	.20/.30	.60/.90	.80/1.10	....	....	.15 min
6130	.25/.35	.60/.90	.80/1.10	....	....	.15 min
6135	.30/.40	.60/.90	.80/1.10	....	....	.15 min
6140	.35/.45	.60/.90	.80/1.10	....	....	.15 min
6145	.43/.48	.70/.90	.80/1.10	....	....	.15 min
6195	.90/1.05	.20/.45	.80/1.10	....	....	.15 min
						W
71360	.50/.70	.30 max	3.00/4.00	....	....	12.00/15.00
71660	.50/.70	.30 max	3.00/4.00	....	....	15.00/18.00
7260	.50/.70	.30 max	.50/1.00	....	....	1.50/2.00

* B = .0005/.003

[b] Formerly PS 30

FORMERLY STANDARD STEELS – continued
Chemical Composition Ranges and Limits

SAE No.	C	Mn	Cr	Ni	Mo	Other
8115	.13/.18	.70/.90	.30/.50	.20/.40	.08/.15	....
81B45*	.43/.48	.75/1.00	.35/.55	.20/.40	.08/.15	....
8625	.23/.28	.70/.90	.40/.60	.40/.70	.15/.25	....
8627	.25/.30	.70/.90	.40/.60	.40/.70	.15/.25	....
8632	.30/.35	.70/.90	.40/.60	.40/.70	.15/.25	....
8635	.33/.38	.75/1.00	.40/.60	.40/.70	.15/.25	....
8637	.38/.43	.75/1.00	.40/.60	.40/.70	.15/.25	....
8641†	.38/.43	.75/1.00	.40/.60	.40/.70	.15/.25	....
8642	.40/.45	.75/1.00	.40/.60	.40/.70	.15/.25	....
86B45*	.43/.48	.75/1.00	.40/.60	.40/.70	.15/.25	....
8647	.45/.50	.75/1.00	.40/.60	.40/.70	.15/.25	....
8650	.48/.53	.75/1.00	.40/.60	.40/.70	.15/.25	....
8653	.50/.56	.75/1.00	.50/.80	.40/.70	.15/.25	....
8655	.51/.59	.75/1.00	.40/.60	.40/.70	.15/.25	....
8660	.56/.64	.75/1.00	.40/.60	.40/.70	.15/.25	....
8715	.13/.18	.70/.90	.40/.60	.40/.70	.20/.30	....
8717	.15/.20	.70/.90	.40/.60	.40/.70	.20/.30	....
8719	.18/.23	.60/.80	.40/.60	.40/.70	.20/.30	....
8735	.33/.38	.75/1.00	.40/.60	.40/.70	.20/.30	....
8740	.38/.43	.75/1.00	.40/.60	.40/.70	.20/.30	....
8742	.40/.45	.75/1.00	.40/.60	.40/.70	.20/.30	....
8745	.43/.48	.75/1.00	.40/.60	.40/.70	.20/.30	....
8750	.48/.53	.75/1.00	.40/.60	.40/.70	.20/.30	....
9250[1]	.45/.55	.60/.90	....	....	....	....
9254[2]	.51/.59	.60/.80	.60/.80	....	....	....
9255[1]	.51/.59	.70/.95	....	....	....	....
9261[1]	.55/.65	.75/1.00	.10/.25	....	....	....
9262[1]	.55/.65	.75/1.00	.25/.40	....	....	....
9310	.08/.13	.45/.65	1.00/1.40	3.00/3.50	.08/.15	....
9315	.13/.18	.45/.65	1.00/1.40	3.00/3.50	.08/.15	....
9317	.15/.20	.45/.65	1.00/1.40	3.00/3.50	.08/.15	....
94B15	.13/.18	.75/1.00	.30/.50	.30/.60	.08/.15	....
94B17	.15/.20	.75/1.00	.30/.50	.30/.60	.08/.15	....
94B30*	.28/.33	.75/1.00	.30/.50	.30/.60	.08/.15	....
9437	.35/.40	.90/1.20	.30/.50	.30/.60	.08/.15	....
9440	.38/.43	.90/1.20	.30/.50	.30/.60	.08/.15	....
94B40*	.38/.43	.75/1.00	.30/.60	.30/.60	.08/.15	....
9442	.40/.45	.90/1.20	.30/.50	.30/.60	.08/.15	....
9445	.43/.48	.90/1.20	.30/.50	.30/.60	.08/.15	....
9447	.45/.50	.90/1.20	.30/.50	.30/.60	.08/.15	....
9747	.45/.50	.50/.80	.10/.25	.40/.70	.15/.25	....
9763	.60/.67	.50/.80	.10/.25	.40/.70	.15/.25	....
9840	.38/.43	.70/.90	.70/.90	.85/1.15	.20/.30	....
9845	.43/.48	.70/.90	.70/.90	.85/1.15	.20/.30	....
9850	.48/.53	.70/.90	.70/.90	.85/1.15	.20/.30	....
						V
438V12*	.08/.13	.75/1.00	.40/.60	1.65/2.00	.20/.30	.03 min
438V14*	.10/.15	.45/.65	.40/.60	1.65/2.00	.08/.15	.03 min

* B = .0005/.003
† S = .04/.60
[1] Si = 1.80/2.20
[2] Si = 1.20/1.60

SELECTED MILITARY SPECIFICATIONS
Chemical Composition Ranges and Limits

MIL*	Solid or Tube	C	Mn	P Max	S Max	Si	Cr	Ni	Mo	Nearest Equivalent AMS	Nearest Equivalent SAE No.
S-5000	S	.38/.43	.65/.85	.025	.025	.15/.35	.70/.90	1.65/2.00	.20/.30	6415	E4340
S-50783[1]	S	1.00/1.15	1.60/1.90	.035	.040	.70/1.00	.20 max	.25 max	.06 max		
S-5626	S	.38/.43	.75/1.00	.025	.025	.20/.35	.80/1.10	.25 max	.15/.25	6382/6349	4140
S-6049	S	.38/.43	.75/1.00	.025	.025	.20/.35	.40/.60	.40/.70	.20/.30	6322/6325/6327	8740
S-6050†	S	.28/.33	.70/.90	.025	.025	.20/.35	.40/.60	.40/.70	.15/.25	6280	8630
S-6709[2]	S	.38/.43	.50/.70	.025	.025	.20/.40	1.40/1.80	....	.30/.40	6470/6472	....
S-6758	S	.28/.33	.40/.60	.025	.025	.15/.35	.80/1.10	.25 max	.15/.25	637	4130
S-7108[3]	S	.23/.28	1.20/1.50	.040	.040	1.30/1.70	.40 max.	1.65/2.00	.35/.45	6425	4625M4**
S-7393†	S	.08/.13	.45/.60	.025	.025	.20/.35	1.25/1.75	3.25/3.75	....	6250	3310
	S	.14/.19	.45/.60	.025	.025	.20/.35	1.25/1.75	3.25/4.00	....	....	3316
	S	.07/.13	.40/.70	.025	.025	.20/.35	1.00/1.40	3.00/3.50	.08/.15	....	9310
S-7420	S	.98/1.10	.25/.45	.025	.025	.20/.35	1.30/1.60	....	....	6440/6444/6447	52100
S-8503[4]	S	.48/.53	.70/.90	.025	.025	.20/.35	.75/1.20	....	....	6448	6150

* Some MIL numbers cancelled. Replaced by AMS numbers.
** Timken Company mill type.

Aircraft Quality Steels Except Where Indicated
Cu = .35 max unless specified

[1] Al = .020 max
[2] Al = .95/1.35
[3] P & S = .025 max if Basic Electric Furnace Steel is specified
[4] V = .15 min
† Inactive/Cancelled

SELECTED MILITARY SPECIFICATIONS – continued
Chemical Composition Ranges and Limits

MIL*	Solid or Tube	C	Mn	P Max	S Max	Si	Cr	Ni	Mo	Nearest Equivalent AMS	Nearest Equivalent SAE No.
S-8690[5]	S	18/.23	.70/1.00	.025	.025	.20/.35	.40/.60	.40/.70	.15/.25	6274	8620
S-8695[3]	S	.34/.41	.60/1.00	.040	.040	.20/.35	....	....	.20/.30	6300	4037
S-8699[3,6]	S	.28/.33	.80/1.00	.040	.040	.20/.35	.75/.95	1.65/2.00	.35/.50	6411/6427	4330M4V1*
S-8707[†]	S	.38/.43	.70/.90	.040	.040	.20/.35	.70/.90	.85/1.15	.20/.30	....	984
S-8844-1	S or T	.38/.43	.65/.90	.010	.010	.15/.35	.70/.90	1.65/2.00	.20/.30	6414	4340
S-8844-2[6]	S or T	.40/.44	.65/.90	.010	.010	1.45/1.80	.70/.95	1.65/2.00	.35/.45	6257	300M
T-5066	T	.22/.28	.30/.60	.025	.025	.30 max	....	....	....	T5066	1025
S-11595[7]	S	.48/.55	.75/1.00	.040	.040	.20/.35	.80/1.10	....	.15/.25	....	4150
S-11595[7]	S	.47/.55	.70/1.00	.040	.05/.09	.20/.35	.80/1.15	....	.15/.25	....	41R50
S-11595[7,8]	S	.41/.49	.60/.90	.040	.040	.20/.35	.80/1.15	....	.30/.40	....	4142M3V2*
S-46047[8]	S	.38/.45	.75/1.00	.025	.020	.20/.35	.95/1.25	....	.55/.70	....	....

* Some MIL numbers cancelled. Replaced by AMS numbers.
** Timken Company mill type.

Aircraft Quality Steels Except Where Indicated
Cu = .35 max unless specified

[5] P & S = .015 max if consumable vacuum melted steel is specified
[6] V = .05/.10
[7] Al = .040 max
[8] V = .20/.30
[†] Inactive/Cancelled

SELECTED AMS ALLOY STEEL SPECIFICATIONS

Chemical Composition Ranges and Limits

AMS Number	C	Mn	Si	Cr	Ni	Mo	V	SAE Designations
6250	.07/.13	.40/.70	.15/.35	1.25/1.75	3.25/3.75	.06 max	....	3310
6260[1]	.07/.13	.40/.70	.15/.35	1.00/1.40	3.00/3.50	.08/.15	....	9310
6263	.11/.17	.40/.70	.15/.35	1.00/1.40	3.00/3.50	.08/.15	....	9315
6264	.14/.20	.40/.70	.15/.35	1.00/1.40	3.00/3.50	.08/.15	....	9317
6265[2]	.07/.13	.40/.70	.15/.35	1.00/1.40	3.00/3.50	.08/.15	....	CV9310
6266[3]	.08/.13	.75/1.00	.20/.40	.40/.60	1.65/2.00	.20/.30	.03/.08	43BV12
6270	.13/.18	.70/.90	.15/.35	.40/.60	.40/.70	.15/.25	....	8615
6272	.15/.20	.70/.90	.15/.35	.40/.60	.40/.70	.15/.25	....	8617
6274	.17/.23	.60/.95	.15/.35	.35/.65	.35/.75	.15/.25	....	....
6275[3]	.15/.20	.60/.95	.15/.35	.30/.50	.30/.60	.08/.15	....	94B17
6280	.28/.33	.70/.90	.15/.35	.40/.60	.40/.70	.15/.25	....	8630
6281	.28/.33	.70/.90	.15/.35	.40/.60	.40/.70	.15/.25	....	8630
6282	.33/.38	.75/1.00	.15/.35	.40/.60	.40/.70	.20/.30	....	8735
6290	.11/.17	.45/.65	.15/.35	.20 max	1.65/2.00	.20/.30	....	4615
6292	.15/.20	.45/.65	.15/.35	.20 max	1.65/2.00	.20/.30	....	4617
6294	.17/.22	.45/.65	.15/.35	.20 max	1.65/2.00	.20/.30	....	4620
6299	.17/.23	.40/.70	.15/.35	.35/.65	1.55/2.00	.20/.30	....	4320H
6300[4]	.35/.40	.70/.90	.15/.35	.20 max	.25 max	.20/.30	....	4037

P & S = .025 max, Cu = .35 max unless specified

[1] B = .001 max
[2] P & S = .015 max
[3] B = .0005/.005
[4] P & S = .040 max

SELECTED AMS ALLOY STEEL SPECIFICATIONS – continued
Chemical Composition Ranges and Limits

AMS Number	C	Mn	Si	Cr	Ni	Mo	V	SAE Designations
6302	.28/.33	.45/.65	.55/.75	1.00/1.50	.25 max.	.40/.60	.20/.30	17-22-AS®
6303[5]	.25/.30	.60/.90	.55/.75	1.00/1.50	.50 max.	.40/.60	.75/.95	17-22-AV®
6304	.40/.50	.40/.70	.15/.35	.80/1.10	.25 max.	.45/.65	.25/.35	
6312	.38/.43	.60/.80	.15/.35	.20 max	1.65/2.00	.20/.30	....	4640
6320	.33/.38	.75/1.00	.15/.35	.40/.60	.40/.70	.20/.30	....	8735
6321[6]	.38/.43	.75/1.00	.15/.35	.30/.55	.20/.40	.08/.15	....	81B40
6322	.38/.43	.75/1.00	.15/.35	.40/.60	.40/.70	.20/.30	....	8740
6323	.38/.43	.75/1.00	.15/.35	.40/.60	.40/.70	.20/.30	....	8740
6324	.38/.43	.75/1.00	.15/.35	.55/.75	.55/.85	.20/.30	....	8740 Mod
6328	.48/.53	.75/1.00	.15/.35	.40/.60	.40/.70	.20/.30	....	8750
6342	.38/.43	.70/.90	.15/.35	.70/.90	.85/1.15	.20/.30	....	9840
6371	.28/.33	.40/.60	.15/.35	.80/1.10	.25 max	.15/.25	....	4130
6372	.33/.38	.70/.90	.15/.35	.80/1.10	.25 max	.15/.25	....	4135
6381	.38/.43	.75/1.00	.15/.35	.80/1.10	.25 max	.15/.25	....	4140
6382	.38/.43	.75/1.00	.15/.35	.80/1.10	.25 max	.15/.25	....	4140
6407	.27/.33	.60/.80	.40/.70	1.00/1.35	1.85/2.25	.35/.55	....	HS220-07
6409[7]	.38/.43	.65/.85	.15/.35	.70/.90	1.65/2.00	.20/.30		4340*

P & S = .025 max, Cu = .35 max unless specified
* Special Aircraft Quality – Normalized and Tempered

[5] Cu = .50 max
[6] B = .0005/.005
[7] P = .015 max, S = .008 max

SELECTED AMS ALLOY STEEL SPECIFICATIONS – continued
Chemical Composition Ranges and Limits

AMS Number	C	Mn	Si	Cr	Ni	Mo	V	SAE Designations
6412	.35/.40	.65/.85	.15/.35	.70/.90	1.65/2.00	.20/.30	....	4337
6414[8]	.38/.43	.65/.90	.15/.35	.70/.90	1.65/2.00	.20/.30	....	CV4340
6415	.38/.43	.65/.85	.15/.35	.70/.90	1.65/2.00	.20/.30	....	4340
6418	.23/.28	1.20/1.50	1.30/1.70	.20/.40	1.65/2.00	.35/.45	....	4625M4
6419[9]	.40/.45	.60/.90	1.45/1.80	.70/.95	1.65/2.00	.30/.50	.05/.10	CV300M
6421[10]	.35/.40	.65/.85	.15/.35	.70/.90	.70/1.00	.15/.25	....	98B37 Mod
6422[10]	.38/.43	.65/.85	.15/.35	.70/.90	.70/1.00	.15/.25	.01/.06	98BV40 Mod
6427	.28/.33	.75/1.00	.15/.35	.75/1.00	1.65/2.00	.35/.50	.05/.10	4330M4V1
6428	.32/.38	.60/.80	.15/.35	.65/.90	1.65/2.00	.30/.40	.17/.23	4335 Mod
6430[8]	.32/.38	.60/.90	.40/.60	.65/.90	1.65/2.00	.30/.40	.17/.23	4335M4V2
6431[9]	.45/.50	.60/.90	.15/.30	.90/1.20	.40/.70	.90/1.10	.08/.15	D6-AC
6440	.93/1.05	.25/.45	.15/.35	1.35/1.60	.25 max	.10 max	....	52100
6444[8]	.98/1.10	.25/.45	.15/.35	1.30/1.60	.25 max	.08 max	....	CV52100*
6445[8]	.92/1.02	.95/1.25	.50/.70	.90/1.15	.25 max	.08 max	....	CV51100 Mod
6448	.48/.53	.70/.90	.15/.35	.80/1.10	.25 max	.06 max	.15/.30	6150

P & S = .025 max, Cu = .35 max unless specified
* Premium Aircraft Quality

[8] P & S = .015 max
[9] P & S = .010 max
[10] B = .0005/.005

NITRIDING STEELS

Chemical Composition Ranges and Limits

AMS Number	C	Mn	Si	Cr	Ni	Mo	Al	Other Designations
6470	.38/.43	.50/.80	.20/.40	1.40/1.80	.25 max	.30/.40	.95/1.30	135M or #3
6471	.38/.43	.50/.80	.20/.40	1.40/1.80	.25 max	.30/.40	.95/1.30	CV Nit #3
6472*	.38/.43	.50/.80	.20/.40	1.40/1.80	.25 max	.30/.40	.95/1.30	
6475	.21/.26	.50/.70	.20/.40	1.00/1.25	3.25/3.75	.20/.30	1.10/1.40	N

* P = .035 max, S = .040 max

AUSTENITIC STAINLESS STEELS
Chemical Composition Ranges and Limits

Type Number	C Max	Mn Max	Si Max	P Max	S Max	Cr	Ni	Others
201	.15	5.5/7.5	1.00	.060	.030	16.00/18.00	3.50/5.50	N = 0.25 max
202	.15	7.5/10.0	1.00	.060	.030	17.00/19.00	4.00/6.00	N = 0.25 max
301	.15	2.00	1.00	.045	.030	16.00/18.00	6.00/8.00	N = 0.10 max
302	.15	2.00	.75	.045	.030	17.00/19.00	8.00/10.00	N = 0.10 max
302B	.15	2.00	2.00/3.00	.045	.030	17.00/19.00	8.00/10.00	....
303	.15	2.00	1.00	.200	.15 min	17.00/19.00	8.00/10.00	Zr, Mo = .60 max*
304	.08	2.00	.75	.045	.030	18.00/20.00	8.00/10.50	....
TP304	.08	2.00	.75	.040	.030	18.00/20.00	8.00/11.00	....
304L	.03	2.00	.75	.045	.030	18.00/20.00	8.00/12.00	N = 0.10 max
TP304L	.035	2.00	.75	.040	.030	18.00/20.00	8.00/13.00	....
TP304H	.04/.10	2.00	.75	.040	.030	18.00/20.00	8.00/11.00	....
305	.12	2.00	.75	.045	.030	17.00/19.00	10.50/13.00	....
308	.08	2.00	1.00	.045	.030	19.00/21.00	10.00/12.00	....
309	.20	2.00	1.00	.045	.030	22.00/24.00	12.00/15.00	....
310	.25	2.00	1.50	.045	.030	24.00/26.00	19.00/22.00	....
TP310	.15	2.00	.75	.040	.030	24.00/26.00	19.00/22.00	....
314	.25	2.00	1.50/3.00	.045	.030	23.00/26.00	19.00/22.00	....
316	.08	2.00	.75	.045	.030	16.00/18.00	10.00/14.00	Mo = 2.00/3.00 N = 0.10 max
TP316	.08	2.00	.75	.040	.030	16.00/18.00	11.00/14.00	Mo = 2.00/3.00
316L	.03	2.00	.75	.045	.030	16.00/18.00	10.00/14.00	Mo = 2.00/3.00 N = 0.10 max

* At producers option, reported only when intentionally added.

AUSTENITIC STAINLESS STEELS – continued
Chemical Composition Ranges and Limits

Type Number	C Max	Mn Max	Si Max	P Max	S Max	Cr	Ni	Others
TP316L	.035	2.00	.75	.040	.030	16.00/18.00	10.00/15.00	Mo = 2.00/3.00
TP316H	.04/.10	2.00	.75	.040	.030	....	11.00/14.00	Mo = 2.00/3.00
TP317	.08	2.00	.75	.040	.030	18.00/20.00	11.00/14.00	Mo = 3.00/4.00
321	.08	2.00	1.00	.045	.030	17.00/19.00	9.00/12.00	Ti = 5 × C min, .60 max
TP321	.08	2.00	.75	.040	.030	17.00/20.00	9.00/13.00	Ti = 5 × C min, .60 max
TP321H	.04/.10	2.00	.75	.040	.030	17.00/20.00	9.00/13.00	Ti = 4 × C min, .60 max
347	.08	2.00	1.00	.045	.030	17.00/19.00	9.00/13.00	Cb + Ta = 10 × C min
TP347	.08	2.00	.75	.040	.030	17.00/20.00	9.00/13.00	Cb + Ta = 10 × C min = 1.00 max
TP347H	.04/.10	2.00	.75	.040	.030	17.00/20.00	9.00/13.00	Cb + Ta = 8 × C min = 1.00 max
348	.08	2.00	1.00	.045	.030	17.00/19.00	9.00/13.00	Cb + Ta = 10 × C min Ta = .10 max
TP348	.08	2.00	.75	.040	.030	17.00/20.00	9.00/13.00	Cb + Ta = 10 × C min Cb + Ta = 1.00 max
TP348H	.04/.10	2.00	.75	.040	.030	17.00/20.00	9.00/13.00	Cb + Ta = 8 × C min Ta = .10 max Cb + Ta = 1.00 max
384	.08	2.00	1.00	.045	.030	15.00/17.00	17.00/19.00	....
385	.08	2.00	1.00	.045	.030	11.50/13.50	14.00/16.00	....

H = Grades for high temperature service.
TP = Tubular Products

CHROMIUM STAINLESS STEELS
Chemical Composition Ranges and Limits

Type Number	C Max	Mn Max	Si Max	P Max	S Max	Cr	Ni	Others
403	.15	1.00	.50	.040	.030	11.50/13.00	....	Turbine Quality
405	.08	1.00	1.00	.040	.030	11.50/14.50	.60 max	Al = .10/.30
TP405	.08	1.00	.75	.040	.030	11.50/13.50	.50 max	Al = .10/.30
410	.15	1.00	1.00	.040	.030	11.50/13.50	.75 max	....
TP410	.15	1.00	.75	.040	.030	11.50/13.50	.50 max	....
414	.15	1.00	1.00	.040	.030	11.50/13.50	1.25/2.50	....
416	.15	1.25	1.00	.060	.150 min	12.00/14.00	....	Zr, Mo = .60 max*
420	Over .15	1.00	1.00	.040	.030	12.00/14.00	....	....
TP420	Over .15	1.00	.75	.030	.030	12.00/14.00	.50 max	....
430	.12	1.00	1.00	.040	.030	16.00/18.00	....	....
430F	.12	1.25	1.00	.060	.150 min	16.00/18.00	....	Mo = .60 max*
431	.20	1.00	1.00	.040	.030	15.00/17.00	1.25/2.50	....
440A	.60/.75	1.00	1.00	.040	.030	16.00/18.00	....	Mo = .75 max
440B	.75/.95	1.00	1.00	.040	.030	16.00/18.00	....	Mo = .75 max
440C	.95/1.20	1.00	1.00	.040	.030	16.00/18.00	....	Mo = .75 max
TP443	.20	1.00	.75	.040	.030	18.00/23.00	.50 max	Cu = .90/1.25
501	Over .10	1.00	1.00	.040	.030	4.00/6.00	....	Mo = .40/.65
502	.10	1.00	1.00	.040	.030	4.00/6.00	....	Mo = .40/.65

Prefix TP denotes tubular products.
Suffixes A, B and C denote differing carbon ranges for the same grade. F denotes a free machining grade.
* At producer's option, reported only when intentionally added.

SELECTED ASTM SPECIFICATIONS
Chemical Composition Ranges and Limits

ASTM Number	Grade	C	Mn	Si	Cr	Ni	Mo	V
A106*	A	.25 max	.27/.93	.10 min	.40 max	.40 max	.15 max	.08 max
	B	.30 max	.29/1.06	.10 min	.40 max	.40 max	.15 max	.08 max
	C	.35 max	.29/1.06	.10 min	.40 max	.40 max	.15 max	.08 max
A182	F11	.10/.20	.30/.80	.50/1.00	1.00/1.50	....	.44/.65	....
	F12	.10/.20	.30/.80	.10/.60	.80/ 1.25	....	.44/.65	....
A192	A	.06/.18	.27/.63	.25 max	....	....	....	....
A200	T4	.05/.15	.30/.60	.50/1.00	2.15/2.85	....	.44/.65	....
	T5†	.15 max	.30/.60	.50 max	4.00/6.00	....	.45/.65	....
	T7†	.15 max	.30/.60	.50/1.00	6.00/8.00	....	.45/.65	....
	T9†	.15 max	.30/.60	.25/1.00	8.00/10.00	....	.90/1.10	....
	T11†	.05/.15	.30/.60	.50/1.00	1.00/1.50	....	.44/.65	....
	T21†	.05/.15	.30/.60	.50 max	2.65/3.35	....	.80/1.06	....
	T22†	.05/.15	.30/.60	.50 max	1.90/2.60	....	.87/1.13	....
	T91**	.08/.12	.30/.60	.20/.50	8.00/9.00	.40 max	.85/1.05	.18/.25
A209	T1	.10/.20	.30/.80	.10/.50	....	....	.44/.65	....
	T1b	.14 max	.30/.80	.10/.50	....	....	.44/.65	....

See current ASTM specifications for P & S limitations.
† These grades also included in ASTM Specifications A213 and A335.
* The combined elements of Cr, Ni, Mo, V and Cu must not exceed 1%
** Cb = .06/.10, N = .03/.07, Al = .04 max

SELECTED ASTM SPECIFICATIONS – continued
Chemical Composition Ranges and Limits

ASTM Number	Grade	C	Mn	Si	Cr	Ni	Mo	Others
A210	A1	.27 max	.93 max	.10 min	....	....	....	
	C	.35 max	.29/1.06	.10 min	....	....	....	
A213	T5b	.15 max	.30/.60	1.00/2.00	4.00/6.00	....	.45/.65	
	T5c	.12 max	.30/.60	.50 max	4.00/6.00	....	.45/.65	Ti = 4 × C min, .70 max
	T12	.05/.15	.30/.61	.50 max	.80/1.25	....	.44/.65	
	TP304H‡	.04/.10	2.00 max	.75 max	18.00/20.00	8.00/11.00	....	
	TP310H‡	.04/.10	2.00 max	.75 max	24.00/26.00	19.00/22.00	....	
	TP316H‡	.04/.10	2.00 max	.75 max	16.00/18.00	11.00/14.00	2.00/3.00	
	TP321H‡	.04/.10	2.00 max	.75 max	17.00/20.00	9.00/13.00	....	Ti = 4 × C min, .60 max
	TP347H‡	.04/.10	2.00 max	.75 max	17.00/20.00	9.00/13.00	....	Cb + Ta = 8 × C min,1.00 max
	TP348	.08 max	2.00 max	.75 max	17.00/20.00	9.00/13.00	....	Cb + Ta = 10 × C min, Ta = .10 max Cb + Ta = 1.00 max

See current ASTM specifications for P & S limitations

‡ These grades also included in ASTM Specifications A312 and A376.

TIMKEN® TUBULAR HOLLOW DRILL STEELS
Chemical Composition Ranges and Limits

Type	C	Mn	Si	Cr	Ni	Mo
TDS-10®	.72/.85	.30/ .60	....	....	....	....
TDS-30®	.17/.22	.45/ .65	.15/.30	.40/ .60	1.65/2.00	.20/.30
TDS-50®	.27/.33	.60/ .80	.40/.70	1.00/1.35	1.85/2.25	.35/.55
TDS-70®	.25/.31	.80/1.20	.50/.80	1.90/2.40	.25 max.	.25/.35
TDS-90®	.23/.28	.40/ .60	.15/.30	3.00/3.50	....	.45/.60

TIMKEN® OIL COUNTRY STEELS
Chemical Composition Ranges and Limits

Type	C	Mn	Si	Cr	Ni	Mo	Cb	Other
Impact 7	.26/.32	.60/.90	....	1.20/1.50	....	.65/.75	.02/.05	
Impact 8	.26/.32	.90/1.10	.20/.40	1.00/1.50	.15 max	.75/.85	.02/.05	
Impact 10	.26/.32	.90/1.10	.15/.35	.70/.90	.50/.70	.65/.75	.02/.05	
9Cr1Mo	.15 max	.30/.60	.25/1.00	8.00/10.00	....	.90/1.10	....	P = .030 max S = .030 max
410	.15 max	1.00 max	1.00 max	12.00/14.00	....	....	....	P = .040 max
420 Mod	.18/.22	1.00 max	1.00 max	12.50/14.00	....	....	....	P = .020 max

P = .015 max, S = .005 max

CORROSION RESISTANT ALLOYS

Duplex Stainless Steel Ranges and Limits (Not Manufactured by Timken)

Designation	C max	Mn max	Si max	Cr	Ni
44LN	.03	2.0	1.00	24.0-26.0	5.50-6.50
DP-3	.03	1.0	0.75	24.0-26.0	5.50-7.50
3RE60	.03	1.2-2.0*	1.40-2.00*	18.0-19.0	4.25-5.25
2205	.03	2.0	1.00	21.0-23.0	4.50-6.50
2304	.03	2.5	1.00	21.5-24.5	3.00-5.50
Uranus 50	.04	2.0	1.00	20.5-22.5	5.50-8.50
Ferralium 255	.04	1.5	1.00	24.0-27.0	4.50-6.50
7-Mo PLUS	.03	2.0	0.60	26.0-29.0	3.50-5.20

*Range indicates min to max mass functions.

TIMKEN® WELDABLE HIGH STRENGTH STEELS

Chemical Composition Ranges and Limits

Type	C	Mn	Si	Cr	Ni	Mo	V	B
WHS 100™	.13/.21	1.00/1.30	.15/.30	.65/.90	.40/.70	.15/.25	.03/.08	.003 added
WHS 130™	.20/.27	.60/ .80	.15/.30	.70/.90	1.55/2.00	.20/.30	....	....

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TIMKEN® HIGH STRENGTH STEELS

Chemical Composition Ranges and Limits

Type	C	Mn	Si	Cr	Ni	Mo	V
HS-220-07	.27/.33	.60/.80	.40/.70	1.00/1.35	1.85/2.25	.35/.55	....
HS-220-18	.23/.28	1.20/1.50	1.30/1.70	.20/.40	1.65/2.00	.35/.45	....
HS-220-27	.28/.33	.75/1.00	.15/.35	.75/1.00	1.65/2.00	.35/.50	.05/.10
HS-220-28	.32/.38	.60/.80	.15/.35	.65/.90	1.65/2.00	.30/.40	.17/.23
HS-220-30	.32/.38	.60/.90	.40/.60	.65/.90	1.65/2.00	.30/.40	.17/.23

TIMKEN® MICROALLOY STEELS

Chemical Composition Ranges and Limits

Type	C	Mn	V	S	Si	Other
MicroTec 2W60	0.10/0.18	1.20/1.60	0.05/0.10	....	....	
MicroTec 2W65	0.16/0.20	1.20/1.40	0.06/0.10	....	....	
MicroTec 2W70	0.16/0.20	1.40/1.60	0.07/0.11	....	....	
MicroTec 2W75	0.16/0.22	1.30/1.70	0.10/0.20	....	....	
MicroTec 3W70	0.28/0.33	0.90/1.30	0.07/0.18	....	....	
MicroTec 3W75	0.26/0.30	1.00/1.30	0.13/0.23	....	....	
MicroTec 3W75A	0.28/0.32	0.90/1.20	0.13/0.18	....	....	
MicroTec 3M80	0.28/0.33	1.30/1.60	0.08/0.18	....	....	N = .008/.015
MicroTec 3M80A	0.28/0.33	1.30/1.50	0.08/0.18	0.025/0.050	....	N = .008/.015
MicroTec 3M80B	0.32/0.36	1.35/1.45	0.06/0.10	0.010 max.	0.40/0.50	
MicroTec 3M80C	0.32/0.36	1.35/1.45	0.07/0.09	0.005/0.020	0.20/0.30	
MicroTec 3M85	0.31/0.35	1.30/1.50	0.10/0.14	0.030/0.050	....	
MicroTec 4M85	0.36/0.40	1.20/1.40	0.04/0.10	0.030/0.050	0.30/0.50	
MicroTec 4M90	0.36/0.41	1.10/1.30	0.10/0.18	....	....	
MicroTec 4M90A	0.36/0.41	1.10/1.30	0.10/0.18	0.030/0.050	....	
MicroTec 4M95	0.36/0.40	1.30/1.50	0.08/0.12	0.045 max.	0.50/0.70	
MicroTec 4M95A	0.38/0.43	1.35/1.45	0.08/0.12	0.030/0.045	0.50/0.65	
MicroTec 5H85	0.53/0.57	0.70/0.85	0.08/0.12	0.020/0.035	....	
MicroTec 5H90	0.52/0.57	0.70/1.00	0.05/0.20	0.025/0.035	0.15/0.35	
MicroTec 5H95	0.52/0.57	1.05/1.25	0.08/0.18	0.040/0.060	0.45/0.65	
MicroTec 5H95A	0.52/0.57	1.15/1.35	0.10/0.20	0.040/0.060	0.45/0.65	Cr = .15/.45

TIMKEN® ALLOY STEELS FOR HIGH TEMPERATURE SERVICE
Chemical Composition Range and Limits

Type	C	Mn	P Max	S Max	Si	Cr	Mo	ASTM No
.50Mo*	.10/.20	.30/.80	.045	.045	.10/.50	....	.44/.65	1
DM®	.15 max	.30/.60	.030	.030	.50/1.00	1.00/1.50	.44/.65	11
DM-2	.15 max	.30/.60	....	....	.50 max	.80/1.25	.44/.65	....
2 1/4 Cr 1 Mo	.15 max	.30/.60	.030	.030	.50 max	1.90/2.60	.87/1.13	22
5 Cr 1/2 Mo	.15 max	.30/.60	.030	.030	.50 max	4.00/6.00	.45/.65	5
5 Cr 1/2 Mo+Ti**	.12 max	.30/.60	.030	.030	.50 max	4.00/6.00	.45/.65	5c
5 Cr 1/2 Mo+Si	.15 max	.30/.60	.030	.030	1.00/2.00	4.00/6.00	.45/.65	5b
5 Cr 1 Mo+Si	.15 max	.30/.60	.030	.030	1.00/1.50	4.00/6.00	.09/1.10	....
7 Cr 1/2 Mo	.15 max	.30/.60	.030	.030	.50/1.00	6.00/8.00	.45/.65	7
9 Cr 1 Mo	.15 max	.30/.60	.030	.030	.25/1.00	8.00/10.00	.90/1.10	9
T9***	.08/.12	.30/.60	.020	.010	.20/.50	8.00/9.50	.85/1.05	91

*.50 Mo steel also available with .08/.14 C. ** Ti = 4 × C min, .70 max *** Ni = .40 max, V = .18/.25, Cb = .06/.10, N = .03/.07, Al = .04 max

TIMKEN® HIGH TEMPERATURE ENGINEERING STEELS
Chemical Composition Ranges

Type	C	Mn	P Max	S Max	Si	Cr	Mo	V	AMS No
17-22-A®	.41/.48	.45/.65	.040	.040	.55/.75	1.00/1.50	.40/.60	.20/.30	....
17-22-AS®	.28/.33	.45/.65	.040	.040	.55/.75	1.00/1.50	.40/.60	.20/.30	6302
17-22-AV®	.25/.30	.60/.90	.040	.040	.55/.75	1.00/1.50	.40/.60	.75/.95	6303

TIMKEN® TUBING FOR POLYETHYLENE PRODUCTION
Chemical Composition Ranges

Type	C	Mn	Cr	Ni	Mo
4333M4	.30/.38	.70/1.00	.70/.90	1.65/2.00	.35/.45
4333M6	.30/.38	.70/1.00	.80/1.20	2.00/2.50	.50/.65

TIMKEN® SPECIAL BEARING STEELS
Chemical Composition Ranges and Limits

Type	C	Mn	Si	Cr	Ni	Mo	V
52100*	.98/1.10	.25/.45	.15/.35	1.30/1.60	....	....	....
ASTM-A485-1(#1 Mod.)[a]	.90/1.05	.95/1.25	.45/.75	.90/1.20	....	....	....
ASTM-A485-2(#2 Mod.)	.85/1.00	1.40/1.70	.50/.80	1.40/1.80	....	....	....
ASTM-A485-3(T-1)[a]	.95/1.10	.65/.90	.15/.35	1.10/1.50	....	.20/.30	....
ASTM-A485-4(T-2)[a]	.95/1.10	1.05/1.35	.15/.35	1.10/1.50	....	.45/.60	....
TBS-600™ [b]	.95/1.10	.60/.80	.85/1.20	1.25/1.65	....	.25/.35	....
CBS-600™ [c]	.16/.22	.40/.70	.90/1.25	1.25/1.65	....	.90/1.10	....
CBS1000M™ [d]	.10/.16	.40/.60	.40/.60	.90/1.20	2.75/3.25	4.00/5.00	.25/.50
CBS-50NiL**	.11/.15	.15/.35	.10/.25	4.00/4.25	3.20/3.60	4.00/4.50	1.13/1.33
TBA-2[e]	.70/.80	1.05/1.35	.15/.35	.90/1.20	1.30/1.65	1.20/1.40	....
M-50	.77/.85	.35 max.	.25 max.	3.75/4.25	.10 max.	4.00/4.50	.90/1.10
440C	.95/1.20	1.00 max.	1.00 max.	16.00/18.00	....	.75 max.	....
TBS-9®	.89/1.01	.50/.80	.15/.35	.40/.60	.25 max.	.08/.15	....

* 52100 shown for reference purposes only
** Max Cu .10, Co .25, W .25, P .015, S .010
[a] Deep hardening steels.
[b] Through hardening steel for service up to 600 F.
[c] Carburizing steel for service up to 600 F.
[d] Carburizing steel for service up to 1000 F.
[e] Through hardening steel can be air quenched.

TIMKEN® GRAPHITIC TOOL STEELS

Nominal Chemical Composition

ASTM	Type	C	Mn	S	Si	Cr	Ni	Mo	W	Other
O6	Graph-Mo®	1.45	1.00	0.015	0.90	....	....	0.25	....	....
A10	Graph-Air®	1.35	1.80	0.015	1.20	....	1.85	1.50	....	....

HIGH-SPEED STEELS

Nominal Chemical Composition

ASTM	C	Si	Mn	W	Cr	V	Mo	Co	Other
M1	0.83	0.30	0.25	1.75	3.75	1.15	8.50	....	
M2	0.85	0.30	0.28	6.15	4.15	1.85	5.00	....	
M2-HC	0.98	0.30	0.28	6.15	4.15	1.85	5.00	....	Alloy Sulfides
M3-1	1.02	0.30	0.25	6.00	4.10	2.40	5.00	....	
M3-2	1.20	0.30	0.25	6.00	4.10	3.00	5.00	....	
M4	1.32	0.30	0.25	5.35	4.50	3.85	4.40	....	
M7	1.02	0.30	0.25	1.75	3.75	1.90	8.50	....	Nitrogen
M10	0.87	0.30	0.30	0.75	4.00	1.90	8.00	....	
M42	1.08	0.45	0.25	1.50	3.85	1.20	9.50	8.00	
M50	0.84	0.50	0.30	....	4.10	1.00	4.25	....	
M52	0.89	0.45	0.25	1.10	4.00	1.85	4.50	....	
T15	1.57	0.50	0.30	12.25	4.00	5.00	0.50	5.00	

COLD WORK DIE STEELS

Nominal Chemical Composition

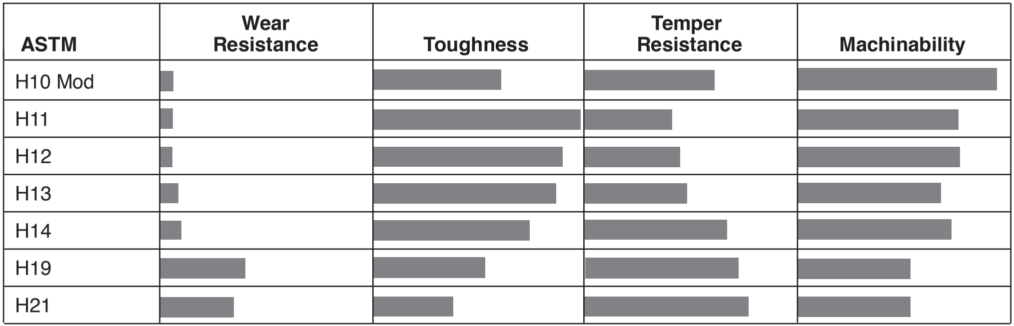
ASTM	C	Si	Mn	W	Cr	V	Mo	Ni	Other
A2	1.00	0.30	0.75	....	5.00	0.25	1.00	....	
A6	0.70	0.30	2.00	....	1.00	....	1.25	....	
A7	2.60	0.30	0.60	....	8.25	4.50	1.20	....	
A8	0.55	0.95	0.30	1.25	5.00	....	1.25	....	
A10	1.35	1.20	1.80	....	....	....	1.50	1.85	
D2	1.50	0.30	0.30	....	12.00	0.90	0.75	....	
D3	2.15	0.40	0.40	....	12.25	0.25	....	....	
D5	1.50	0.50	0.35	....	11.65	....	0.80	....	Co = 2.80
D7	2.30	0.40	0.40	....	12.50	4.00	1.10	....	
L6	0.70	0.25	0.60	....	0.70	....	....	1.40	
O1	0.94	0.30	1.20	0.50	0.50	....	....	....	
O6	1.45	0.90	1.00	....	....	....	0.25	....	
S1	0.53	0.25	0.25	2.00	1.35	0.25	....	....	
S5	0.61	1.90	0.90	....	0.18	0.28	1.40	....	
S7	0.50	0.25	0.75	....	3.25	....	1.40	....	

HOT WORK DIE STEELS
Nominal Chemical Composition

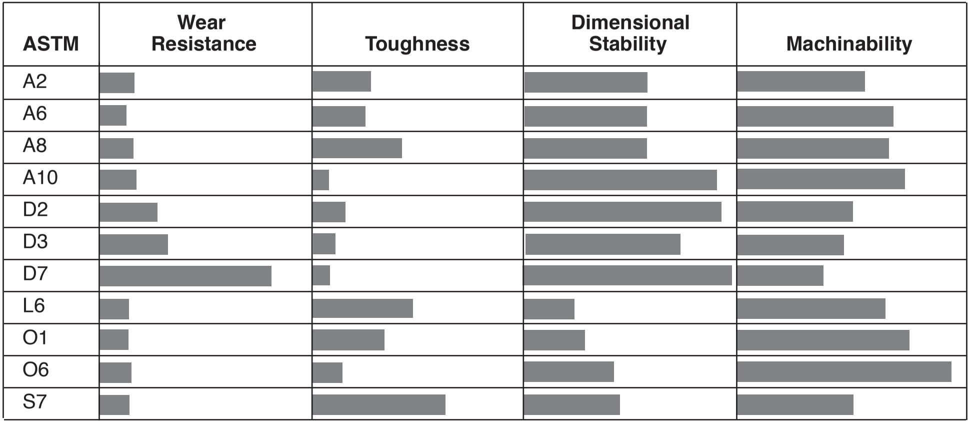
ASTM	C	Si	Mn	W	Cr	V	Mo	Co	Other
H10	0.35	1.00	0.30	....	3.30	0.65	2.45	2.00	
H11	0.40	1.00	0.30	....	5.00	0.50	1.30	....	
H12	0.35	1.00	0.30	1.30	5.00	0.30	1.40	....	
H13	0.40	1.00	0.40	....	5.25	1.00	1.35	....	
H14	0.40	1.00	0.25	4.75	5.25	....	....	....	
H19	0.40	0.30	0.30	4.25	4.25	2.00	....	4.25	
H21	0.33	0.45	0.25	9.15	3.30	0.45	....	....	
P20	0.33	0.65	0.80	....	1.75	....	0.40	....	

COMPARATIVE PROPERTIES FOR THE SELECTION AND USE OF HIGH SPEED STEELS

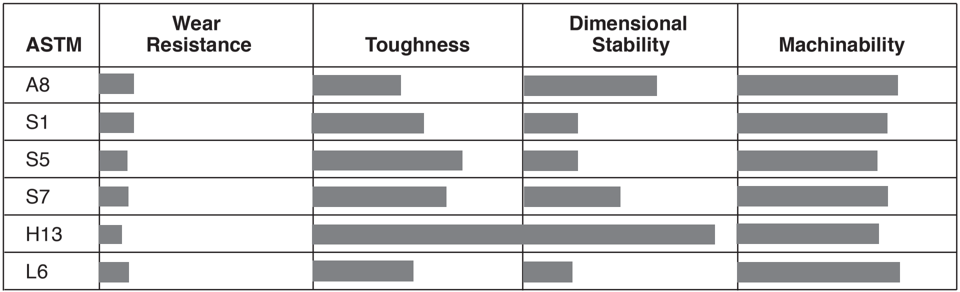
COMPARATIVE PROPERTIES FOR THE SELECTION AND USE OF HOT WORK DIE STEELS



COMPARATIVE PROPERTIES FOR THE SELECTION AND USE OF COLD WORK DIE STEELS



COMPARATIVE PROPERTIES FOR THE SELECTION AND USE OF SHOCK STEELS



END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 1038 H to 15B21 H

These values were adjusted to the nearest Rockwell “C” point, and are used when points are selected and specified

“J” Distance Sixteenths of an Inch	GRADE													
	1038 H		1045 H		1522 H		1524 H		1526 H		1541 H		15B21 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	58	51	62	55	50	41	51	42	53	44	60	53	48	41
1.5	56	42	61	52	48	41	49	42	50	42	59	52	48	41
2	55	34	59	42	47	32	48	38	49	38	59	50	47	40
2.5	53	29	56	34	46	27	47	34	47	33	58	47	47	39
3	49	26	52	31	45	22	45	29	46	26	57	44	46	38
3.5	43	24	46	29	42	21	43	25	42	25	56	41	45	36
4	37	23	38	28	39	20	39	22	39	21	55	38	44	30
4.5	33	22	34	27	37	...	38	20	37	20	53	35	42	23
5	30	22	33	26	34	...	35	...	33	...	52	32	40	20
5.5	29	21	32	26	32	...	34	...	31	...	50	29	38	...
6	28	21	32	25	30	...	32	...	30	...	48	27	35	...
6.5	27	20	31	25	28	...	30	...	28	...	46	26	32	...
7	27	...	31	25	27	...	29	...	27	...	44	25	27	...
7.5	26	...	30	24	...	...	28	...	26	...	41	24	22	...
8	26	...	30	24	...	...	27	...	26	...	39	23	20	...
9	25	...	29	23	...	...	26	...	24	...	35	23	...	...
10	25	...	29	22	...	...	25	...	24	...	33	22	...	...
12	24	...	28	21	...	...	23	...	23	...	32	21	...	...
14	23	...	27	20	...	...	22	...	22	...	31	20	...	...
16	21	...	26	...	...	...	20	...	21	...	30	...	...	...
18	...	...	25	...	...	...	...	...	20	...	30	...	...	...
20	...	...	23	...	...	...	...	...	...	...	29	...	...	...
22	...	...	22	...	...	...	...	...	...	...	28	...	...	...
24	...	...	21	...	...	...	...	...	...	...	26	...	...	...

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 15B28 H to 1330 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	15B28 H		15B30 H		15B35 H		15B37 H		15B41 H		15B48 H		15B62 H		1330 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	53	47	55	48	58	51	58	50	60	53	63	56	...	60	56	49
2	53	47	53	47	56	50	56	50	59	52	62	56	...	60	56	47
3	52	46	52	46	55	49	55	49	59	52	62	55	...	60	55	44
4	51	45	51	44	54	48	54	48	58	51	61	54	...	60	53	40
5	51	42	50	32	53	39	53	43	58	51	60	53	65	59	52	35
6	50	32	48	22	51	28	52	37	57	50	59	52	65	58	50	31
7	49	25	43	20	47	24	51	33	57	49	58	42	64	57	48	28
8	48	21	38	...	41	22	50	26	56	48	57	34	64	52	45	26
9	46	20	33	...	...	...	...	...	55	44	56	31	64	43	43	25
10	43	...	29	...	30	20	45	22	55	37	55	30	63	39	42	23
11	40	...	27	...	...	...	...	...	54	32	53	29	63	37	40	22
12	37	...	26	...	27	...	40	21	53	28	51	28	63	35	39	21
13	34	...	25	...	...	...	...	...	52	26	48	27	62	35	38	20
14	31	...	24	...	26	...	33	20	51	25	45	27	62	34	37	...
15	30	...	23	...	...	...	...	...	50	25	41	26	61	33	36	...
16	29	....	22	...	25	...	29	...	49	24	38	26	60	33	35	...
18	27	...	20	...	...	...	...	...	46	23	34	25	58	32	34	...
20	25	...	...	...	24	...	27	...	42	22	32	24	54	31	33	...
22	25	...	...	...	...	...	...	...	39	21	31	23	48	30	32	...
24	24	...	...	...	22	...	25	...	36	21	30	22	43	30	31	...
26	23	...	...	...	...	...	...	...	34	20	29	21	40	29	31	...
28	22	...	...	...	20	...	23	...	33	...	29	20	37	28	31	...
30	21	...	...	...	...	...	...	...	31	...	28	...	35	27	30	...
32	20	...	...	...	...	...	21	...	31	...	28	...	34	26	30	...

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 1335 H to 4037 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distan Sixteenths of an Inch	GRADE															
	1340 H		1345 H		3310 H*		3316 H*		4028 H		4032 H		4037 H		4042 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	60	53	63	56	43	36	47	40	52	45	57	50	59	52	62	55
2	60	52	63	56	43	36	47	39	50	40	54	45	57	49	60	52
3	59	51	62	55	42	35	47	38	46	31	51	36	54	42	58	48
4	58	49	61	54	42	35	46	38	40	25	46	29	51	35	55	40
5	57	46	61	51	42	34	46	37	34	22	39	25	45	30	50	33
6	56	40	60	44	42	33	46	37	30	20	34	23	38	26	45	29
7	55	35	60	38	41	32	45	36	28	...	31	22	34	23	39	27
8	54	33	59	35	41	31	45	35	26	...	29	21	32	22	36	26
9	52	31	58	33	41	30	45	34	25	...	28	20	30	21	34	25
10	51	29	57	32	40	30	45	33	25	...	26	...	29	20	33	24
11	50	28	56	31	40	29	45	33	24	...	26	...	28	...	32	24
12	48	27	55	30	40	29	45	32	23	...	25	...	27	...	31	23
13	46	26	54	29	39	28	45	32	23	....	24	...	26	...	30	23
14	44	25	53	29	39	28	44	32	22	...	24	...	26	...	30	23
15	42	25	52	28	38	27	44	31	22	...	23	...	26	...	29	22
16	41	24	51	28	38	27	44	31	21	...	23	...	25	...	29	22
18	39	23	49	27	37	26	44	31	21	...	23	...	25	...	28	22
20	38	23	48	27	37	26	43	31	20	...	22	...	25	...	28	21
22	37	22	47	26	37	26	43	31	...	...	22	...	25	...	28	20
24	36	22	46	26	36	26	43	31	...	...	21	...	24	...	27	20
26	35	21	45	25	36	25	42	31	...	...	21	...	24	...	27	...
28	35	21	45	25	36	25	42	30	...	...	20	...	24	...	27	...
30	34	20	45	24	35	25	42	30	...	...	...	...	23	...	26	...
32	34	20	45	24	35	25	41	30	...	...	...	...	23	...	26	...

* Formerly Standard Steels

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 4042 H to 4142 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	4047 H		4118 H		4120 H		4130 H		4135 H		4137 H		4140 H		4142 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	64	57	48	41	48	41	56	49	58	51	59	52	60	53	62	55
2	62	55	46	36	47	37	55	46	58	50	59	51	60	53	62	55
3	60	50	41	27	44	32	53	42	57	49	58	50	60	52	62	54
4	58	42	35	23	41	37	51	38	56	48	58	49	59	51	61	53
5	55	35	31	20	37	23	49	34	56	47	57	49	59	51	61	53
6	52	32	28	...	34	21	47	31	55	45	57	48	58	50	61	52
7	47	30	27	...	32	...	44	29	54	42	56	45	58	48	60	51
8	43	28	25	...	30	...	42	27	53	40	55	43	57	47	60	50
9	40	28	24	...	29	...	40	26	52	38	55	40	57	44	60	49
10	38	27	23	...	28	...	38	26	51	36	54	39	56	42	59	47
11	37	26	22	...	27	...	36	25	50	34	53	37	56	40	59	46
12	35	26	21	...	26	...	35	25	49	33	52	36	55	39	58	44
13	34	25	21	...	25	...	34	24	48	32	51	35	55	38	58	42
14	33	25	20	...	25	...	34	24	47	31	50	34	54	37	57	41
15	33	25	...	...	24	...	33	23	46	30	49	33	54	36	57	40
16	32	25	...	...	24	...	33	23	45	30	48	33	53	35	56	39
18	31	24	...	...	23	...	32	22	44	29	46	32	52	34	55	37
20	30	24	...	...	23	...	32	21	42	28	45	31	51	33	54	36
22	30	23	...	...	23	...	32	20	41	27	44	30	49	33	53	35
24	30	23	...	...	23	...	31	...	40	27	43	30	48	32	53	34
26	30	22	...	...	23	...	31	...	39	27	42	30	47	32	52	34
28	29	22	...	...	22	...	30	...	38	26	42	29	46	31	51	34
30	29	21	...	...	22	...	30	...	38	26	41	29	45	31	51	33
32	29	21	...	...	22	...	29	...	37	26	41	29	44	30	50	33

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 4145 H to 4620 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	4145 H		4147 H		4150 H		4161 H		4320 H		4340 H		E 4340 H		4620 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	63	56	64	57	65	59	65	60	48	41	60	53	60	53	48	41
2	63	55	64	57	65	59	65	60	47	38	60	53	60	53	45	35
3	62	55	64	56	65	59	65	60	45	35	60	53	60	53	42	27
4	62	54	64	56	65	58	65	60	43	32	60	53	60	53	39	24
5	62	53	63	55	65	58	65	60	41	29	60	53	60	53	34	21
6	61	53	63	55	65	57	65	60	38	27	60	53	60	53	31	...
7	61	52	63	55	65	57	65	60	36	25	60	53	60	53	29	...
8	61	52	63	54	64	56	65	60	34	23	60	52	60	53	27	...
9	60	51	63	54	64	56	65	59	33	22	60	52	60	53	26	...
10	60	50	62	53	64	55	65	59	31	21	60	52	60	53	25	...
11	60	49	62	52	64	54	65	59	30	20	59	51	60	53	24	...
12	59	48	62	51	63	53	64	59	29	20	59	51	60	52	23	...
13	59	46	61	49	63	51	64	58	28	...	59	50	60	52	22	...
14	59	45	61	48	62	50	64	58	27	...	58	49	59	52	22	...
15	58	43	60	46	62	48	64	57	27	...	58	49	59	52	22	...
16	58	42	60	45	62	47	64	56	26	...	58	48	59	51	21	...
18	57	40	59	42	61	45	64	55	25	...	58	48	58	51	21	...
20	57	38	59	40	60	43	63	63	25	...	57	46	58	50	20	...
22	56	37	58	39	59	41	63	50	24	...	57	45	58	49	...	...
24	55	36	57	38	59	40	63	48	24	...	57	44	57	48	...	...
26	55	35	57	37	58	39	63	45	24	...	57	43	57	47	...	...
28	55	35	57	37	58	38	63	43	24	...	56	42	57	46	...	...
30	55	34	56	37	58	38	63	42	24	...	56	41	57	45	...	...
32	54	34	56	36	58	38	63	41	24	...	56	40	57	44	...	...

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 4626 H to 50B44 H

These values were adjusted to the nearest Rockwell “C” point, and are used when points are selected and specified

“J” Distance Sixteenths of an Inch	GRADE															
	4626 H*		4718 H		4720 H		4815 H		4817 H		4820 H		50B40 H		50B44 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	51	45	47	40	48	41	45	38	46	39	48	41	60	53	63	56
2	48	36	47	40	47	39	44	37	46	38	48	40	60	53	63	56
3	41	29	45	38	43	31	44	34	45	35	47	39	59	52	62	55
4	33	24	43	33	39	27	42	30	44	32	46	38	59	51	62	55
5	29	21	40	29	35	23	41	27	42	29	45	34	58	50	61	54
6	27	...	37	27	32	21	39	24	41	27	43	31	58	48	61	52
7	25	...	35	25	29	...	37	22	39	25	42	29	57	44	60	48
8	24	...	33	24	28	...	35	21	37	23	40	27	57	39	60	43
9	23	...	32	23	27	...	33	20	35	22	39	26	56	34	59	38
10	22	...	31	22	26	...	31	...	33	21	37	25	55	31	58	34
11	22	...	30	22	25	...	30	...	32	20	36	24	53	29	57	31
12	21	...	29	21	24	...	29	...	31	20	35	23	51	28	56	30
13	21	...	29	21	24	...	28	...	30	...	34	22	49	27	54	29
14	20	...	28	21	23	...	28	...	29	...	33	22	47	26	52	29
15	...	...	27	20	23	...	27	...	28	...	32	21	44	25	50	28
16	...	...	27	20	22	...	27	...	28	...	31	21	41	25	48	27
18	...	...	27	...	21	...	26	...	27	...	29	20	38	23	44	26
20	...	...	26	...	21	...	25	...	26	...	28	20	36	21	40	24
22	...	...	26	...	21	...	24	...	25	...	28	...	35	...	38	23
24	...	...	25	...	20	...	24	...	25	...	27	...	34	...	37	21
26	...	...	25	...	...	...	24	...	25	...	27	...	33	...	36	20
28	...	...	24	...	...	...	23	...	25	...	26	...	32	...	35	...
30	...	...	24	...	...	...	23	...	24	...	26	...	30	...	34	...
32	...	...	24	...	...	...	23	...	24	...	25	...	29	...	33	...

* Formerly Standard Steels

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 5046 H to 5135 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	5046 H		50B46 H		50B50 H		50B60 H		5120 H		5130 H		5132 H		5135 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	63	56	63	56	65	59	....	60	48	40	56	49	57	50	58	51
2	62	55	62	54	65	59	....	60	46	34	55	46	56	47	57	49
3	60	45	61	52	64	58	....	60	41	28	53	42	54	43	56	47
4	56	32	60	50	64	57	....	60	36	23	51	39	52	40	55	43
5	52	28	59	41	63	56	....	60	33	20	49	35	50	35	54	38
6	46	27	58	32	63	55	....	59	30	....	47	32	48	32	52	35
7	39	26	57	31	62	52	....	57	28	....	45	30	45	29	50	32
8	35	25	56	30	62	47	65	53	27	....	42	28	42	27	47	30
9	34	24	54	29	61	42	65	47	25	....	40	26	40	25	45	28
10	33	24	51	28	60	37	64	42	24	....	38	25	38	24	43	27
11	33	23	47	27	60	35	64	39	23	....	37	23	37	23	41	25
12	32	23	43	26	59	33	64	37	22	....	36	22	36	22	40	24
13	32	22	40	26	58	32	63	36	21	....	35	21	35	21	39	23
14	31	22	38	25	57	31	63	35	21	....	34	20	34	20	38	22
15	31	21	37	25	56	30	63	34	20	....	34	....	34	....	37	21
16	30	21	36	24	54	29	62	34	....	....	33	....	33	....	37	21
18	29	20	35	23	50	28	60	33	....	....	32	....	32	....	36	20
20	28	....	34	22	47	27	58	31	....	....	31	....	31	....	35	....
22	27	....	33	21	44	26	55	30	....	....	30	....	30	....	34	....
24	26	....	32	20	41	25	53	29	....	....	29	....	29	....	33	....
26	25	....	31	....	39	24	51	28	....	....	27	....	28	....	32	....
28	24	....	30	....	38	22	49	27	....	....	26	....	27	....	32	....
30	23	....	29	....	37	21	47	26	....	....	25	....	26	....	31	....
32	23	....	28	....	36	20	44	25	....	....	24	....	25	....	30	....

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 5140 H to 6150 H

These values were adjusted to the nearest Rockwell “C” point, and are used when points are selected and specified

“J” Distance Sixteenths of an Inch	GRADE															
	5140 H		5147 H		5150 H		5155 H		5160 H		51B60 H		6118 H		6150 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	60	53	64	57	65	59	....	60	....	60	....	60	46	39	65	59
2	59	52	64	56	65	58	65	59	....	60	....	60	44	36	65	58
3	58	50	63	55	64	57	64	58	....	60	....	60	38	28	64	57
4	57	48	62	54	63	56	64	57	65	59	....	60	33	24	64	56
5	56	43	62	53	62	53	63	55	65	58	....	60	30	22	63	55
6	54	38	61	52	61	49	63	52	64	56	....	59	28	20	63	53
7	52	35	61	49	60	42	62	47	64	52	....	58	27	....	62	50
8	50	33	60	45	59	38	62	41	63	47	....	57	26	....	61	47
9	48	31	60	40	58	36	61	37	62	42	....	54	26	....	61	43
10	46	30	59	37	56	34	60	36	61	39	....	50	25	....	60	41
11	45	29	59	35	55	33	59	35	60	37	....	44	25	....	59	39
12	43	28	58	34	53	32	57	34	59	36	65	41	24	....	58	38
13	42	27	58	33	51	31	55	34	58	35	65	40	24	....	57	37
14	40	27	57	32	50	31	52	33	56	35	64	39	23	....	55	36
15	39	26	57	32	48	30	51	33	54	34	64	38	23	....	54	35
16	38	25	56	31	47	30	49	32	52	34	63	37	22	....	52	35
18	37	24	55	30	45	29	47	31	48	33	61	36	22	....	50	34
20	36	23	54	29	43	28	45	31	47	32	59	34	21	....	48	32
22	35	21	53	27	42	27	44	30	46	31	57	33	21	....	47	31
24	34	20	52	26	41	26	43	29	45	30	55	31	20	....	46	30
26	34	....	51	25	40	25	42	28	44	29	53	30	....	....	45	29
28	33	....	50	24	39	24	41	27	43	28	51	28	....	....	44	27
30	33	....	49	22	39	23	41	26	43	28	49	27	....	....	43	26
32	32	....	48	21	38	22	40	25	42	27	47	25	....	....	42	25

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 81B45 H to 86B30 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	81B45 H		8617 H		8620 H		8622 H		8625 H		8627 H		8630 H		86B30 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	63	56	46	39	48	41	50	43	52	45	54	47	56	49	56	49
2	63	56	44	33	47	37	49	39	51	41	52	43	55	46	55	49
3	63	56	41	27	44	32	47	34	48	36	50	38	54	43	55	48
4	63	56	38	24	41	27	44	30	46	32	48	35	52	39	55	48
5	63	55	34	20	37	23	40	26	43	29	45	32	50	35	54	48
6	63	54	31	....	34	21	37	24	40	27	43	29	47	32	54	48
7	62	53	28	....	32	....	34	22	37	25	40	27	44	29	53	48
8	62	51	27	....	30	....	32	20	35	23	38	26	41	28	53	47
9	61	48	26	....	29	....	31	....	33	22	36	24	39	27	52	46
10	60	44	25	....	28	....	30	....	32	21	34	24	37	26	52	44
11	60	41	24	....	27	....	29	....	31	20	33	23	35	25	52	42
12	59	39	23	....	26	....	28	....	30	....	32	22	34	24	51	40
13	58	38	23	....	25	....	27	....	29	....	31	21	33	23	51	39
14	57	37	22	....	25	....	26	....	28	....	30	21	33	22	50	38
15	57	36	22	....	24	....	26	....	28	....	30	20	32	22	50	36
16	56	35	21	....	24	....	25	....	27	....	29	20	31	21	49	35
18	55	34	21	....	23	....	25	....	27	....	28	....	30	21	48	34
20	53	32	20	....	23	....	24	....	26	....	28	....	30	20	47	32
22	52	31	....	....	23	....	24	....	26	....	28	....	29	20	45	31
24	50	30	....	....	23	....	24	....	26	....	27	....	29	....	44	29
26	49	29	....	....	23	....	24	....	26	....	27	....	29	....	43	28
28	47	28	....	....	22	....	24	....	25	....	27	....	29	....	41	27
30	45	28	....	....	22	....	24	....	25	....	27	....	29	....	40	26
32	43	27	....	....	22	....	24	....	25	....	27	....	29	....	39	25

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 8637 H to 8660 H

These values were adjusted to the nearest Rockwell “C” point, and are used when points are selected and specified

“J” Distance Sixteenths of an Inch	GRADE															
	8637 H		8640 H		8642 H		8645 H		86B45 H		8650 H		8655 H		8660 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	59	52	60	53	62	55	63	56	63	56	65	59	....	60	....	60
2	58	51	60	53	62	54	63	56	63	56	65	58	....	59	....	60
3	58	50	60	52	62	53	63	55	62	55	65	57	....	59	....	60
4	57	48	59	51	61	52	63	54	62	54	64	57	....	58	....	60
5	56	45	59	49	61	50	62	52	62	54	64	56	....	57	....	60
6	55	42	58	46	60	48	61	50	61	53	63	54	....	56	....	59
7	54	39	57	42	59	45	61	48	61	52	63	53	....	55	....	58
8	53	36	55	39	58	42	60	45	60	52	62	50	....	54	....	57
9	51	34	54	36	57	39	59	41	60	51	61	47	....	52	....	55
10	49	32	52	34	55	37	58	39	60	51	60	44	65	49	....	53
11	47	31	50	32	54	34	56	37	59	50	60	41	65	46	....	50
12	46	30	49	31	52	33	55	35	59	50	59	39	64	43	....	47
13	44	29	47	30	50	32	54	34	59	49	58	37	64	41	....	45
14	43	28	45	29	49	31	52	33	59	48	58	36	63	40	....	44
15	41	27	44	28	48	30	51	32	58	46	57	35	63	39	....	43
16	40	26	42	28	46	29	49	31	58	45	56	34	62	38	65	42
18	39	25	41	26	44	28	47	30	58	42	55	33	61	37	64	40
20	37	25	39	26	42	28	45	29	58	39	53	32	60	35	64	39
22	36	24	38	25	41	27	43	28	57	37	52	31	59	34	63	38
24	36	24	38	25	40	27	42	28	57	35	50	31	58	34	62	37
26	35	24	37	24	40	26	42	27	57	34	49	30	57	33	62	36
28	35	24	37	24	39	26	41	27	57	32	47	30	56	33	61	36
30	35	23	37	24	39	26	41	27	56	32	46	29	55	32	60	35
32	35	23	37	24	39	26	41	27	56	31	45	29	53	32	60	35

END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 8720 H to 94B30 H

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	8720 H		8740 H		8822 H		9260 H		9310 H		94B15 H		94B17 H		94B30 H	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	48	41	60	53	50	43	....	60	43	36	45	38	46	39	56	49
2	47	38	60	53	49	42	....	60	43	35	45	38	46	39	56	49
3	45	35	60	52	48	39	65	57	43	35	44	37	45	38	55	48
4	42	30	60	51	46	33	64	53	42	34	44	36	45	37	55	48
5	38	26	59	49	43	29	63	46	42	32	43	32	44	34	54	47
6	35	24	58	46	40	27	62	41	42	31	42	28	43	29	54	46
7	33	22	57	43	37	25	60	38	42	30	40	25	42	26	53	44
8	31	21	56	40	35	24	58	36	41	29	38	23	41	24	53	42
9	30	20	55	37	34	24	55	36	40	28	36	21	40	23	52	39
10	29	....	53	35	33	23	52	35	40	27	34	20	38	21	52	37
11	28	....	52	34	32	23	49	34	39	27	33	....	36	20	51	34
12	27	....	50	32	31	22	47	34	38	26	31	....	34	....	51	32
13	26	....	49	31	31	22	45	33	37	26	30	....	33	....	50	30
14	26	....	48	31	30	22	43	33	36	26	29	....	32	....	49	29
15	25	....	46	30	30	21	42	32	36	26	28	....	31	....	48	28
16	25	....	45	29	29	21	40	32	35	26	27	....	30	....	46	27
18	24	....	43	28	29	20	38	31	35	26	26	....	28	....	44	25
20	24	....	42	28	28	....	37	31	35	25	25	....	27	....	42	24
22	23	....	41	27	27	....	36	30	34	25	24	....	26	....	40	23
24	23	....	40	27	27	....	36	30	34	25	23	....	25	....	38	23
26	23	....	39	27	27	....	35	29	34	25	23	....	24	....	37	22
28	23	....	39	27	27	....	35	29	34	25	22	....	24	....	35	21
30	22	....	38	26	27	....	35	28	33	24	22	....	23	....	34	21
32	22	....	38	26	27	....	34	28	33	24	22	....	23	....	34	20

RESTRICTED END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 15B21 RH to 4130 RH

These values were adjusted to the nearest Rockwell “C” point, and are used when points are selected and specified

“J” Distance Sixteenths of an Inch	GRADE													
	15B21 RH		15B35 RH		3310 RH		4027 RH		4118 RH		4120 RH		4130 RH	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	47	42	57	52	42	37	51	46	47	42	47	42	55	50
2	46	41	55	51	42	37	48	42	44	38	45	39	54	48
3	44	39	54	50	42	37	43	34	38	30	41	35	52	44
4	42	33	53	49	41	36	37	28	33	25	38	30	49	40
5	37	24	50	41	41	36	32	24	29	22	34	26	46	36
6	30	20	46	33	41	35	28	22	27	20	31	24	44	34
7	24	....	42	28	40	33	26	20	25	....	29	22	41	32
8	22	....	36	24	40	33	24	....	24	....	28	21	39	30
9	20	....	32	23	39	32	23	....	23	....	26	20	37	28
10	....	....	28	21	39	32	22	....	22	....	25	....	35	27
11	....	....	....	....	39	31	22	....	21	....	24	....	33	26
12	....	....	25	....	39	31	21	....	20	....	23	....	32	26
13	....	....	....	....	38	30	21	....	....	....	23	....	32	26
14	....	....	24	....	38	30	20	....	....	....	22	....	31	25
15	....	....	....	....	37	29	....	....	....	....	22	....	31	25
16	....	....	23	....	37	29	....	....	....	....	21	....	31	25
18	....	....	....	....	36	28	....	....	....	....	20	....	30	24
20	....	....	22	....	36	28	....	....	....	....	....	....	30	23
22	....	....	....	....	35	27	....	....	....	....	....	....	30	23
24	....	....	20	....	35	27	....	....	....	....	....	....	29	22
26	....	....	....	....	35	27	....	....	....	....	....	....	29	22
28	....	....	....	....	34	26	....	....	....	....	....	....	28	21
30	....	.....	....	....	34	26	....	....	....	....	....	....	28	21
32	....	....	....	....	34	26	....	....	....	....	....	....	27	20

RESTRICTED END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 4140 RH to 50B40 RH

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE													
	4140 RH		4145 RH		4161 RH		4320 RH		4620 RH		4820 RH		50B40 RH	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	59	54	62	57	65	60	47	42	47	42	47	42	59	54
2	59	54	62	57	65	60	46	40	44	37	47	42	59	54
3	59	54	61	56	65	60	44	37	40	30	46	41	58	53
4	59	53	61	56	65	60	41	34	37	27	45	40	58	53
5	58	52	60	55	65	60	39	31	32	24	43	36	57	52
6	57	51	60	55	65	60	36	29	29	21	41	33	56	50
7	56	50	59	54	65	60	34	27	27	20	40	32	55	47
8	55	49	59	53	65	60	32	25	25	....	38	30	54	43
9	54	48	58	52	65	60	31	24	24	....	36	28	52	38
10	53	46	58	52	65	60	29	23	23	....	35	27	50	35
11	52	44	58	51	65	60	28	22	22	....	34	26	49	33
12	52	43	57	50	64	59	26	21	21	....	33	25	47	32
13	51	42	57	49	64	59	25	20	20	....	32	24	45	31
14	50	41	56	48	64	59	24	....	....	....	31	24	44	30
15	50	40	56	47	63	58	24	....	....	....	30	23	41	29
16	49	39	55	46	63	57	23	....	....	....	29	23	38	28
18	48	38	54	44	62	56	22	....	....	....	28	22	36	26
20	47	37	53	43	62	54	22	....	....	....	27	22	34	24
22	46	37	52	42	61	53	21	....	....	....	26	21	33	23
24	45	36	51	40	60	51	21	....	....	....	25	20	32	22
26	44	35	51	40	59	49	21	....	....	....	25	20	31	21
28	43	35	50	39	58	47	21	....	....	....	25	....	30	20
30	42	34	50	38	57	46	21	....	....	....	24	....	29	....
32	41	33	49	37	57	45	21	....	....	....	23	....	28	....

RESTRICTED END-QUENCH HARDENABILITY BANDS

Tabulations of Band Limits – 5130 RH to 9310 RH

These values were adjusted to the nearest Rockwell "C" point, and are used when points are selected and specified

"J" Distance Sixteenths of an Inch	GRADE															
	5130 RH		5140 RH		5160 RH		8620 RH		8622 RH		8720 RH		8822 RH		9310 RH	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	55	50	59	54	65	60	47	42	49	44	47	42	49	44	42	37
2	53	47	58	53	65	60	45	39	47	41	45	39	48	43	42	36
3	51	44	57	51	65	60	41	35	45	37	43	37	47	40	42	36
4	49	41	55	49	65	59	38	30	41	32	40	32	43	35	41	35
5	46	37	53	45	64	58	34	26	38	29	36	28	40	31	41	34
6	44	35	51	41	63	57	31	24	35	27	33	26	37	29	40	33
7	42	33	48	38	62	54	29	22	32	24	31	24	35	27	40	32
8	39	31	46	36	60	50	28	21	30	22	29	23	33	26	39	31
9	37	29	44	34	58	45	26	20	29	21	28	22	32	25	38	30
10	35	27	43	33	56	42	25	....	28	20	27	21	31	25	37	29
11	34	26	41	32	55	40	24	....	27	....	26	20	30	24	37	29
12	33	25	40	31	53	39	23	....	26	....	25	....	30	23	36	28
13	32	24	39	30	51	38	23	....	25	....	25	....	29	23	35	28
14	31	23	37	29	50	37	22	....	24	....	24	....	28	23	34	28
15	30	22	36	28	48	36	22	....	24	....	24	....	28	22	34	28
16	29	21	35	27	47	36	21	....	23	....	23	....	27	22	33	27
18	28	20	34	26	44	35	20	....	23	....	23	....	27	21	33	27
20	27	....	33	25	43	34	....	....	22	....	22	....	26	20	32	26
22	26	....	32	24	42	33	....	....	22	....	22	....	26	....	32	26
24	25	....	31	23	41	32	....	....	22	....	21	....	26	....	32	26
26	24	....	30	22	40	31	....	....	22	....	20	....	26	....	32	26
28	23	....	30	21	39	30	....	....	22	....	....	....	25	....	32	26
30	22	....	29	20	39	29	....	....	22	....	....	....	25	....	31	25
32	21	....	29	....	38	29	....	....	22	....	....	....	25	....	31	25

INTRODUCTION TO JOMINY CORRELATION WITH ROUND BARS

The following correlation of Jominy values with quenching severity and surface to center hardnesses obtainable in round bars is based on calculated and practical experience data.

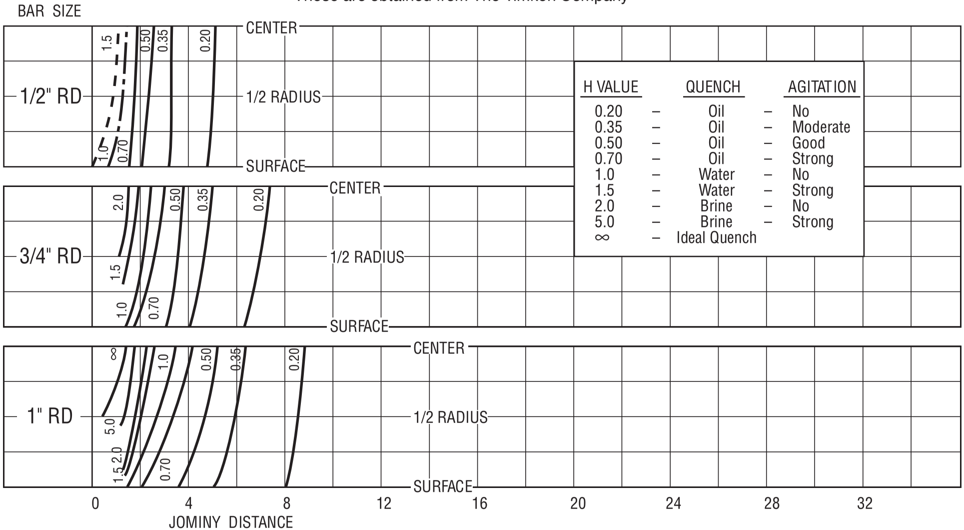
Since practical heat treatment results are subject to several variables that are always difficult to determine, i.e., surface condition of piece being quenched, furnace atmosphere, and quenching severity of the coolant, the metallurgist or heat treater may find some differences in applying this correlation to his particular heat treatment setup.

However, as experience is gained by their use, it is believed that these charts will be found helpful as a guide to the selection of steel of proper hardenability based on Jominy end quench results. As a value-added service, Timken Company hardenability data will be supplied upon request, with each heat of steel.

CHART FOR PREDICTING APPROXIMATE CROSS SECTION HARDNESS OF QUENCHED ROUND BARS USING JOMINY TEST RESULTS

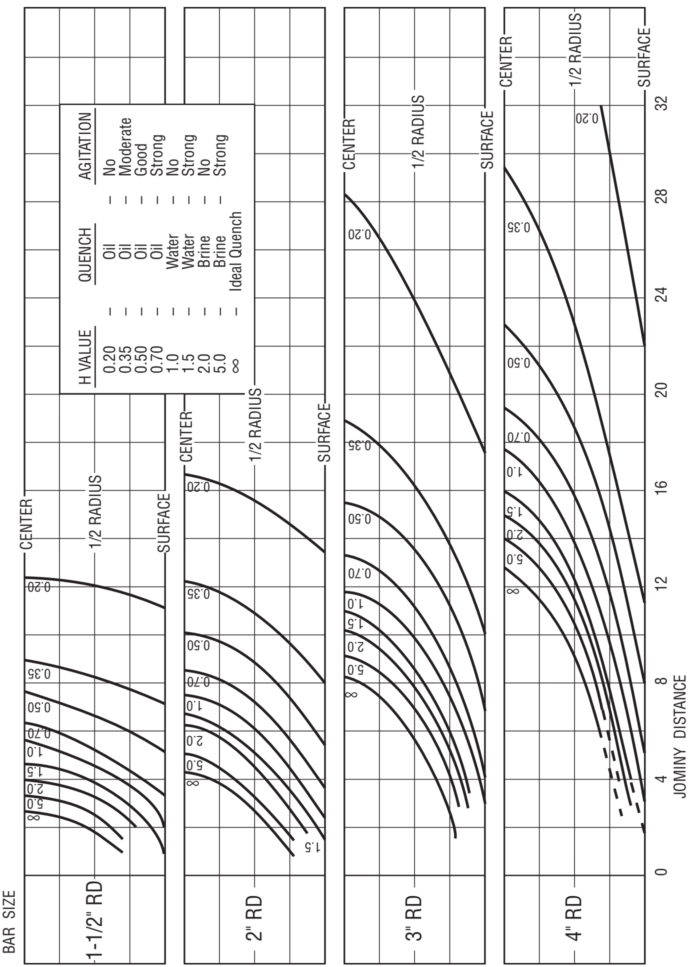
INSTRUCTIONS FOR USE OF CHART

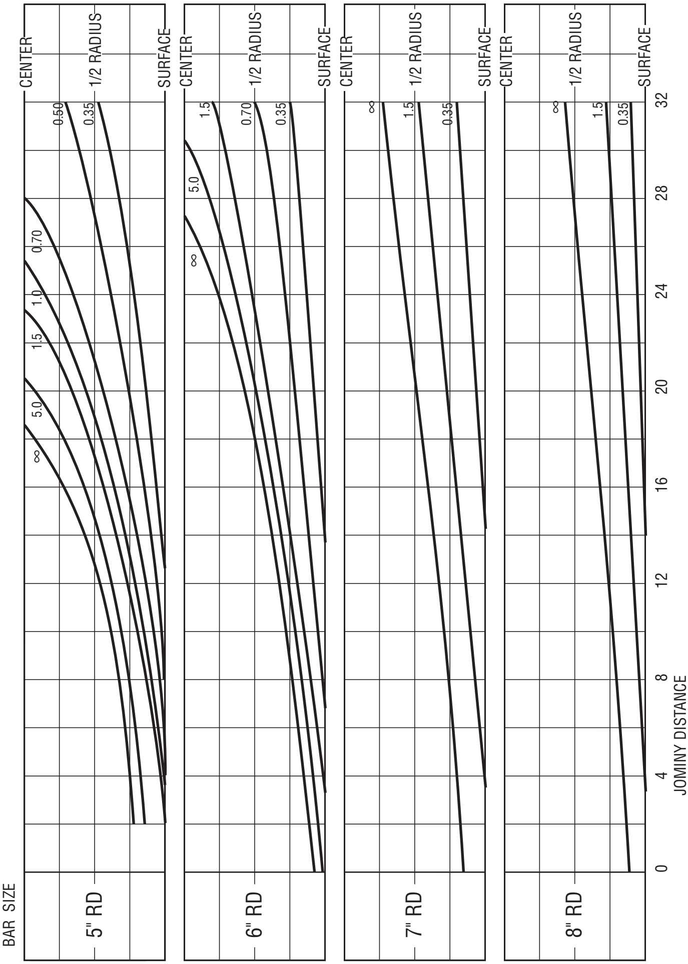
1. Select proper round bar size to be quenched.
2. Select the curve most representative of quenching conditions (H value) to be used.
3. Read the curve to the Jominy Distance.
4. Insert Rockwell "C" hardness values corresponding to the Jominy Distance. These are obtained from The Timken Company



H VALUE		QUENCH		AGITATION
0.20	–	Oil	–	No
0.35	–	Oil	–	Moderate
0.50	–	Oil	–	Good
0.70	–	Oil	–	Strong
1.0	–	Water	–	No
1.5	–	Water	–	Strong
2.0	–	Brine	–	No
5.0	–	Brine	–	Strong
∞	–	Ideal Quench		

Hardenability Data available with each shipment of steel. These hardness values represent the approximate surface-to-center hardness obtainable for the type of steel being heat treated.


BAR SIZE
1-1/2" RD
2" RD
3" RD
4" RD
CENTER
1/2 RADIUS
SURFACE
0.20
0.35
0.50
0.70
1.0
1.5
2.0
5.0
∞
H VALUE — QUENCH — AGITATION
0.20 — Oil — No
0.35 — Oil — Moderate
0.50 — Oil — Good
0.70 — Oil — Strong
1.0 — Water — No
1.5 — Water — Strong
2.0 — Brine — No
5.0 — Brine — Strong
∞ — Ideal Quench
0
4
8
12
16
20
24
28
32
JOMINY DISTANCE


BAR SIZE
5" RD
6" RD
7" RD
8" RD
CENTER
1/2 RADIUS
SURFACE
0.50
0.35
0.70
1.0
1.5
5.0
∞
0
4
8
12
16
20
24
28
32
JOMINY DISTANCE

EXPLANATION OF COMBINED HARDENABILITY CHARTS

The following charts present hardenability data for thirteen popular steels. They may be used to determine the approximate mid-radius hardness which is developed, in various sized rounds up to 9" in diameter using a good oil quench (.4-.5 Hv), or rounds up to 15" in diameter when air cooling. The effect of a subsequent 1000°F 2 hour temper is also illustrated.

The relationship between hardness and section size was determined using data from the Jominy end quench test, and air hardenability test, and controlled cooling tests. It must be remembered that the results for a particular steel type are based on one chemical analysis and one austenitizing temperature. Variations of these will affect hardenability, as shown by the Jominy hardenability bands (shaded area). Therefore, the charts should be used to determine estimated, rather than exact, hardness values.

USE OF CHARTS

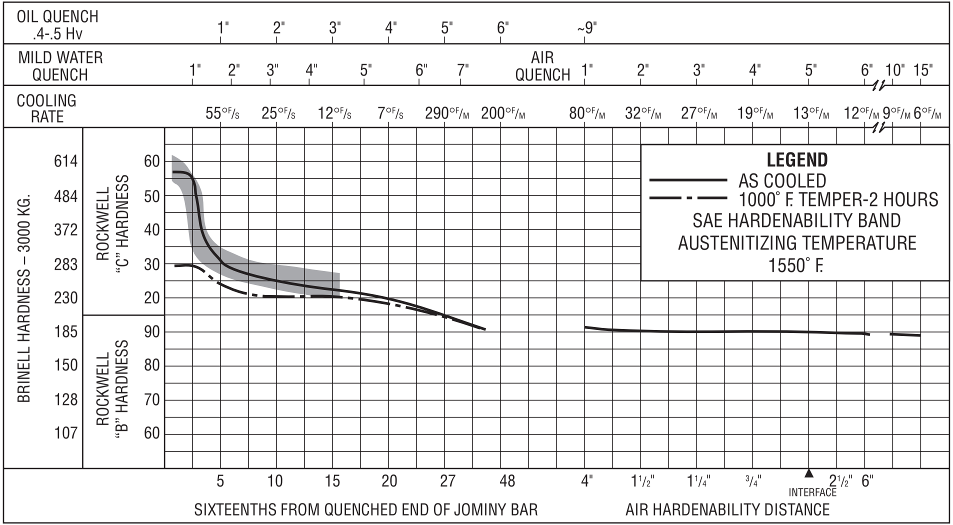
1. Select steel type.
2. Find desired diameter for the quenching medium employed.
3. Read the approximate as-quenched or tempered hardness using the appropriate curve; read hardness range using hardenability band.

For example, a 2-inch round made of 1045 type steel will develop the following mid-radius hardnesses:

	Mild Water	**Oil .4-.5 Hv**	**Air**
As-Cooled	28(25/32) Rc	25(22/29) Rc	91Rb
Tempered 1000 °F-2 Hours	22.5 Rc	21 Rc	91Rb

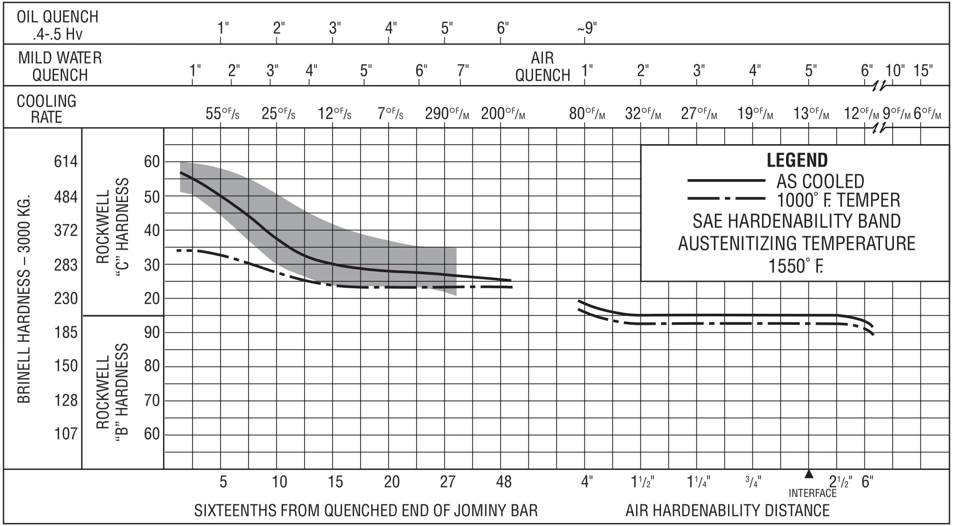
TYPE 1045	HEAT TREATMENT: NORMALIZED 1600° F. — AUSTENITIZED 1550° F.												
CHEMICAL ANALYSIS		C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
		.42	.79	.019	.023	.22	.11	.18	.04	.04	—	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



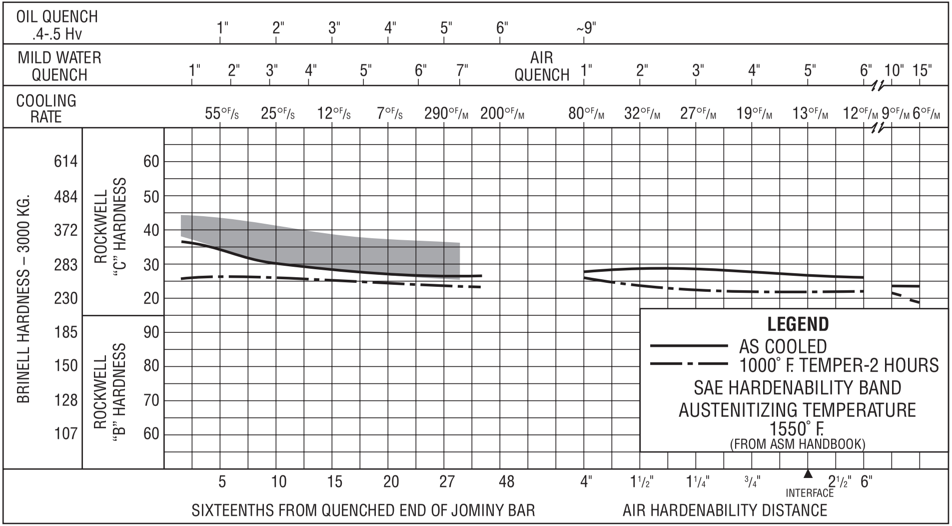
TYPE 1340	HEAT TREATMENT **NORMALIZED 1600° F. — AUSTENITIZED 1550° F.**												
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.40	1.87	.011	.013	.24	.08	.09	.02	.11	.019	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



TYPE 3310	HEAT TREATMENT: NORMALIZED 1700° F. — AUSTENITIZED 1550° F.												
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.08	.54	.012	.012	.25	1.56	3.42	.05	.10	.032	—	—	—

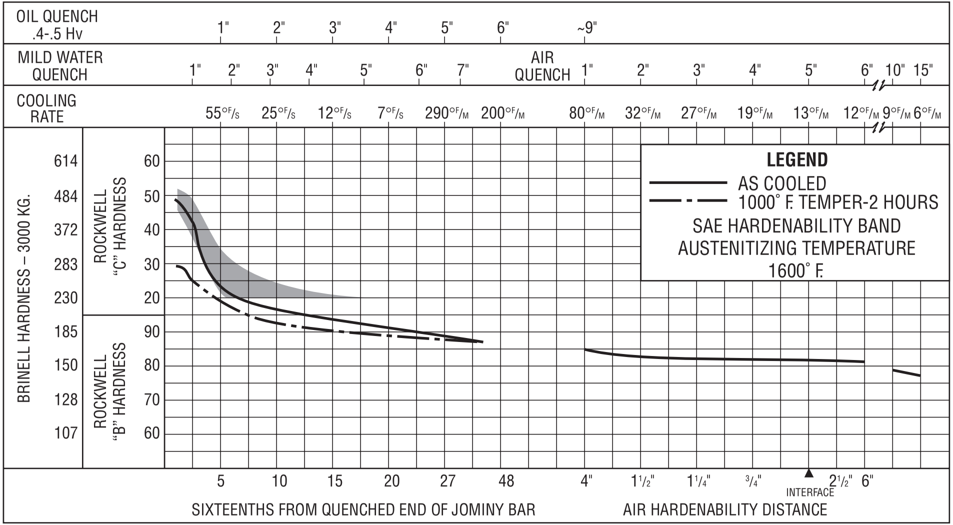
ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



TYPE	HEAT TREATMENT
4027	**NORMALIZED 1650° F. — AUSTENITIZED 1600° F.**

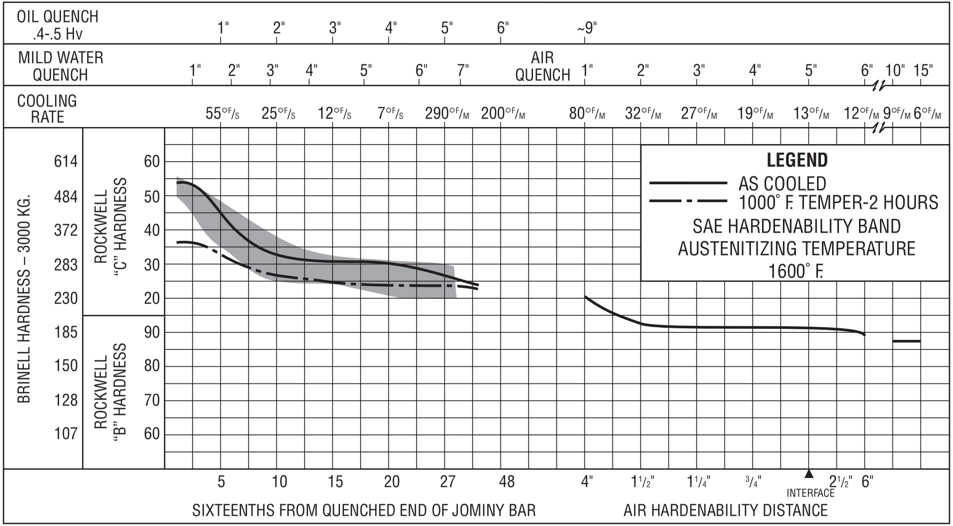
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.26	.86	.011	.027	.29	.05	.09	.22	.07	.032	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



TYPE	HEAT TREATMENT												
4130	**NORMALIZED 1650° F. — AUSTENITIZED 1600° F.**												
CHEMICAL ANALYSIS	C .31	Mn .51	P .013	S .020	Si .30	Cr .96	Ni .20	Mo .21	Cu .12	Al —	V —	W —	B —

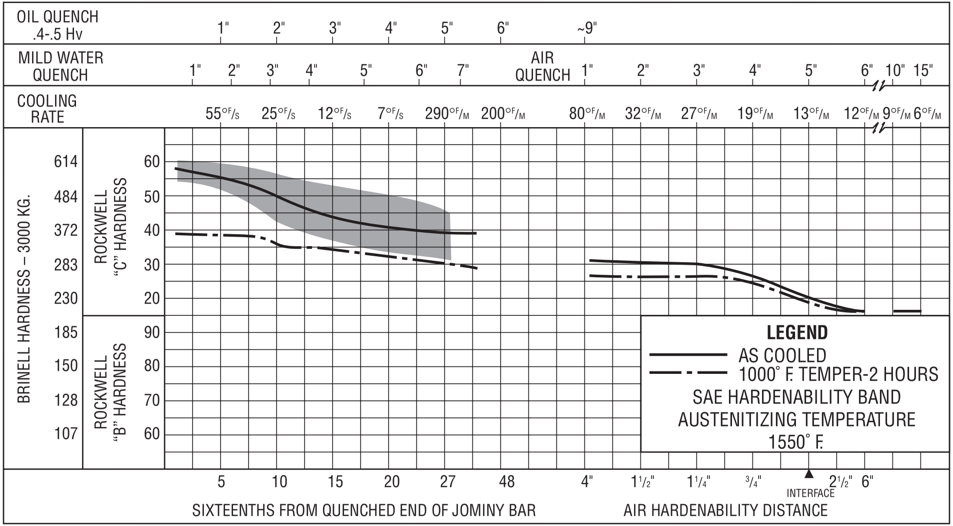
ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



TYPE	HEAT TREATMENT
4140	**NORMALIZED 1600° F. — AUSTENITIZED 1550° F.**

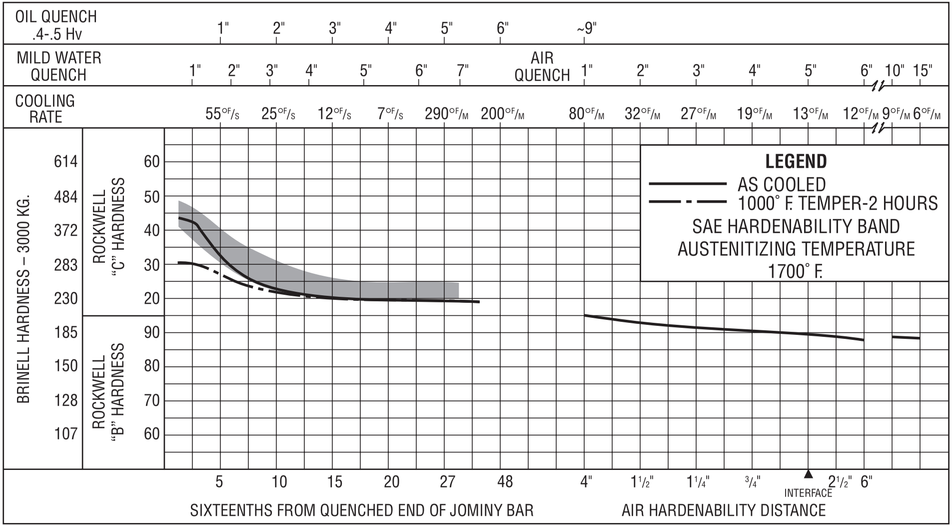
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.39	.82	.031	.021	.31	.96	.13	.20	.08	—	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



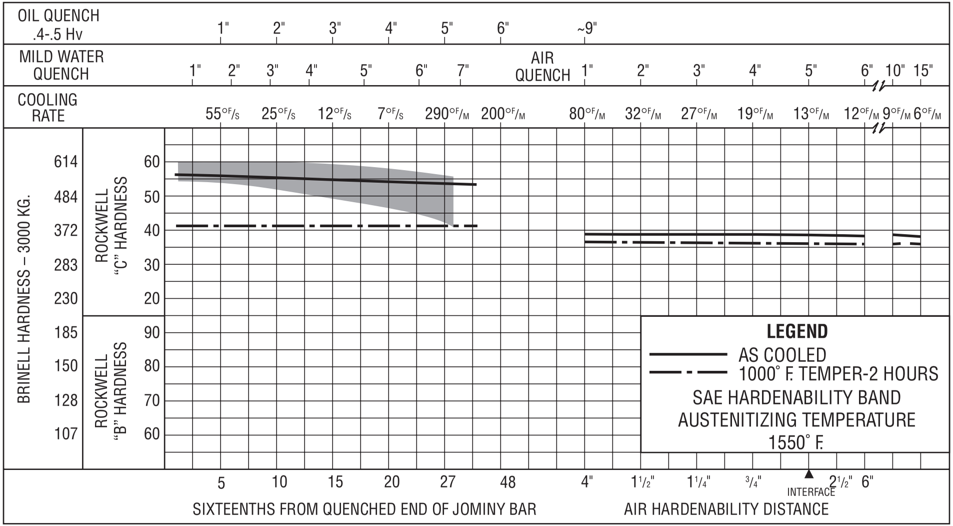
TYPE 4320	HEAT TREATMENT NORMALIZED 1700° F. — AUSTENITIZED 1700° F.											
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.18	.61	.010	.014	.29	.50	1.79	.23	.09	.021	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



TYPE 4340	HEAT TREATMENT: NORMALIZED 1600° F. — AUSTENITIZED 1550° F.												
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.41	.74	.014	.015	.30	.72	1.75	.26	.13	—	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



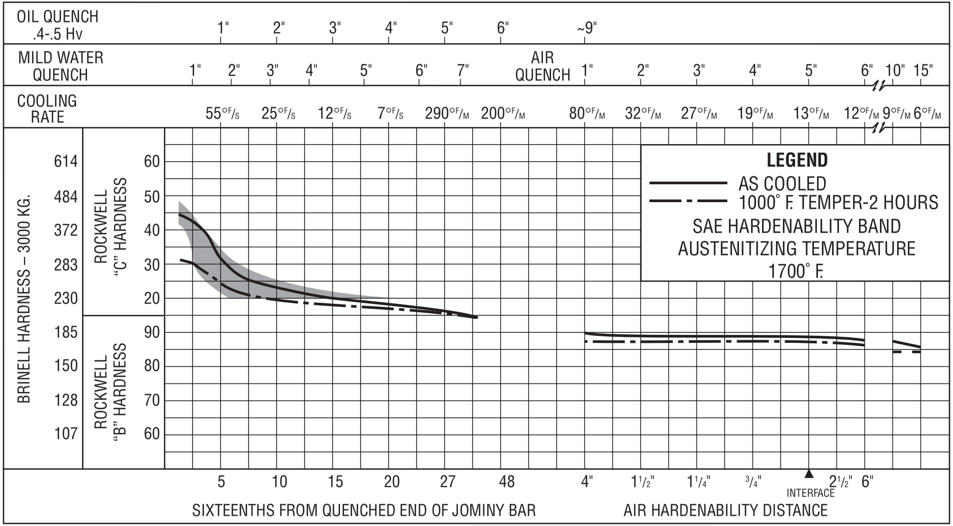
TYPE **4620**

HEAT TREATMENT

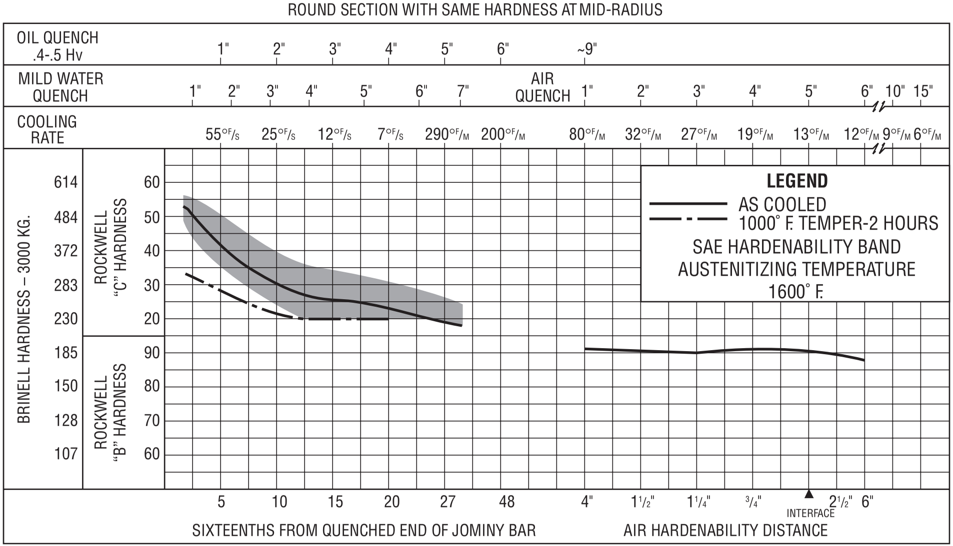
NORMALIZED 1700° F. — AUSTENITIZED 1700° F.

CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.19	.60	.013	.019	.32	.20	1.75	.22	.05	—	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS

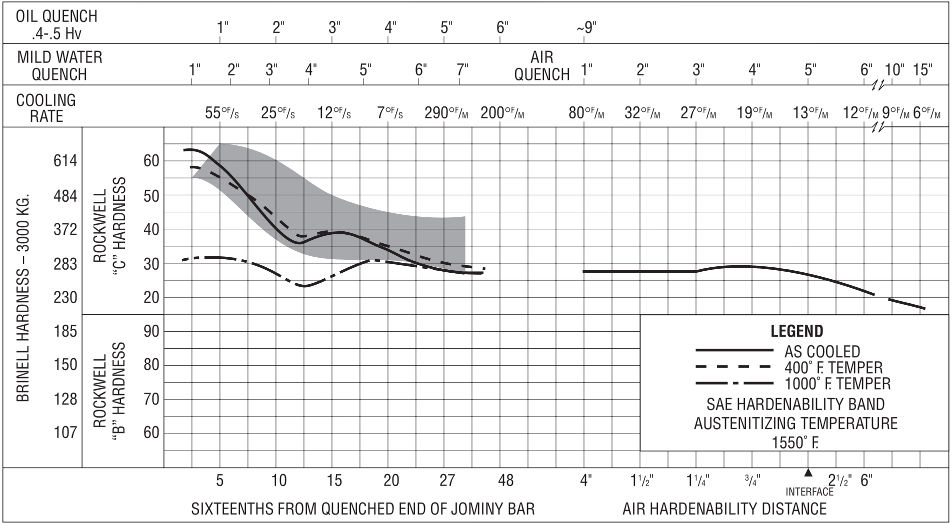


TYPE 5130	HEAT TREATMENT NORMALIZED 1650° F. — AUSTENITIZED 1600° F.												
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.30	.79	.022	.026	.26	.98	.09	.02	.14	.019	—	—	—



TYPE 5160	HEAT TREATMENT: NORMALIZED 1600° F. — AUSTENITIZED 1550° F.												
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.58	.91	.014	.016	.29	.78	.07	.01	.05	.023	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



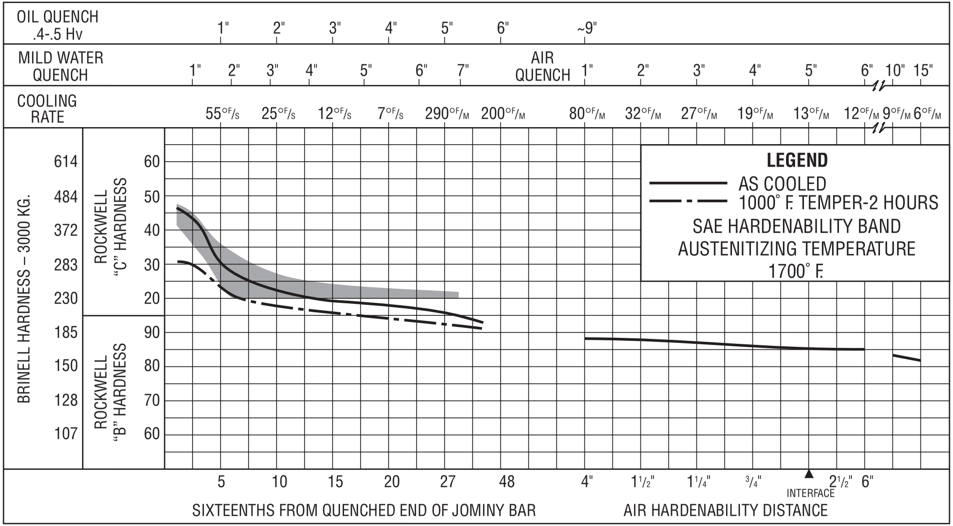
TYPE **8620**

HEAT TREATMENT

NORMALIZED 1700° F. — AUSTENITIZED 1700° F.

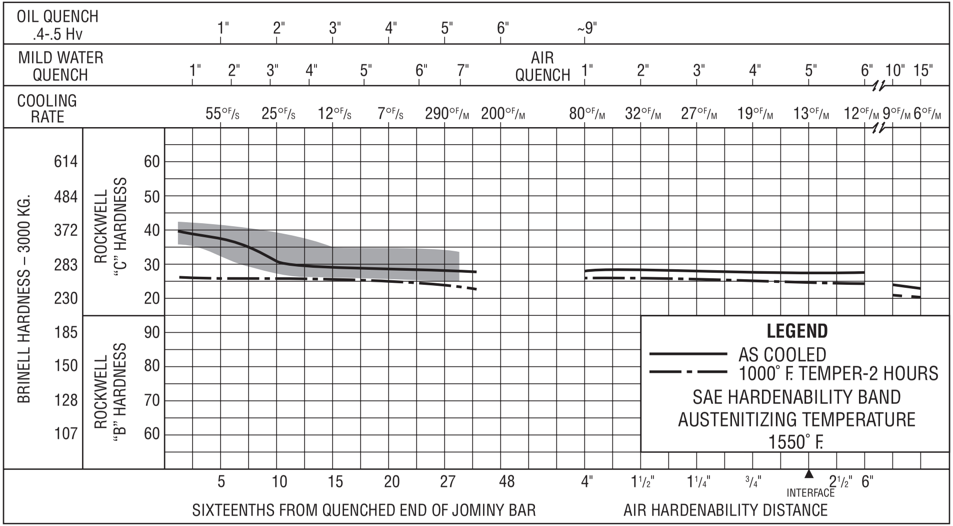
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.20	.85	.010	.014	.30	.50	.51	.19	.09	.031	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS

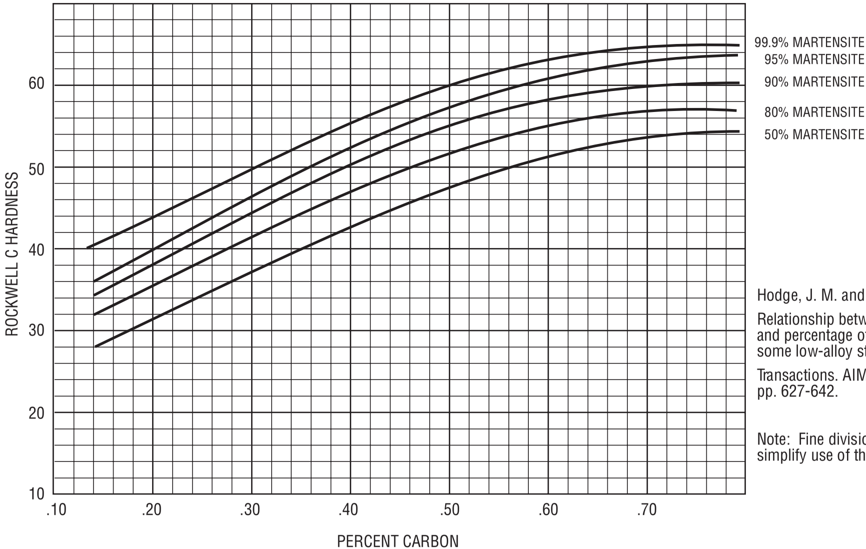


TYPE 9310	HEAT TREATMENT: NORMALIZED 1700° F. — AUSTENITIZED 1550° F.												
CHEMICAL ANALYSIS	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	V	W	B
	.10	.58	.012	.015	.30	1.26	3.26	.11	.11	.044	—	—	—

ROUND SECTION WITH SAME HARDNESS AT MID-RADIUS



AVERAGE RELATIONSHIPS BETWEEN CARBON CONTENT, HARDNESS AND PERCENTAGE OF MARTENSITE IN QUENCHING

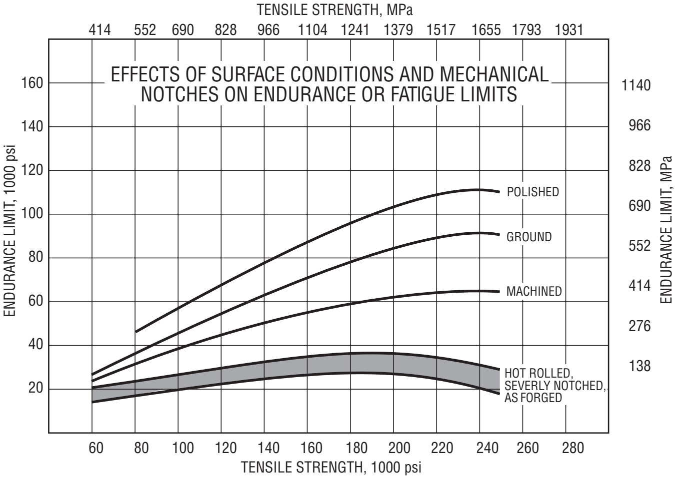


Hodge, J. M. and Orehoski, M. A.

Relationship between hardenability and percentage of martensite in some low-alloy steels.

Transactions. AIME, 1946, v. 167, pp. 627-642.

Note: Fine divisions added to simplify use of the graph.



Note: Endurance limits for surfaces exposed to corrosive environment fall below the band for hot rolled, severly notched, and as forged surfaces.

CONDITIONS WHICH AFFECT FATIGUE STRENGTH

The fatigue strength of a material depends on many factors of which the following are considered among the most important: (1) the strength of the material and the magnitude of the stress being applied to the material in its application, (2) the surface integrity of the material including its finish and method of manufacture, magnitude of residual stress present, and the presence of decarburization, (3) the environment in which the material is exposed in service.

It must be noted that fatigue data such as that represented by the curves shown above are averages obtained from laboratory tests which approach ideal conditions and should not be considered more than a guide.

F.B. Stulen and W.C. Schulte, Metals Engineering Quarterly (Am. Soc. Metals), Vol. 5, No. 3, Aug. 1965

SAE Fatigue Design Handbook (AE4) - 1968

Proceedings of the International Conference on Fatigue of Metals, (IME-ASME) - 1956

CARBURIZING INFORMATION

For .10% Carbon (Approx.) Higher Alloy Carburizing Steels, i.e., 3310, 9310, etc.

"EFFECTIVE" CASE DEPTH
for
VARIOUS CARBURIZING TIMES AND TEMPERATURES
(Calculated in Inches to .40% CARBON LEVEL)

Carburizing Time, Hours	Carburizing Temperature (°F)			
	1600°	1650°	1700°	1750°
1	.011"	.013"	.016"	.019"
2	.015"	.019"	.023"	.027"
3	.019"	.023"	.028"	.034"
4	.021"	.026"	.033"	.039"
5	.024"	.030"	.037"	.044"
6	.026"	.033"	.040"	.048"
7	.028"	.035"	.043"	.052"
8	.030"	.038"	.046"	.056"
9	.032"	.040"	.049"	.059"
10	.034"	.042"	.052"	.062"
11	.036"	.044"	.054"	.065"
12	.037"	.046"	.057"	.068"
16	.043"	.053"	.065"	.078"
20	.048"	.059"	.073"	.088"
24	.052"	.065"	.080"	.096"
30	.059"	.073"	.089"	.108"

Note: Case depth tables are based on data published in Metals Progress Data Sheet in May 1974 by F. E. Harris.

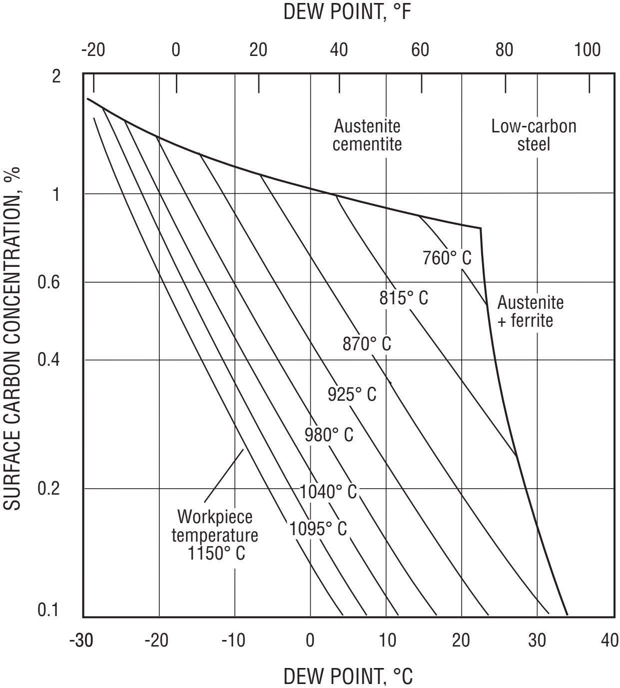
CARBURIZING INFORMATION

For .20% Carbon (Approx.) Lower Alloy Carburizing Steels, i.e., 4017, 4620, 8620, etc.

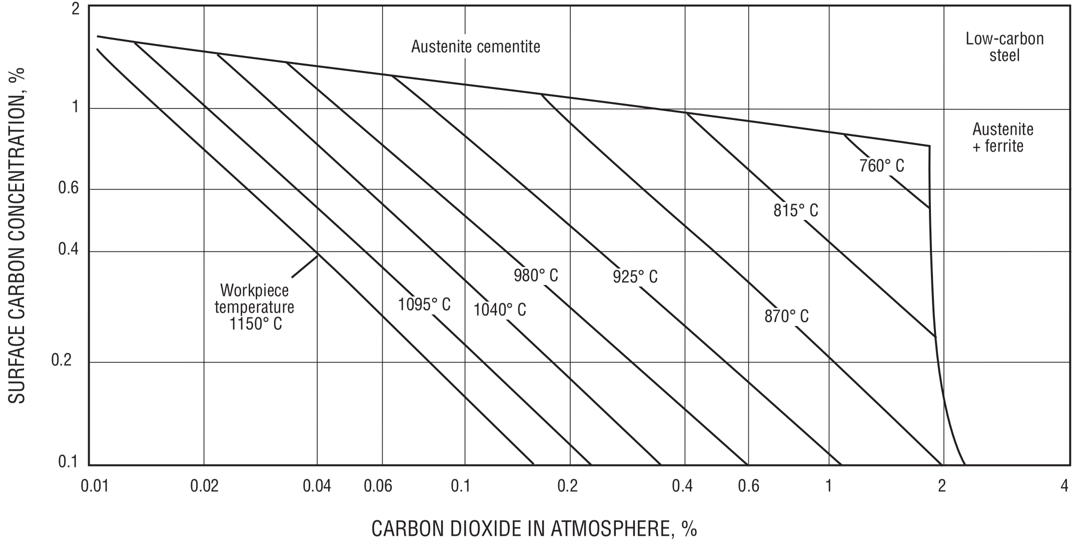
"EFFECTIVE" CASE DEPTH
for
VARIOUS CARBURIZING TIMES AND TEMPERATURES
(Calculated in Inches to .40% CARBON LEVEL)

Carburizing Time, Hours	Carburizing Temperature (°F)			
	1600°	1650°	1700°	1750°
1	.013"	.015"	.019"	.022"
2	.018"	.022"	.026"	.031"
3	.022"	.027"	.032"	.039"
4	.025"	.031"	.037"	.045"
5	.029"	.034"	.042"	.050"
6	.031"	.038"	.045"	.055"
7	.034"	.041"	.049"	.059"
8	.036"	.044"	.053"	.063"
9	.038"	.046"	.056"	.067"
10	.040"	.049"	.059"	.071"
11	.042"	.051"	.062"	.073"
12	.044"	.053"	.065"	.077"
16	.051"	.061"	.075"	.088"
20	.057"	.069"	.084"	.099"
24	.062"	.075"	.092"	.109"
30	.070"	.085"	.103"	.122"

Note: Case depth tables are based on data published in Metals Progress Data Sheet in May 1974 by F. E. Harris

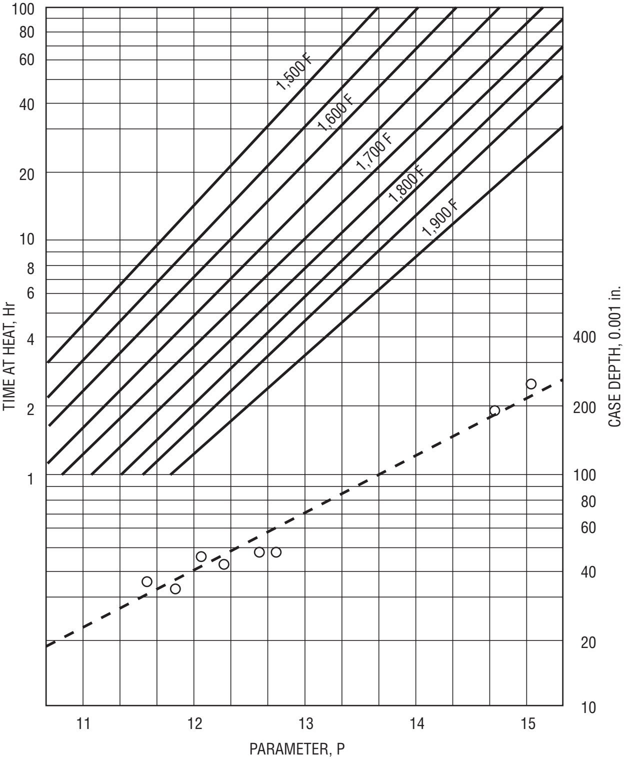


Variation of carbon potential with dew point for an endothermic-based atmosphere containing 20% CO and 40% H_2 in contact with plain carbon steel at various workpiece temperatures.



Variation of carbon potential with carbon dioxide concentration for an endothermic-based atmosphere containing 20% CO and 40% H_2 in contact with plain carbon steel at various workpiece temperatures.

DETERMINING CARBURIZING TIMES AND TEMPERATURES



TO USE THE CHART

In the upper grid, select a point (time and temperature) for which the case depth results are known. Go vertically down from that point to the known case depth and plot the point. Pass a line through this point parallel to the dashed line shown. Projecting a line vertically upward from any point on this line into the grid will give the combinations of time and temperature that will result in the same depth of case. For instance, a vertical line drawn upward from the dashed line at 100 thousandths indicates that a 0.100 in. case will be produced by 6 hr. at 1900°F, 11 hr. at 1800°F, or 22 hr. at 1700°F. Shop experience of the Cook Heat Treat Co., Houston, is depicted by this line and its related points.

Adapted from information provided by Charles F. Lewis, Cook Heat Treating Co., Div. Lindberg Corp.

APPROXIMATE CRITICAL TEMPERATURES AND Ms/Mf POINTS OF CARBON AND ALLOY STEELS

SAE	Heating (°F)		Cooling (°F)		Quench			SAE
No.	Ac_1	Ac_3	Ar_3	Ar_1	Temp °F	Ms (°F)	Mf (°F)	No.
1015	1370	1565	1545	1270	....	....	....	**1015**
1020	1350	1555	1515	1270	....	....	....	**1020**
1030	1350	1485	1465	1270	....	....	....	**1030**
1035	1350	1475	1440	1270	....	....	....	**1035**
1040	1350	1460	1420	1270	....	....	....	**1040**
1045	1350	1440	1405	1270	....	....	....	**1045**
1050	1340	1420	1390	1270	....	....	....	**1050**
1065	....	....	....	....	1500	525	300	**1065**
1090	....	....	....	....	1625	420	175	**1090**
1330	1325	1470	1340	1160	....	....	....	**1330**
1335	1315	1460	1340	1165	1550	640	450	**1335**
1340	1340	1420	1310	1160	....	....	....	**1340**
1345	1325	1420	1300	1160	....	....	....	**1345**
2317	1285	1435	1265	1065	....	....	....	**2317**
2330	1280	1360	1205	910/1050	....	....	....	**2330**
2340	1285	1350	1185	1060	1450	580	400	**2340**
2345	1265	1335	1125	1040	....	....	....	**2345**
2512	1290	1400	1150	1060	....	....	....	**2512**
2515	1260	1400	1160	1090	....	....	....	**2515**
3115	1355	1500	1480	1240	....	....	....	**3115**
3120	1350	1480	1445	1230	....	....	....	**3120**
3130	1345	1460	1360	1220	....	....	....	**3130**
3140	1355	1410	1275	1225	1550	630	440	**3140**
3141	1355	1410	1300	1215	....	....	....	**3141**
3150	1355	1380	1275	1215	....	....	....	**3150**

CRITICAL TEMPERATURES AND Ms/Mf POINTS – continued

SAE No.	Heating (°F)		Cooling (°F)		Quench			SAE No.
	Ac_1	Ac_3	Ar_3	Ar_1	Temp °F	Ms (°F)	Mf (°F)	
3310	1335	1440	1235	1160	....	....	....	**3310**
3316	1335	1425	1235	1160	....	....	....	**3316**
4027	1360	1500	1400	1230	....	....	....	**4027**
4032	1340	1500	1350	1250	....	....	....	**4032**
4042	1340	1460	1340	1210	1500	610	....	**4042**
4053	1310	1400	1320	1200	....	....	....	**4053**
4063	1360	1390	1220	1190	1500	445	....	**4063**
4068	1365	1395	1215	1195	....	....	....	**4068**
4118	1385	1500	1410	1275	....	....	....	**4118**
4130	1380	1475	1350	1250	1600	710	550	**4130**
4140	1380	1460	1370	1280	1500	640	425	**4140**
4147	....	....	....	....	1500	590	....	**4147**
4150	1390	1450	1290	1245	....	....	....	**4150**
4160	....	....	....	....	1575	500	....	**4160**
4320	1355	1485	1330	840/1170	....	....	....	**4320**
4340	1350	1425	1220	725/1210	1550	550	330	**4340**
4342	....	....	....	....	1500	530	....	**4342**
4615	1340	1485	1400	1200	....	....	....	**4615**
4620	1300	1490	1335	1220	....	....	....	**4620**
4640	1325	1400	1220	875/1130	1550	640	490	**4640**
4695*	....	....	....	....	1550	255	....	**4695***
4718	1285	1510	1410	1200	....	....	....	**4718**
4815	1285	1450	1310	860/1110	....	....	....	**4815**
4820	1290	1440	1260	825/1110	....	....	....	**4820**
5045	1360	1430	1305	1255	....	....	....	**5045**
5060	1370	1410	1305	1285	....	....	....	**5060**
5120	1380	1525	1460	1305	....	....	....	**5120**
5140	1360	1450	1345	1230	1550	630	460	**5140**

* Represents the case of 4600 grades of carburizing steels

CRITICAL TEMPERATURES AND Ms/Mf POINTS – continued

SAE	Heating (°F)		Cooling (°F)		Quench			SAE
No.	Ac_1	Ac_3	Ar_3	Ar_1	Temp °F	Ms (°F)	Mf (°F)	No.
51100	1385	1415	1320	1300	....	....	....	**51100**
52100	1340	1415	1320	1270	1560	345	....	
52100					1650	305	....	**52100**
52100					1740	260	....	**52100**
6117	1400	1560	1430	1270	1650	305	....	**6117**
6120	1410	1530	1440	1300	1740	260	....	**6120**
6140	....	....	....	....	1550	620	460	**6140**
6150	1380	1450	1375	1275	....	....	....	**6150**
8615	1360	1550	1455	1265	....	....	....	**8615**
8620	1350	1525	1400	1200	....	....	....	**8620**
8630	1350	1480	1340	1210	1600	690	540	**8630**
8640	1350	1435	1275	1170	....	....	....	**8640**
8650	1325	1390	1240	1195	....	....	....	**8650**
8695*	....	....	....	....	1500	275	....	**8695***
8720	1380	1520	1400	1200	....	....	....	**8720**
8740	1350	1450	1300	1180	....	....	....	**8740**
8750	1350	1410	1265	1190	....	....	....	**8750**
9310	1315	1490	1305	830/1080	....	....	....	**9310**
9317	1300	1455	1290	800	....	....	....	**9317**
9395*	....	....	....	....	1700	170	....	**9395***
9442	1350	1435	1280	1190	1575	620	410	**9442**
9 Cr 1 Mo	1515	1645	1430	1350	....	....	....	**9 Cr 1 Mo**
17-22-A®	1370	1480	1350	1245	....	....	....	**17-22-A®**
17-22-AS®	1440	1600	1460	1280	....	....	....	**17-22-AS®**
17-22-AV®	1435	1700	1525	1230	....	....	....	**17-22-AV®**
Graph Mo®	1380	1415	1365	1275	1450	410	....	**Graph Mo®**
Graph Air®	1275	1415	1260	1150	1460	325	....	**Graph Air®**

* Represents the case of 8600 and 9300 grades of carburizing steels, respectively.

Note: (1) All data in this table is empirically derived unless noted otherwise.
(2) When two temperatures are given for Ar_1, the higher represents the pearlitic reaction and the lower represents the bainitic reaction.
(3) See USEFUL EQUATIONS FOR HARDENABLE ALLOY STEELS (see Table of Contents) for formulas to calculate approximate critical temperatures and Ms points.

RECOMMENDED MAXIMUM HOT WORKING TEMPERATURES FOR STEELS

SAE No.	Temperature (°F)	SAE No.	Temperature (°F)
1008	2250	4320	2200
1010	2250	4337	2200
1015	2250	4340	2200
1040	2200		
		4422	2250
1118	2250	4427	2250
1141	2200		
		4520	2250
1350	2200		
		4615	2300
2317	2250	4620	2300
2340	2200	4640	2200
2512	2250	4718	2250
3115	2250	4820	2250
3135	2200		
3140	2200	5060	2150
3240	2200	5120	2250
		5140	2200
3310	2250	5160	2150
3316	2250		
3335	2250	51100	2050
		52100	2050
4017	2300		
4032	2200	6120	2250
4047	2200	6135	2250
4063	2150	6150	2200
4130	2200	8617	2250
4132	2200	8620	2250
4135	2200	8630	2200
4140	2200	8640	2200
4142	2200	8650	2200

RECOMMENDED MAXIMUM HOT WORKING TEMPERATURES FOR STEELS – continued

SAE No.	Temperature (°F)	Timken Type	Temperature (°F)
8720	2250	2 1/4 Cr 1 Mo	2250
8735	2200	5 Cr 1/2 Mo (.05C)	2250
8740	2200	5 Cr 1/2 Mo (.15C)	2250
9310	2250	5 Cr 1/2 Mo (.25C)	2250
		5 Cr 1/2 Mo + Ti	2100
302	2200	5 Cr 1/2 Mo + Si	2200
303	2200	7 Cr 1/2 Mo	2250
304	2200	9 Cr 1 Mo	2200
309	2150		
310	2050	8 1/2 Ni	2200
316	2150		
317	2150	Graph-Mo®	1950
321	2150	Graph-Air®	1925
347	2150		
		5 Cr Mo (1.00C)	2050
410	2200	5Cr Mo W (1.00W)	2300
416	2200		
420	2200	10105	2050
430	2100	Nitriding #3	2200
440A	2100		
440C	2050	17-22A®	2200
443	2100	17-22AS®	2200
446	1900	17-22AV®	2250
C-Mo	2300	A 485-1	2050
DM	2300	A 485-2	2050
		A 485-3	2100
DM-2	2300	A 485-4	2100
		TBS-600	2050
		CBS-600	2250
		CBS-1000M	2200

NOTE: Information obtained from hot-twist test data publshed in "Evaluating The Forgeability of Steels" (3rd edition,The Timken Company) occasionally modified by actual Forge Shop experience.

MECHANICAL TUBING TOLERANCES

Standard Timken Company Tolerances

HOT ROLLED, ROUND[1]

OD Tolerances

As rolled or single thermal treatment:

- inches
  $T_{OD} = \pm$ (.0045 OD + .005) or $\pm$.015 min.
- mm
  $T_{OD} = \pm$ (.0045 OD + .13) or $\pm$.38 min.
- over 10.75 inches (273mm) to 12.0 inches (305mm)
  inches $T_{OD} = \pm.095$
  mm $T_{OD} = \pm2.41$
- greater than 12.00 inches (305mm) to 13 inches (330mm)—refer to mill

Quenched and tempered, or normalized and tempered:

- inches
  $T_{OD} = \pm1.5$ (.0045 OD + .005) or $\pm$.023 min.
- mm
  $T_{OD} = \pm1.5$ (.0045 OD + .13) or $\pm$.58 min.
- over 10.75 inches (273mm) to 12.00 inches (305 mm)
  inches $T_{OD} = \pm.113$
  mm $T_{OD} = \pm2.87$

Wall Tolerances (All Thermal Conditions)

OD to wall ratio over 10:1 or over 10.75 inches (273 mm) to 13.00 inches (330 mm) OD

(all OD to wall ratios). . . . . $\pm$10%

OD to wall ratio of 10:1 or less . . . .$\pm$7.5%

Note: Minimum wall tolerance is $\pm$.020 inch (.51mm).

OD - Outside Diameter **T - Tolerance** **ID - Inside Diameter** **W - Wall Thickness**

[1] Hot rolled and rough turned tubes can be purchased to outside diameter (OD) and wall thickness (W) only.

Timken Company guaranteed tube sizes are calculated using Timken Company tolerances.

ROUGH TURNED, ROUND[1]

OD Tolerances

As turned or single thermal treatment:

- under 6.75 inches (171.5mm)
  inches $T_{OD} = \pm.005$
  mm $T_{OD} = \pm.13$
- 6.75 inches (171.5mm) and over
  inches $T_{OD} = \pm.010$
  mm $T_{OD} = \pm.25$

Straightened and/or tempered or stress relieved after rough turning:

inches $T_{OD} = \pm.010$
mm $T_{OD} = \pm.25$

Quenched and tempered, or normalized and tempered:

- Under 6.75 inches (171.5mm)
  Heat Treated Before Rough Turned
  $T_{OD} = \pm.010$ inches ($\pm.25$mm)
  Heat Treated After Rough Turned
  $T_{OD} = \pm.015$ inches ($\pm.38$mm)
- 6.75 inches (171.5mm) and over
  Heat Treated Before Rough Turned
  $T_{OD} = \pm.020$ inches ($\pm.51$mm)
  Heat Treated After Rough Turned
  $T_{OD} = \pm.030$ inches ($\pm.76$mm)

Wall Tolerances (All Thermal Conditions)

OD to wall ratio over 10:1 . . . . $\pm$12.5%
OD to wall ratio of 10:1 or less . . . . $\pm$10.0%

Note: Minimum wall tolerance is $\pm$.020 inch (.51mm).

OD - Outside Diameter T - Tolerance ID - Inside Diameter W - Wall Thickness

[1] Hot rolled and rough turned tubes can be purchased to outside diameter (OD) and wall thickness (W) only.

Timken Company guaranteed tube sizes are calculated using Timken Company tolerances.

COLD DRAWN, ROUND[2]

OD Tolerances

As drawn:

inches

$T_{OD/ID} = \pm$ (.0023 OD − .003) or ±.004 min.

mm

$T_{OD/ID} = \pm$ (.0023 OD − .08) or ±.10 min.

Drawn and annealed, normalized, tempered or stress relieved:

inches

$T_{OD/ID} = \pm1.8$ (.0023 OD − .003) or ±.007 min.

mm

$T_{OD/ID} = \pm1.8$ (.0023 OD − .08) or ±.18 min.

Quenched and tempered, or normalized and tempered (OD & wall or ID & wall dimensions only):

inches

$T_{OD/ID} = \pm2.5$ (.0023 OD − .003) or ±.010 min.

mm

$T_{OD/ID} = \pm2.5$ (.0023 OD − .08) or ±.25 min.

Quenched and tempered, or normalized and tempered (OD & ID dimensions only):

inches

$T_{OD/ID} = \pm3.75$ (.0023 OD − .003) or ±.015 min.

mm

$T_{OD/ID} = \pm3.75$ (.0023 OD − .08) or ±.38 min.

Wall Tolerances (All Thermal Conditions)

OD to wall ratio over 10:1 . . . .±7.5%
OD to wall ratio 10:1 to 4:1 . . . . ±6%
OD to wall ratio under 4:1 . . . .±7.5%

Note: (1) Minimum wall tolerance is ±.012 inch (.30mm)
(2) When ID is under 1.000 inch (25.4mm), inquiry basis
(3) Walls 6% of OD and lighter, inquiry basis

OD - Outside Diameter T - Tolerance ID - Inside Diameter W - Wall Thickness

[2] Tubes with a final OD/W ratio less than 4:1 or a nominal finish wall size greater than 1.250 inches (31.75mm) will have a hot rolled ID and will be produced to cold drawn OD tolerances and hot rolled wall tolerances.

ASTM A-519 tolerances are acceptable except for cold finished sizes smaller than 2.500 inches (63.50mm) diameter, where Timken Company tolerances apply.

(4) When OD & ID dimensions, use ±7.5% wall

ROTOROLLED®, ROUND

OD Tolerances

As Rotorolled®:

inches

$T_{OD/ID} = \pm$ (.0024 OD + .0016) or ±.005 min. OD
±.010 min. ID

mm

$T_{OD/ID} = \pm$ (.0024 OD + .041) or ±.13 min.

Rotorolled® and annealed, normalized, tempered or stress relieved:

inches

$T_{OD/ID} = \pm$ (.0024 OD + .007) or ±.010 min.

mm

$T_{OD/ID} = \pm$ (.0024 OD + .18) or ±.25 min.

Quenched and tempered, or normalized and tempered (OD & wall or ID & wall dimensions only):

inches

$T_{OD/ID} = \pm 2$ (.0024 OD + .0016) or ±.010 min.

mm

$T_{OD/ID} = \pm 2$ (.0024 OD + .041) or ±.25 min.

Quenched and tempered, or normalized and tempered (OD & ID dimensions only):

inches

$T_{OD/ID} = \pm 3$ (.0024 OD + .0016) or ±.015 min.

mm

$T_{OD/ID} = \pm 3$ (.0024 OD + .041) or ±.38 min.

Wall Tolerances (All Thermal Conditions)

All wall thicknesses . . . . ±5%

Note: Minimum wall tolerance is ±.012 inches (.30mm)

OD - Outside Diameter **T - Tolerance** **ID - Inside Diameter** **W - Wall Thickness**

MECHANICAL TUBING TOLERANCES
Special Processed Tubing Tolerances

COLD DRAWN, SHAPED (Square, Rectangular or Oval)

OD Tolerances

As drawn or tempered:

inches

$T_{OD/ID} = \pm.005$ OD or $\pm.020$ min.

mm

$T_{OD} = \pm.005$ OD or $\pm.51$ min.

Quenched and tempered, or normalized and tempered:

inches

$T_{OD/ID} = \pm.01$ OD or $\pm.040$ min.

mm

$T_{OD/ID} = \pm.01$ OD or ±1.02 min.

Wall Tolerances (All Thermal Conditions)

All wall thicknesses $\pm10\%$ at center of flats

COLD DRAWN, SHAPED[3] (Dissimilar OD and ID Configuration)

OD Tolerances

As drawn or tempered:

inches

$T_{OD/ID} = \pm.005$ OD or $\pm.010$ min.

mm

$T_{OD/ID} = \pm.005$ OD or $\pm.25$ min.

Quenched and tempered, or normalized and tempered:

inches

$T_{OD/ID} = \pm.01$ OD or $\pm.020$ min.

mm

$T_{OD/ID} = \pm.01$ OD or $\pm.51$ min.

Wall Tolerances (All Thermal Conditions)

All wall thicknesses $\pm10\%$ at center of flats

OD - Outside Diameter **T - Tolerance** **ID - Inside Diameter** **W - Wall Thickness**

[3] When corner radii and twist are important, they must be reviewed by our mill before we accept the order.

LENGTH TOLERANCES

All Conditions – Seamless Steel Tubing

Random Lengths
Tubing shipped on random-length orders has a length spread of 7 feet (2.1 meters) with a mean length 10 feet to 26 feet (3 to 8 meters) unless otherwise specified.

Multiple Lengths
For tubing ordered in multiple lengths, it is standard practice for the customer to make their own allowances for loss of steel due to cutting operations. These allowances will vary from one customer to another due to their cutting practices and the amount of facing required on the ends of the part. Therefore, tubing is furnished to the multiple length as specified by the individual customer.

In Inches

Specified Length	Specified Size Outside Diameter	Permissible Variations	
		Over	Under
4 feet and under	Up to 2 inches incl.	1/16 inch	0
4 feet and under	Over 2 inches to 4 inches incl.	3/32 inch	0
4 feet and under	Over 4 inches	1/8 inch	0
Over 4 feet to 10 feet, incl.	Up to 2 inches incl.	3/32 inch	0
Over 4 feet to 10 feet, incl.	Over 2 inches	1/8 inch	0
Over 10 feet to 24 feet, incl.	All	3/16 inch	0
Over 24 feet to 34 feet, incl.	All	5/16 inch	0
Over 34 feet to 44 feet, incl.	All	7/16 inch	0

In Meters

Specified Length	Specified Size Outside Diameter	Permissible Variations	
		Over	Under
1 meter and under	Up to 50mm incl.	1mm	0
1 meter and under	Over 50mm to 100mm incl.	2mm	0
1 meter and under	Over 100mm	3mm	0
Over 1 meter to 3 meters	Up to 50mm incl.	2mm	0
Over 1 meter to 3 meters	Over 50mm	3mm	0
Over 3 meters to 7 meters	All	5mm	0
Over 7 meters to 10 meters	All	8mm	0
Over 10 meters to 13 meters	All	11mm	0

STRAIGHTNESS TOLERANCES
All Conditions – Seamless Steel Tubing

Straightness tolerances (T) should not exceed those shown in the tables below. The tolerance (T) for any 3-foot (1 meter) length is measured as shown in Figure 1. The total tolerance, the maximum curvature in the total length, is measured as shown in Figure 2. The table applies to lengths not exceeding 22 feet (6.7 meters).

The tolerances shown apply to conventional steel grades of as rolled, annealed, and heat treated tubing up to 302 Brinell maximum or micro alloy grades with a hardness of 229 Brinell or below. Heat treated tubes with a Brinell hardness of 302 maximum up to 401 maximum or micro alloy grades with a Brinell hardness exceeding 229 will have tolerance (T) twice the values shown in the table. Tubes with lighter walls, or with hardness exceeding 401 Brinell maximum, or weighing greater than 140 pounds per foot, require agreement on tolerances at time of order.

FIGURE 1

Measuring technique for straightness in any three feet

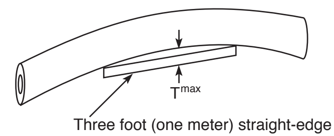
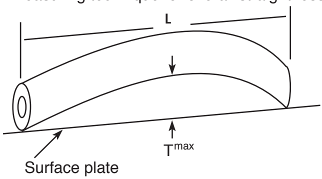


FIGURE 2

Measuring technique for overall straightness



STRAIGHTNESS TOLERANCES – continued
All Conditions—Seamless Steel Tubing

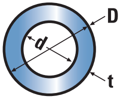
In Inches

Specified Size	Maximum Curvature in any 3 feet	Maximum Curvature in Total Lengths of 5 feet or more	Maximum Curvature for Lengths Under 5 feet
OD 5 inches and smaller. Wall thickness, over 3% of OD	.030 inch	$\frac{.020 \text{ inch} \times \text{length in feet}}{3}$	Ratio of .010 inch per foot
OD over 5 inches to 8 inches inclusive. Wall thickness, over 4% of OD	.045 inch	$\frac{.030 \text{ inch} \times \text{length in feet}}{3}$	Ratio of 0.015 inch per foot
OD over 8 inches to 11 inches inclusive. Wall thickness, over 4% of OD	.060 inch	$\frac{.045 \text{ inch} \times \text{length in feet}}{3}$	Ratio of 0.020 inch per foot

In Meters

Specified Size	Maximum Curvature in 1 meter	Maximum Curvature in Total Lengths of 1.5 meters or more	Maximum Curvature for Lengths Under 1.5 meters
OD 125mm and smaller. Wall thickness, over 3% of OD	.85mm	.55mm × length in meters	Ratio of .85mm per meter
OD over 125mm to 200mm inclusive. Wall thickness, over 4% of OD	1.25mm	.85mm × length in meters	Ratio of 1.25mm per meter
OD over 200mm to 280mm inclusive. Wall thickness, over 4% of OD	1.65mm	1.25 mm × length in meters	Ratio of 1.65mm per meter

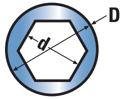
SEAMLESS STEEL TUBING SHAPES



$W = 10.68\,(D - t)\,t$

$M = .02466\,(D - t)\,t$

$A = \pi\,(D - t)\,t$

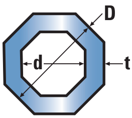


$W = 10.68\,(D - et)\,et$

$M = .02466\,(D - et)\,et$

$et = \dfrac{D - 1.050\,d}{2}$

$ed = 1.050\,d$

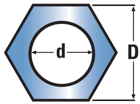


$W = 11.27\,(D - t)\,t$

$M = .02601\,(D - t)\,t$

$eD = 1.027\,D$

$ed = 1.027\,d$

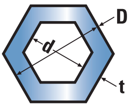


$W = 10.68\,(eD - et)\,et$

$M = .02466\,(eD - et)\,et$

$et = \dfrac{1.050\,D - d}{2}$

$eD = 1.050\,D$

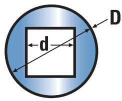


$W = 11.78\,(D - t)\,t$

$M = .02719\,(D - t)\,t$

$eD = 1.050\,D$

$ed = 1.050\,d$

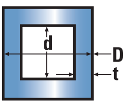


$W = 10.68\,(D - et)\,et$

$M = .02466\,(D - et)\,et$

$et = \dfrac{D - 1.128\,d}{2}$

$ed = 1.128\,d$

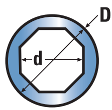


$W = 13.60\,(D - t)\,t$

$M = .03138\,(D - t)\,t$

$eD = 1.128\,D$

$ed = 1.128\,d$

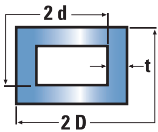


$W = 10.68\,(D - et)\,et$

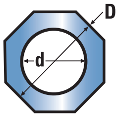
$M = .02466\,(D - et)\,et$

$et = \dfrac{D - 1.027\,d}{2}$

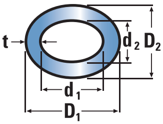
$ed = 1.027\,d$



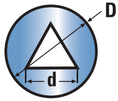
$W = 13.60\ (D - t)\ t$
$M = .03138\ (D - t)\ t$
$eD = 1.128\ D$
$ed = 1.128\ d$



$W = 10.68\ (eD - et)\ et$
$M = .02466\ (eD - et)\ et$
$et = \dfrac{1.027\ D - d}{2}$
$eD = 1.027\ D$



$W = 5.34\ (D_1 + D_2 - 2t)\ t$
$M = .01233\ (D_1 + D_2 - 2t)\ t$
$eD = \dfrac{D_1 + D_2}{2}$
$ed = \dfrac{d_1 + d_2}{2}$



$W = 10.68\ (D - et)\ et$
$M = .02466\ (D - et)\ et$
$et = \dfrac{D - .7425\ d}{2}$
$ed = .7425\ d$

Legend

A = Tubing cross sectional area. Round OD and ID.

W = Weight in pounds per foot

M = Mass in kilograms per meter

D = Outside diameter or distance across flats in inches (or millimeters)

d = Inside diameter or distance across flats in inches (or millimeters)

t = Wall thickness in inches (or millimeters)

eD = Equivalent round outside diameter in inches (or millimeters)

ed = Equivalent round inside diameter in inches (or millimeters)

et = Equivalent wall thickness in inches (or millimeters)

D_1 = Major outside diameter of oval tube in inches (or millimeters)

d_1 = Major inside diameter of oval tube in inches (or millimeters)

D_2 = Minor outside diameter of oval tube in inches (or millimeters)

d_2 = Minor inside diameter of oval tube in inches (or millimeters)

TUBE SIZE CALCULATIONS

How Mechanical Tube Sizes Are Calculated

The Timken Company has pioneered a method to determine the most economical tube size, which insures that all part dimensions will clean up during machining. This program has the capability to determine what we call a "guaranteed" tube size for either full or bright metal cleanup on the outer diameter and/or the inner diameter, based on the condition of the tube.

The guaranteed tube size is based on the part's critical finished dimensions and critical machining position. The required critical dimensions are: 1) maximum finished OD, 2) minimum finished ID, and 3) maximum finished part length. All applicable tolerances and surface finishes ("machined" or "ground") should be included. The critical machining position is based on whether the tube is chucked on the tube OD or the tube ID during the initial machining operation.

Critical finished part dimensions and machining position influence the amount of cleanup, the size tolerances and the tube eccentricity variables. These variables are then factored into the tube size calculation.

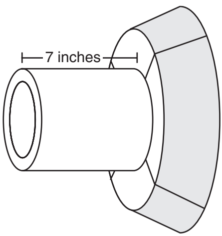
Cleanup Allowance

"Cleanup allowance" must be added to the finished OD dimension or subtracted from the finished ID dimension to provide for the elimination of surface imperfections, decarburization and camber (out-of-straightness). Other allowances specific to the application may be needed. (See table, page 98.)

Examples of Tube Size Calculation

Finished Part Dimensions

4.995 inches ±.005 inch OD × 4.005 inches ±.005 inch ID × 7 inches. Part is cut to length and held on one end. Allowance for camber is made for parts over 3 inches, measured from the end of the part to the face of the chuck. Examples on page 96 are for a hot rolled tube using Timken Company cleanup allowances.



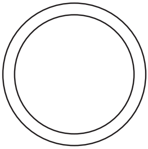


Figure 1
Cross section of finished part requiring full cleanup of OD and ID surfaces.

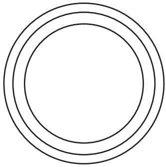


Figure 2
Finished part with addition of cleanup stock to OD. (Refer to Example 1, Operation 1, page 96.)

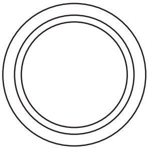


Figure 3
Finished part showing cleanup stock added to ID. (Refer to Example 1, Operaton 2.)

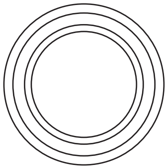


Figure 4
Finished part with cleanup allowance added to OD and ID determines minimum wall required for part to clean up. (Refer to Example 1, Operation 3.) Were it not for eccentricity, this would be the recommended tube size.

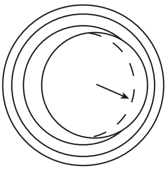


Figure 5
Same tube size machined true to OD showing effect of tube eccentricity. Tube ID is eccentric in relation to tube OD. Note that cleanup stock (dashed line) has been eliminated at A due to tube eccentricity. Part would not clean up at this point.

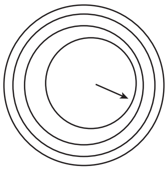


Figure 6
Here enough stock has been added to ID to protect cleanup stock required at minimum wall point A. (Refer to Example 1, Operations 4 and 5.)

When machining true to the ID, similar considerations apply except that stock to compensate for eccentricity is added to the tube OD. (See Example 2, page 97.)

Example 1 – Machined True to OD

Operation	Formula	Example (in)	Example (mm)
1. Determine nominal tube OD (see Figure 2, page 95)	Maximum machined OD	5.000 in	127.00mm
	Plus cleanup stock	+ .054 in	+ 1.37mm
	Plus camber allowance	+ .027 in	+ .69mm
	Plus OD negative tolerance	+ .028 in	+ .71mm
	Nominal tube OD	5.109 in	129.77mm
2. Determine maximum tube ID (see Figure 3)	Minimum machined ID	4.000 in	101.60mm
	Minus cleanup stock	− .042 in	− 1.07mm
	Minus camber allowance	− .027 in	− .69mm
	Maximum tube ID	3.931 in	99.84mm
3. Determine minimum wall required (see Figure 4)	Tube OD (Operation 1)	5.109 in	129.77mm
	Minus tube ID (Operation 2)	− 3.931 in	− 99.84mm
		1.178 in	29.93mm
	Divide by 2	÷ 2	÷ 2
	Minimum tube wall	.589 in	14.96mm
4. Determine average wall required (see Figure 6)	Minimum tube wall	.589 in	14.95mm
	Divide by the complement of minus tolerance	÷ .925	÷ .925
	Average tube wall	.637 in	16.17mm
5. Determine nominal tube ID (see Figure 6)	Tube OD (Operation 1)	5.109 in	129.77mm
	Minus average wall doubled	− 1.274 in	− 32.34mm
	Required tube ID	3.835 in	97.43mm

Guaranteed Tube Size: 5.109 inches OD ±.028 inches × .637 inches ±7.5%   Theoretical Foot Weight: 30.42 lbs.

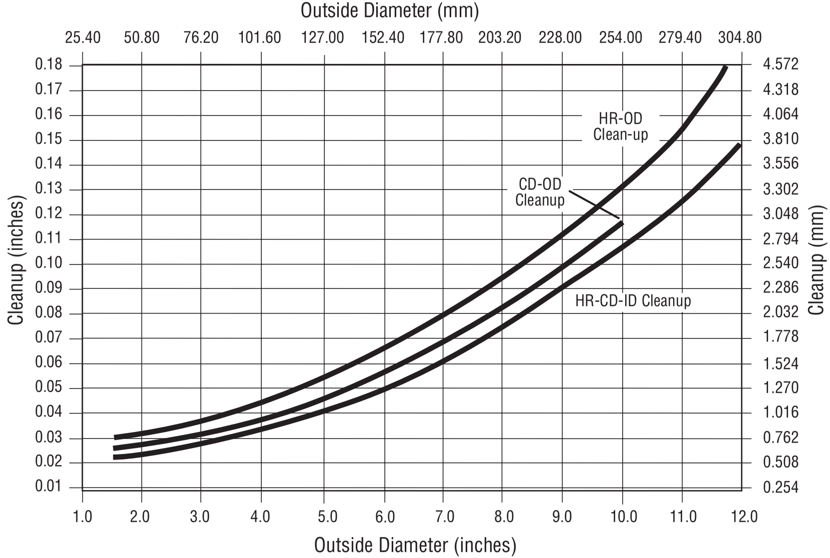
Example 2 – Machined True to ID

When machining true to the ID, similar considerations apply, except that stock to compensate for tube eccentricity is added to the tube OD. This will result in a larger recommended tube size.

Operation	Formula	Example (in)	Example (mm)
1. Determine minimum tube OD	Maximum machined OD	5.000 in	127.00mm
	Plus ID cleanup stock	+ .042 in	+ 1.07mm
	Plus camber allowance	+ .027 in	+ .69mm
	Minimum tube OD	5.069 in	128.76mm
2. Determine nominal tube ID	Minimum machined ID	4.000 in	101.60mm
	Minus minimum OD cleanup	− .054 in	− 1.37mm
	Minus camber allowance	− .027 in	− .69mm
	Minus OD tolerance	− .028 in	− .71mm
	Minus (if hot rolled)	− .030 in	− .76mm
	Nominal tube ID	3.861 in	98.07mm
3. Determine minimum wall required	Minimum tube OD (Operation 1)	5.069 in	128.76mm
	Minus nominal tube ID (Operation 2)	− 3.861 in	− 98.07mm
		1.208 in	30.69mm
	Divide by 2	÷ 2	÷ 2
	Minimum tube wall	.604 in	15.35mm
4. Determine average wall required	Minimum tube wall (Operation 3)	.604 in	15.35mm
	Divide by the complement of minus tolerance	÷ .925	÷ .925
	Average tube wall	.653 in	16.59mm
5. Determine nominal tube OD	Nominal tube ID (Operation 2)	3.861 in	98.07mm
	Plus average wall doubled	+ 1.306 in	+ 33.19mm
	Nominal tube OD	5.167 in	131.26mm

Guaranteed Tube Size: 5.167 inches OD ±.028 inches × .653 inches ±7.5%   Theoretical Foot Weight: 31.48 lbs.

HOT ROLLED AND COLD DRAWN MECHANICAL TUBING CLEANUPS FOR FULL SURFACE INTEGRITY AND BASE METAL



Note: Total stock removal is calculated for the tube diameter

FORMULAS FOR CALCULATING SURFACE CLEANUP

Hot Rolled OD Cleanup $= [.022e^{.18\ OD}]$
Cold Drawn OD Cleanup $= .86[.022e^{.18\ OD}]$
Hot Rolled and Cold Drawn ID Cleanup $= .78[.022e^{.18\ OD}]$

FORMULAS FOR CALCULATING CAMBER (STRAIGHTNESS) CLEANUP

Chucked on one end:
- Part length 3 inches or less—no camber added
- Part length over 3 inches—double the part length to calculate camber.

Chucked on both ends:
- Length 6 inches or less—no camber added
- Length over 6 inches—use formulas below (do not double part length).

Formulas (Calculate all length dimensions in inches):

A) $\text{OD} < 5.000 \text{ inches} = \dfrac{(171 \times \text{length}) - 444 - (1.03 \times \text{length squared})}{100{,}000}$

B) $\text{OD} \geq 5.000 \text{ inches} = \dfrac{(222 \times \text{length}) - 222 - (1.13 \times \text{length squared})}{100{,}000}$

C) $\text{OD} < 5.000 \text{ inches and Part Length} > 60 \text{ inches} = \dfrac{450 + (25 \times \text{length})}{30{,}000}$

D) OD 5.000 inches and Part Length $>$ 60 inches:
Use formula C $+$ .030 inches

BAR CROSS SECTIONAL TOLERANCES FOR HOT ROLLED STEEL BARS

Specified Size of Rounds or Squares (inches)	Variation from Size		Out-of-Round or Square (inches)
	Over (inches)	Under (inches)	
To 5/16 incl.	.005	.005	.008
Over 5/16 to 7/16 incl.	.006	.006	.009
Over 7/16 to 5/8 incl.	.007	.007	.010
Over 5/8 to 7/8 incl.	.008	.008	.012
Over 7/8 to 1 incl.	.009	.009	.013
Over 1 to 1-1/8 incl.	.010	.010	.015
Over 1-1/8 to 1-1/4 incl.	.011	.011	.016
Over 1-1/4 to 1-3/8 incl.	.012	.012	.018
Over 1-3/8 to 1-1/2 incl.	.014	.014	.021
Over 1-1/2 to 2 incl.	1/64	1/64	.023
Over 2 to 2-1/2 incl.	1/32	0	.023
Over 2-1/2 to 3-1/2 incl.	3/64	0	.035
Over 3-1/2 to 4-1/2 incl.	1/16	0	.046
Over 4-1/2 to 5-1/2 incl.	5/64	0	.058
Over 5-1/2 to 6-1/2 incl.	1/8	0	.070
Over 6-1/2 to 8-1/4 incl.	5/32	0	.085
Over 8-1/4 to 9-1/2 incl.	3/16	0	.100
Over 9-1/2 to 10 incl.	1/4	0	.120

BAR LENGTH TOLERANCES FOR HOT ROLLED STEEL BARS

Specified Sizes of Rounds, Squares, Hexagons, Octagons (inches)	10' to 20' Excl.	20' to 30' Excl.	30' to 40' Excl.	40' to 60' Excl.
Up to 3-1/2, incl.	1-1/2	1-3/4	2-1/4	2-3/4
Over 3-1/2 to 5, incl.	2	2-1/4	2-5/8	3
Over 5 to 12 incl.	2-1/2	2-3/4	3	3-1/4

No Tolerance Under

STRAIGHTNESS TOLERANCE HOT ROLLED STEEL BARS

Rounds, Squares, Hexagons, Octagons, Flats, and SpringFlats

Measurement is taken on the concave side of the bar with a straight edge.

Normal Straightness	Special Straightness
1/4" in any 5 ft.	1/8" in any 5 ft.
and	*and*
$\frac{1}{4}" \times \frac{\text{length in ft.}}{5}$	$\frac{1}{8}" \times \frac{\text{length in ft.}}{5}$

Note: Because of warpage, straightness tolerances do not apply to bars if any subsequent heating operation or controlled cooling has been performed.

Note: Tolerances shown are based upon ASTM A29

MACHINING ALLOWANCE FOR HOT ROLLED BARS

Minimum Stock Removal (diameter)	
Standard Grades	1.6% per side
Resulfurized Grades	2.4% per side

Note: Based on bars within special straightness tolerance. Since straightness is a function of length, additional machining allowance may be required for turning on centers.

MASTER WEIGHT TABLES FOR ROUNDS AND SQUARES

Weight Per Ft. - in Lbs.			Weight Per Ft. - in Lbs.		
Size	Sq. Cor. Squares	Rounds	Size	Sq. Cor. Squares	Rounds
1/8"	.0531	.0417	3/4"	1.9125	1.5021
9/64"	.0672	.0528	49/64"	1.9930	1.5653
5/32"	.0830	.0652	25/32"	2.0752	1.6299
11/64"	.1004	.0789	51/64"	2.1590	1.6957
3/16"	.1195	.0939	13/16"	2.2445	1.7629
13/64"	.1403	.1102	53/64"	2.3317	1.8313
7/32"	.1627	.1278	27/32"	2.4205	1.9011
15/64"	.1868	.1467	55/64"	2.5110	1.9721
1/4"	.2125	.1669	7/8"	2.6031	2.0445
17/64"	.2399	.1884	57/64"	2.6969	2.1182
9/32"	.2689	.2112	29/32"	2.7924	2.1931
19/64"	.2997	.2354	59/64"	2.8895	2.2694
5/16"	.3320	.2608	15/16"	2.9883	2.3470
21/64"	.3661	.2875	61/64"	3.0887	2.4259
11/32"	.4018	.3155	31/32"	3.1908	2.5061
23/64"	.4391	.3449	63/64"	3.2946	2.5876
3/8"	.4781	.3755	1"	3.400	2.6704
25/64"	.5188	.4075	1-1/32"	3.616	2.8399
13/32"	.5611	.4407	1-1/16"	3.838	3.0146
27/64"	.6051	.4753	1-3/32"	4.067	3.1945
7/16"	.6508	.5111	1-1/8"	4.303	3.3797
29/64"	.6981	.5483	1-5/32"	4.546	3.5700
15/32"	.7471	.5867	1-3/16"	4.795	3.7656
31/64"	.7977	.6265	1-7/32"	5.050	3.9664
1/2"	.8500	.6676	1-1/4"	5.313	4.1724
33/64"	.9040	.7100	1-9/32"	5.581	4.3836
17/32"	.9596	.7536	1-5/16"	5.587	4.6001
35/64"	1.0168	.7986	1-11/32"	6.139	4.8218
9/16"	1.0758	.8449	1-3/8"	6.428	5.0486
37/64"	1.1364	.8925	1-13/32"	6.724	5.2807
19/32"	1.1986	.9414	1-7/16"	7.026	5.5180
39/64"	1.2625	.9916	1-15/32"	7.335	5.7606
5/8"	1.3281	1.0431	1-1/2"	7.650	6.0083
41/64"	1.3954	1.0959	1-17/32"	7.972	6.2612
21/32"	1.4643	1.1500	1-9/16"	8.301	6.5194
43/64"	1.5348	1.2054	1-19/32"	8.636	6.7838
11/16"	1.6070	1.2622	1-5/8"	8.978	7.0514
45/64"	1.6809	1.3202	1-21/32"	9.327	7.3252
23/32"	1.7564	1.3795	1-11/16"	9.682	7.6043
47/64"	1.8336	1.4401	1-23/32"	10.044	7.8885

“Round Cornered” squares differ in weight from above schedule.

MASTER WEIGHT TABLES FOR ROUNDS AND SQUARES – continued

Size	Weight Per Ft. - in Lbs. Sq. Cor. Squares	Rounds	Size	Weight Per Ft. - in Lbs. Sq. Cor. Squares	Rounds
1-3/4"	10.413	8.1780	3"	30.600	24.033
1-25/32"	10.788	8.4726	3-1/32"	31.241	24.537
1-13/16"	11.170	8.7725	3-1/16"	31.888	25.045
1-27/32"	11.558	9.0776	3-3/32"	32.542	25.559
1-7/8"	11.953	9.3880	3-1/8"	33.203	26.078
1-29/32"	12.355	9.7035	3-5/32"	33.871	26.602
1-15/16"	12.763	10.0243	3-3/16"	34.545	27.131
1-31/32"	13.178	10.3502	3-7/32"	35.225	27.666
2"	13.600	10.6814	3-1/4"	35.913	28.206
2-1/32"	14.028	11.0178	3-9/32"	36.606	28.751
2-1/16"	14.463	11.3595	3-5/16"	37.307	29.301
2-3/32"	14.905	11.7063	3-11/32"	38.014	29.856
2-1/8"	15.353	12.0583	3-3/8"	38.728	30.417
2-5/32"	15.808	12.4156	3-13/32"	39.449	30.983
2-3/16"	16.270	12.7781	3-7/16"	40.176	31.554
2-7/32"	16.738	13.1458	3-15/32"	40.910	32.130
2-1/4"	17.213	13.5187	3-1/2"	41.650	32.712
2-9/32"	17.694	13.8968	3-9/16"	43.151	33.891
2-5/16"	18.182	14.2802	3-5/8"	44.678	35.090
2-11/32"	18.677	14.6687	3-11/16"	46.232	36.311
2-3/8"	19.178	15.0625	3-3/4"	47.813	37.552
2-13/32"	19.686	15.4615	3-13/16"	49.420	38.814
2-7/16"	20.201	15.8657	3-7/8"	51.053	40.097
2-15/32"	20.722	16.2751	3-15/16"	52.713	41.401
2-1/2"	21.250	16.6898	4"	54.400	42.726
2-17/32"	21.785	17.1096	4-1/16"	56.113	44.071
2-9/16"	22.326	17.5346	4-1/8"	57.853	45.438
2-19/32"	22.874	17.9650	4-3/16"	59.620	46.825
2-5/8"	23.428	18.4004	4-1/4"	61.413	48.233
2-21/32"	23.989	18.8410	4-5/16"	63.232	49.662
2-11/16"	24.557	19.2870	4-3/8"	65.078	51.112
2-23/32"	25.131	19.7382	4-7/16"	66.951	52.583
2-3/4"	25.713	20.1946	4-1/2"	68.850	54.075
2-25/32"	26.300	20.656	4-9/16"	70.776	55.587
2-13/16"	26.895	21.123	4-5/8"	72.728	57.121
2-27/32"	27.496	21.595	4-11/16"	74.707	58.675
2-7/8"	28.103	22.072	4-3/4"	76.713	60.250
2-29/32"	28.717	22.555	4-13/16"	78.745	61.846
2-15/16"	29.338	23.042	4-7/8"	80.803	63.463
2-31/32"	29.996	23.535	4-15/16"	82.888	65.100

"Round Cornered" squares differ in weight from above schedule.

MASTER WEIGHT TABLES FOR ROUNDS AND SQUARES – continued

Weight Per Ft. - in Lbs.			Weight Per Ft. - in Lbs.		
Size	Sq. Cor. Squares	Rounds	Size	Sq. Cor. Squares	Rounds
5"	85.000	66.759	7-1/2"	191.25	150.21
5-1/16"	87.138	68.438	7-9/16"	194.45	152.72
5-1/8"	89.303	70.139	7-5/8"	197.68	155.26
5-3/16"	91.495	71.860	7-11/16"	200.93	157.81
5-1/4"	93.713	73.602	7-3/4"	204.21	160.39
5-5/16"	95.957	75.364	7-13/16"	207.52	162.99
5-3/8"	98.228	77.148	7-7/8"	210.85	165.60
5-7/16"	100.526	78.953	7-15/16"	214.21	168.24
5-1/2"	102.850	80.778	8"	217.60	170.90
5-9/16"	105.20	82.62	8-1/16"	221.01	173.58
5-5/8"	107.58	84.49	8-1/8"	224.45	176.29
5-11/16"	109.98	86.38	8-3/16"	227.92	179.01
5-3/4"	112.41	88.29	8-1/4"	231.41	181.75
5-13/16"	114.87	90.22	8-5/16"	234.93	184.52
5-7/8"	117.35	92.17	8-3/8"	238.48	187.30
5-15/16"	119.86	94.14	8-7/16"	242.05	190.11
6"	122.40	96.13	8-1/2"	245.65	192.93
6-1/16"	124.96	98.15	8-9/16"	249.28	195.78
6-1/8"	127.55	100.18	8-5/8"	252.93	198.65
6-3/16"	130.17	102.24	8-11/16"	256.61	201.54
6-1/4"	132.81	104.31	8-3/4"	260.31	204.45
6-5/16"	135.48	106.41	8-13/16"	264.04	207.38
6-3/8"	138.18	108.53	8-7/8"	267.80	210.33
6-7/16"	140.90	110.66	8-15/16"	271.59	213.31
6-1/2"	143.65	112.82	9"	275.40	216.30
6-9/16"	146.43	115.00	9-1/16"	279.2	219.3
6-5/8"	149.23	117.20	9-1/8"	283.1	222.4
6-11/16"	152.06	119.43	9-3/16"	287.0	225.4
6-3/4"	154.91	121.67	9-1/4"	290.9	228.5
6-13/16"	157.79	123.93	9-5/16"	294.9	231.6
6-7/8"	160.70	126.22	9-3/8"	298.8	234.7
6-15/16"	163.64	128.52	9-7/16"	302.8	237.8
7"	166.60	130.85	9-1/2"	306.8	241.0
7-1/16"	169.59	133.19	9-9/16"	310.9	244.2
7-1/8"	172.60	135.56	9-5/8"	315.0	247.4
7-3/16"	175.64	137.95	9-11/16"	319.1	250.6
7-1/4"	178.71	140.36	9-3/4"	323.2	253.9
7-5/16"	181.81	142.79	9-13/16"	327.4	257.1
7-3/8"	184.93	145.24	9-7/8"	331.6	260.4
7-7/16"	188.08	147.71	9-15/32"	335.8	263.7

“Round Cornered” squares differ in weight from above schedule.

MASTER WEIGHT TABLES FOR ROUNDS AND SQUARES – continued

Weight Per Ft. - in Lbs.			Weight Per Ft. - in Lbs.		
Size	Sq. Cor. Squares	Rounds	Size	Sq. Cor. Squares	Rounds
10"	340.0	267.0	11-3/4"	469.4	368.7
10-1/16"	344.3	270.4	11-13/16"	474.4	372.6
10-1/8"	348.5	273.8	11-7/8"	479.5	376.6
10-3/16"	352.9	277.1	11-15/16"	484.5	380.5
10-1/4"	357.2	280.6	12"	489.6	384.5
10-5/16"	361.6	284.0	12-1/16"	494.6	388.5
10-3/8"	366.0	287.4	12-1/8"	499.8	392.5
10-7/16"	370.4	290.9	12-3/16"	505.0	396.6
10-1/2"	374.9	294.4	12-1/4"	510.2	400.7
10-9/16"	379.3	297.9	12-5/16"	515.4	404.8
10-5/8"	383.8	301.5	12-3/8"	520.6	408.9
10-11/16"	388.4	305.0	12-7/16"	525.9	413.0
10-3/4"	392.9	308.6	12-1/2"	531.2	417.2
10-13/16"	397.5	312.2	13"	575	451
10-7/8"	402.1	315.8	13-1/2"	620	487
10-15/16"	406.7	319.5	14"	666	523
11"	411.4	323.1	14-1/2"	715	561
11-1/16"	416.1	326.8	15"	765	601
11-1/8"	420.8	330.5	15-1/2"	817	642
11-3/16"	425.5	334.2	16"	871	684
11-1/4"	430.3	337.9	16-1/2"	926	727
11-5/16"	435.1	341.7	17"	982	772
11-3/8"	439.9	345.5	17-1/2"	1040	818
11-7/16"	448.8	349.3	18"	1102	865
11-1/2"	449.6	353.1	18-1/2"	1164	914
11-9/16"	454.6	357.0	19"	1227	964
11-5/8"	459.5	360.9	19-1/2"	1293	1015
11-11/16"	464.4	364.8	20"	1360	1068

"Round Cornered" squares differ in weight from above schedule.

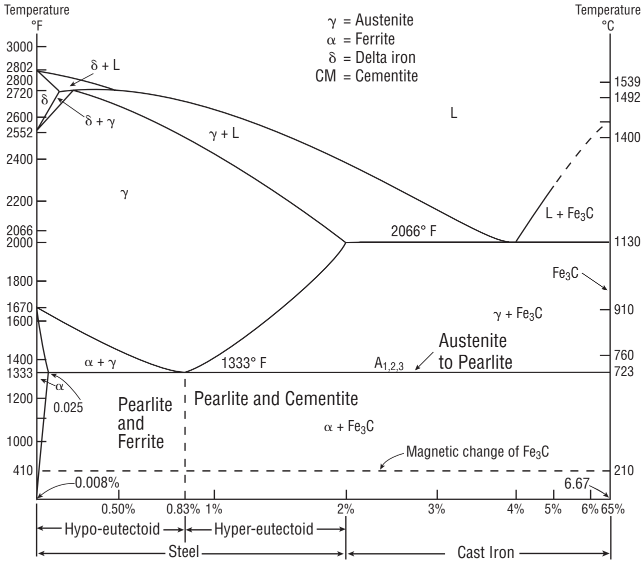
REDUCTION RATIOS FOR ROUND BARS

Product Diameter (inches)	As Cast Size 28" Square	As Cast Size 14" x 11.75"
15.000	4.4	—
14.500	4.7	—
14.000	5.1	—
13.500	5.5	—
13.000	5.9	—
12.500	6.4	—
12.000	6.9	—
11.500	7.5	1.6
11.000	8.2	1.7
10.500	9.1	1.9
10.000	10.0	2.1
9.500	11.1	2.3
9.000	12.3	2.6
8.500	13.8	2.9
8.000	15.6	3.3
7.500	17.7	3.7
7.000	20.4	4.3
6.500	23.6	5.0
6.000	27.7	5.8
5.500	33.0	6.9
5.000	39.9	8.4
4.500	49.3	10.3
4.000	62.4	13.1
3.500	81.5	17.1
3.000	110.9	23.3
2.500	159.7	33.5
2.000	249.6	52.4
1.500	443.7	93.1
1.000	998.2	209.4

REDUCTION RATIOS FOR SQUARE BARS

Product Diameter (inches)	As Cast Size 28" Square	As Cast Size 14" x 11.75"
15.000	3.5	—
14.500	3.7	—
14.000	4.0	—
13.500	4.3	—
13.000	4.6	—
12.500	5.0	—
12.000	5.4	—
11.500	5.9	1.2
11.000	6.5	1.4
10.500	7.1	1.5
10.000	7.8	1.6
9.500	8.7	1.8
9.000	9.7	2.0
8.500	10.9	2.3
8.000	12.3	2.6
7.500	13.9	2.9
7.000	16.0	3.4
6.500	18.6	3.9
6.000	21.8	4.6
5.500	25.9	5.4
5.000	31.4	6.6
4.500	38.7	8.1
4.000	49.0	10.3
3.500	64.0	13.4
3.000	87.1	18.3
2.500	125.4	26.3
2.000	196.0	41.1
1.500	348.4	73.1
1.000	784.0	164.5

IRON CARBON PHASE DIAGRAM



CALCULATIONS FOR $\bar{X}$ AND R CHARTS AND CAPABILITY

CONTROL CHARTS FOR VARIABLES

Calculate the Average ($\bar{X}$) and Range (R) of each subgroup

$$\bar{X} = \frac{X_1 + X_2 + \ldots\ldots X_n}{n}$$

$$R = X_{max} - X_{min}$$

Calculate the Average Range ($\bar{R}$) and the process Average ($\bar{\bar{X}}$)

$$\bar{\bar{X}} = \frac{X_1 + X_2 + \ldots\ldots X_k}{k}$$

$$\bar{R} = \frac{R_1 + R_2 + \ldots\ldots R_k}{k}$$

Calculate the Control Limits

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R} \qquad UCL_R = D_4\bar{R}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R} \qquad LCL_R = D_3\bar{R}$$

PROCESS CAPABILITY

Estimated σ ($\hat{\sigma}$)

$$\hat{\sigma} = \bar{R}/d_2$$

Estimated Process Capability (Cp)

$$Cp = \frac{USL - LSL}{6\hat{\sigma}}$$

Estimated Capability Ratio (Cr)

$$Cr = 1/Cp \times 100\ (\%)$$

Estimated Process Capability (Cpk)

$$C_{PU} = \frac{USL - \bar{\bar{X}}}{3\hat{\sigma}} \qquad C_{PL} = \frac{\bar{\bar{X}} - LSL}{3\hat{\sigma}}$$

$$C_{PK} = \text{Minimum of } C_{PU} \text{ or } C_{PL}$$

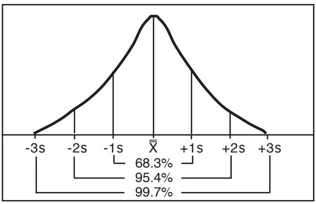
Note: A_2, D_3, D_4, d_2 factors are dependent on subgroup size (n). See factor values table.
Note: Calculations of Process capability (Cp, Cpk, Cr) are only valid for stable processes.

FACTOR VALUES

N =	2	3	4	5	6	12
D_4	3.27	2.57	2.28	2.11	2.00	1.72
D_3	*	*	*	*	*	0.26
A_2	1.86	1.02	0.73	0.58	0.48	0.27
d_2	1.13	1.69	2.06	2.33	2.53	3.26

* No constant for subgroup sizes below 7.

NORMAL DISTRIBUTION



CONTROL CHARTS FOR ATTRIBUTES

The p Chart

$$\bar{p} = \frac{\text{number of rejects in subgroup}}{\text{number inspected in subgroups}}$$

$$UCL_P = \bar{P} + \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$$

$$LCL_P = \bar{P} - \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$$

The u Chart

$$\bar{u} = \frac{\text{total nonconformities}}{\text{total units inspected}}$$

$$UCL_u = \bar{u} + \frac{3\sqrt{\bar{u}}}{\sqrt{n}}$$

$$LCL_u = \bar{u} - \frac{3\sqrt{\bar{u}}}{\sqrt{n}}$$

The np Chart

np = Number of non-conforming units within a sample

$n\bar{p}$ = Average number of nonconforming units per sample

$$UCL_{np} = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})}$$

$$LCL_{np} = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})}$$

The c Chart

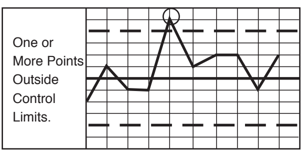
c = The count (number) of nonconformities within a sample

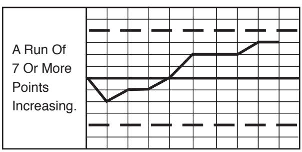
$\bar{c}$ = Average number of non-confomities per sample

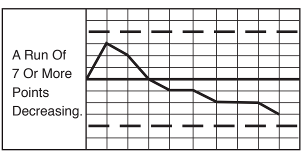
$$UCL_c = c + 3\sqrt{c}$$

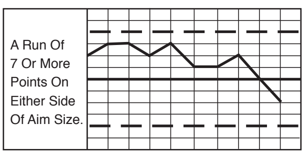
$$LCL_c = c - 3\sqrt{c}$$

IDENTIFICATION OF OUT-OF CONTROL CONDITIONS
(Each point is a subgroup)









HANDY PHYSICAL CONSTANTS

Acceleration of gravity, g	32.17 ft/s^2 = 9.807 m/s^2
Density of water	62.4 lbm/ft^3 = 1 g/cm^3
	1 gal H_2O = 8.345 lbm
Gas Constant, R	1545 ft-lbf/pmole-R = 8.314 J/gmole-K
Gas volume (STP: 68°F, 1 atm)	359 ft^3/pmole = .02241 m^3/gmole
Joule's Constant, J	778 ft-lbf/BTU
Poisson's ratio, μ	.3 (for steel)

STEEL CONSTANTS

Fe-Fe_3C eutectoid composition	0.77 w/o carbon
Fe-Fe_3C eutectoid temperature	1340°F (727°C)
Modulus of Elasticity (steel)	30×10^6 psi
Densities:	
Carbon & Low-Alloy Steels	0.283 lbm/in^3 = 7.84 g/cm^3
304 SS	0.29 lbm/in^3 = 7.88 g/cm^3
Tool Steels	Carbon Steels × 1.000
Moly High Speed	Carbon Steels × 1.035
Multiphase Alloys	Carbon Steels × 1.074
Steel Tensile Strength (psi)	~ 500 × Brinell Number

COMPARISON MATERIALS

Material	Density (g/cm^3)	Modulus of Elasticity (psi)	Poisson's Ratio
Aluminum Alloys	2.6-2.9	10.0×10^6	0.33
Nickel-base Superalloys	8.0-8.9	$28.5 - 31.0 \times 10^6$	0.31
Titanium Alloys	4.4-5.0	$15.0 \times 16.8 \times 10^6$	0.34

SI PREFIXES

giga	G	10^9
mega	M	10^6
kilo	k	10^3
hecto	h	10^2
deka	da	10^1
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

ENGINEERING CONVERSION FACTORS

Explanation of Dimensional Units

All table entries are categorized according to their specific combination of basic dimensions of Length [L], Mass [M] and Time [t]. For example, all units of force have the dimensions $[M][L][t]^{-2}$. The following better illustrates this convention:

$$\text{Force} = [M][L][t]^{-2}$$

$$= (\text{Mass}) \times (\text{Acceleration})$$

$$1\ \text{kgf} = (1\ \text{kg}) \times (9.80665\ \text{m/s}^2)$$

Example Conversion

Meters to Yards

$$(50\ \text{m}) \times (3.28084\ \text{ft/m}) \times (1/3\ \text{yd/ft}) = 54.68066\ \text{yd}$$

Significant Digits

The convention is to retain the number of digits which correctly infers the known accuracy of the numbers involved. Normally, this means using the same number of significant digits as occur in the original number. For the above example, the answer would therefore be rounded to 55 yards.

When the accuracy of the measurement is known, additional digits may become significant. For example, if the measurement of 50 meters is known to be accurate to .01 meters (.0109 yards), then the conversion result may be rounded to 54.68 yards.

CONVERSION FACTORS

EQUATION: A × B = C		
A	**B**	**C**
Area $[L]^2$		
ft^2	0.092903	m^2
in^2	645.16	mm^2
in^2	6.45160	cm^2
Energy, Work or Heat $[M]\ [L]^2\ [t]^{-2}$		
Btu	1.05435	kJ
Btu	0.251996	kcal
Calories (cal)	4.184*	Joules (J)
ft-lbf	1.355818	J
ft-lbf	0.138255	kgf-m
hp-hr	2.6845	MJ
KWH	3.600	MJ
m-kgf	9.80665*	J
N-m	1.	J
Flow Rate $[L]^3\ [t]^{-1}$		
ft^3/min	7.4805	gal/min
ft^3/min	0.471934	l/s
gal/min	0.063090	l/s
Force or Weight $[M]\ [L]\ [t]^{-2}$		
kgf	9.80665*	Newton (N)
lbf	4.44822	N
lbf	0.453592	Kgf
Fracture Toughness		
$ksi\sqrt{in}$	1.098800	$MPa\sqrt{m}$
Heat Content		
Btu/lbm	0.555556	cal/g
Btu/lbm	2.324444	J/g
Btu/ft^3	0.037234	MJ/m^3
Heat Flux		
Btu/hr-ft^2	7.5346 E-5	cal/s-cm^2
Btu/hr-ft^2	3.1525	W/m^2
cal/s-cm^2	4.184*	W/cm^2
Length [L]		
Foot (ft)	0.304800	Meter (m)
Inch (in)	25.4000	Millimeter (mm)
Mile (mi)	1.609344	Kilometer (km)

* Indicates exact conversion(s)

EQUATION: A × B = C		
A	**B**	**C**
Mass Density [M] [L]$^{-3}$		
lbm/in^3	27.68	g/cm^3
lbm/ft^3	16.0184	kg/m^3
Power [M] [L]^2 [t]$^{-3}$		
Btu/hr	0.292875	Watt (W)
ft-lbf/s	1.355818	W
Horsepower (hp)	745.6999	W
Horsepower	550.*	ft-lbf/s
Pressure (fluid) [M] [L]$^{-1}$ [t]$^{-2}$		
Atmosphere (atm)	14.696	lbf/in^2
atm	1.01325 E5*	Pascal (Pa)
lbf/ft^2	47.88026	Pa
lbf/in^2	27.6807	in. H_2O at 39.2°F
Stress [M] [L]$^{-1}$ [t]$^{-2}$		
kgf/cm^2	9.80665 E-2*	MPa
ksi	6.89476	MPa
N/mm^2	1.	MPa
kgf/mm^2	1.42231	ksi
Volume [L]^3 & Capacity		
in^3	16.3871	cm^3
ft^3	0.028317	m^3
ft^3	7.4805	Gallon
ft^3	28.3168	Liter (l)
Gallon	3.785412	Liter
Specific Heat		
Btu/lbm-°F	1.	cal/g-°C
Temperature*		
Fahrenheit	(°F−32)/1.8	Celsius
Fahrenheit	°F+459.67	Rankine
Celsius	°C+273.16	Kelvin
Rankine	R/1.8	Kelvin
Thermal Conductivity		
Btu-ft/hr-ft^2-°F	14.8816	cal-cm/hr-cm^2-°C

* Indicates exact conversion(s)

METRIC-ENGLISH STRESS CONVERSION TABLE

Kg Per Sq Mm to Psi to M Pa

Kg per sq mm	Psi	M Pa	Kg per sq mm	Psi	M Pa	Kg per sq mm	Psi	M Pa	Kg per sq mm	Psi	M Pa
10	14,223	98.1	50	71,117	490.3	90	128,011	882.6	130	184,904	1274.9
11	15,646	107.9	51	72,539	500.1	91	129,433	892.4	131	186,327	1284.7
12	17,068	117.7	52	73,962	510.0	92	130,855	902.2	132	187,749	1294.5
13	18,490	127.5	53	75,384	519.8	93	132,278	912.0	133	189,171	1304.3
14	19,913	137.3	54	76,806	529.6	94	133,700	921.8	134	190,594	1314.1
15	21,335	147.1	55	78,229	539.4	95	135,122	931.6	135	192,016	1323.9
16	22,757	156.9	56	79,651	549.2	96	136,545	941.4	136	193,438	1333.7
17	24,180	166.7	57	81,073	559.0	97	137,967	951.2	137	194,861	1343.5
18	25,602	176.5	58	82,496	568.8	98	139,389	961.0	138	196,283	1353.3
19	27,024	186.3	59	83,918	578.6	99	140,812	970.9	139	197,705	1363.1
20	28,447	196.1	60	85,340	588.4	100	142,234	980.7	140	199,128	1372.9
21	29,869	205.9	61	86,763	598.2	101	143,656	990.5	141	200,550	1382.7
22	31,291	215.7	62	88,185	608.0	102	145,079	1000.3	142	201,972	1392.5
23	32,714	225.6	63	89,607	617.8	103	146,501	1010.1	143	203,395	1402.4
24	34,136	235.4	64	91,030	622.6	104	147,923	1020.0	144	204,817	1412.2
25	35,558	245.2	65	92,452	637.4	105	149,346	1029.7	145	206,239	1422.0
26	36,981	255.0	66	93,874	647.2	106	150,768	1039.5	146	207,662	1431.8
27	38,403	264.8	67	95,297	657.0	107	152,190	1049.3	147	209,084	1441.6
28	39,826	274.6	68	96,719	666.9	108	153,613	1059.1	148	210,506	1451.4
29	41,248	284.4	69	98,141	676.7	109	155,035	1068.9	149	211,929	1461.2
30	42,670	294.2	70	99,564	686.5	110	156,457	1078.7	150	213,351	1471.0
31	44,093	304.0	71	100,986	696.3	111	157,880	1088.5	151	214,773	1480.8
32	45,515	313.8	72	102,408	706.1	112	159,302	1098.3	152	216,196	1490.6
33	46,937	323.6	73	103,831	715.9	113	160,724	1108.2	153	217,618	1500.4
34	48,360	333.4	74	105,253	725.7	114	162,147	1118.0	154	219,040	1510.2
35	49,782	343.2	75	106,675	735.5	115	163,569	1127.8	155	220,463	1520.0
36	51,204	353.0	76	108,098	745.3	116	164,991	1137.6	156	221,885	1529.8
37	52,627	362.8	77	109,520	755.1	117	166,414	1147.4	157	223,307	1539.6
38	54,049	372.7	78	110,943	764.9	118	167,836	1157.2	158	224,730	1549.5
39	55,471	382.5	79	112,365	774.7	119	169,258	1167.0	159	226,152	1559.3
40	56,894	393.3	80	113,787	784.5	120	170,681	1176.8			
41	58,316	402.1	81	115,210	794.3	121	172,103	1186.6			
42	59,738	411.9	82	116,632	804.1	122	173,525	1196.4			
43	61,161	421.7	83	118,054	814.0	123	174,948	1206.2			
44	62,583	431.5	84	119,477	823.8	124	176,370	1216.0			
45	64,005	441.3	85	120,899	833.6	125	177,792	1225.8			
46	65,428	451.1	86	122,321	843.4	126	179,215	1235.6			
47	66,850	460.9	87	123,744	853.2	127	180,637	1245.4			
48	68,272	470.7	88	125,166	863.0	128	182,059	1255.3			
49	69,695	480.5	89	126,588	872.8	129	183,482	1265.1			

WORK-ENERGY CONVERSION TABLE

ft.-lbf		joules	ft.-lbf		joules
0.7376	1	1.356	37.6157	51	69.147
1.4751	2	2.712	38.3532	52	70.503
2.2127	3	4.067	39.0908	53	71.858
2.9502	4	5.423	39.8284	54	73.214
3.6878	5	6.779	40.5659	55	74.570
4.4254	6	8.135	41.3035	56	75.926
5.1629	7	9.491	42.0410	57	77.282
5.9005	8	10.847	42.7786	58	78.637
6.6381	9	12.202	43.5162	59	79.993
7.3756	10	13.558	44.2537	60	81.349
8.1132	11	14.914	44.9913	61	82.705
8.8507	12	16.270	45.7289	62	84.061
9.5883	13	17.626	46.4664	63	85.417
10.3259	14	18.981	47.2040	64	86.772
11.0634	15	20.337	47.9415	65	88.128
11.8010	16	21.693	48.6791	66	89.484
12.5386	17	23.049	49.4167	67	90.840
13.2761	18	24.405	50.1542	68	92.196
14.0137	19	25.761	50.8918	69	93.551
14.7512	20	27.116	51.6294	70	94.907
15.4888	21	28.472	52.3669	71	96.263
16.2264	22	29.828	53.1045	72	97.619
16.9639	23	31.184	53.8420	73	98.975
17.7015	24	32.540	54.5796	74	100.331
18.4391	25	33.895	55.3172	75	101.686
19.1766	26	35.251	56.0547	76	103.042
19.9142	27	36.607	56.7923	77	104.398
20.6517	28	37.963	57.5298	78	105.754
21.3893	29	39.319	58.2674	79	107.110
22.1269	30	40.675	59.0050	80	108.465
22.8644	31	42.030	59.7425	81	109.821
23.6020	32	43.386	60.4801	82	111.177
24.3396	33	44.742	61.2177	83	112.533
25.0771	34	46.098	61.9552	84	113.889
25.8147	35	47.454	62.6928	85	115.245
26.5522	36	48.809	63.4303	86	116.600
27.2898	37	50.165	64.1679	87	117.956
28.0274	38	51.521	64.9055	88	119.312
28.7649	39	52.877	65.6430	89	120.668
29.5025	40	54.233	66.3806	90	122.024
30.2400	41	55.589	67.1182	91	123.379
30.9776	42	56.944	67.8557	92	124.735
31.7152	43	58.300	68.5933	93	126.091
32.4527	44	59.656	69.3308	94	127.447
33.1903	45	61.012	70.0684	95	128.803
33.9279	46	62.368	70.8060	96	130.159
34.6654	47	63.723	71.5435	97	131.514
35.4030	48	65.079	72.2811	98	132.870
36.1405	49	66.435	73.0186	99	134.226
36.8781	50	67.791	73.7562	100	135.582

Examples: 1 ft-lbf = 1.356 joules
1 joule = 0.7376 ft-lbf

TABLES FOR CONVERSION FROM INCHES INTO MILLIMETERS

Inches				Millimeters
		1/64	.015625	.396875
	1/32		.031250	.793750
		3/64	.046875	1.190625
1/16			**.062500**	**1.587500**
		5/64	.078125	1.984375
	3/32		.093750	2.381250
		7/64	.109375	2.778125
1/8			**.125000**	**3.175000**
		9/64	.140625	3.571875
	5/32		.156250	3.968750
		11/64	.171875	4.365625
3/16			**.187500**	**4.762500**
		13/64	.203125	5.159375
	7/32		.218750	5.556250
		15/64	.234375	5.953125
1/4			**.250000**	**6.350000**
		17/64	.265625	6.746875
	9/32		.281250	7.143750
		19/64	.296875	7.540625
5/16			**.312500**	**7.937500**
		21/64	.328125	8.334375
	11/32		.343750	8.731250
		23/64	.359375	9.128125
3/8			**.375000**	**9.525000**
		25/64	.390625	9.921875
	13/32		.406250	10.318750
		27/64	.421875	10.715625
7/16			**.437500**	**11.112500**
		29/64	.453125	11.509375
	15/32		.468750	11.906250
		31/64	.484375	12.303125
1/2			**.500000**	**12.700000**

* On the basis of the conversion factor 1 in. = 25.4 mm.

TABLES FOR CONVERSION – continued

Inches				Millimeters
		33/64	.515625	13.096875
	17/32		.531250	13.493750
		35/64	.546875	13.890625
9/16			**.562500**	**14.287500**
		37/64	.578125	14.684375
	19/32		.593750	15.081250
		39/64	.609375	15.478125
5/8			**.625000**	**15.875000**
		41/64	.640625	16.271875
	21/32		.656250	16.668750
		43/64	.671875	17.065625
11/16			**.687500**	**17.462500**
		45/64	.703125	17.859375
	23/32		.718750	18.256250
		47/64	.734375	18.653125
3/4			**.750000**	**19.050000**
		49/64	.765625	19.446875
	25/32		.781250	19.843750
		51/64	.796875	20.240625
13/16			**.812500**	**20.637500**
		53/64	.828125	21.034375
	27/32		.843750	21.431250
		55/64	.859375	21.828125
7/8			**.875000**	**22.225000**
		57/64	.890625	22.621875
	29/32		.906250	23.018750
		59/64	.921875	23.415625
15/16			**.937500**	**23.812500**
		61/64	.953125	24.209375
	31/32		.968750	24.606250
		63/64	.984375	25.003125
1			**1.000000**	**25.400000**

(All the values in these tables are exact).

TEMPERATURE CONVERSION TABLES

Albert Sauveur type of table. Values revised.

—459.4 to 0			0 to 100						100 to 1000					
C	**F/C**	**F**	**C**	**F/C**	**F**	**C**	**F/C**	**F**	**C**	**F/C**	**F**	**C**	**F/C**	**F**
-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	- .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	.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	227	440	824	454	850	1562
-79	-110	-166	2.2	36	96.8	30.0	86	186.8	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	33.3	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

Look up reading in middle column. If in degress Celsius, read Fahrenheit equivalent in right hand column; if in Fahrenheit degrees, read Celsius equivalent in left hand column.

TEMPERATURE CONVERSION TABLES – continued
Albert Sauveur type of table. Values revised.

1000 to 2000						2000 to 3000					
C	**F/C**	**F**	**C**	**F/C**	**F**	**C**	**F/C**	**F**	**C**	**F/C**	**F**
538	1000	1832	816	1500	2732	1093	2000	3632	1371	2500	4532
543	1010	1850	821	1510	2750	1099	2010	3650	1377	2510	4650
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
610	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	3956	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	3488	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

Look up reading in middle column. If in degress Celsius, read Fahrenheit equivalent in right hand column; if in Fahrenheit degrees, read Celsius equivalent in left hand column.

HARDNESS CONVERSION TABLES BASED ON BRINELL

(APPROXIMATE)

BRINELL HARDNESS		ROCKWELL HARDNESS				Diamond Pyramid Hardness Number (Vickers)	Approx. Tensile Stength 1000 psi
Diameter mm 3000 Kg	Tungsten Carbide 10 mm Ball	A-Scale 60 Kg Brale	B-Scale 100 Kg 1/16" Ball	C-Scale 150 Kg Brale	Superficial 30 N		
....	....	86.5	....	70.0	86.0	1076	....
....	....	86.0	....	69.0	85.0	1004	....
....	....	85.6	....	68.0	84.4	940	....
....	....	85.0	....	67.0	83.6	900	....
....	757	84.4	....	65.9	82.7	860	....
2.25	745	84.1	....	65.3	82.2	840	....
....	722	83.4	....	64.0	81.1	800	....
....	710	83.0	....	63.3	80.4	780	....
2.35	682	82.2	....	61.7	79.0	737	....
2.40	653	81.2	....	60.0	77.5	697	....
2.45	627	80.5	....	58.7	76.3	667	323
2.50	601	79.8	....	57.3	75.1	640	309
2.55	578	79.1	....	56.0	73.9	615	297
2.60	555	78.4	....	54.7	72.7	591	285
2.65	534	77.8	....	53.5	71.6	569	274
2.70	514	76.9	....	52.1	70.3	547	263
2.75	495	76.3	....	51.0	69.4	528	253
2.80	477	75.6	....	49.6	68.2	508	243
2.85	461	74.9	....	48.5	67.2	491	235
2.90	444	74.2	....	47.1	65.8	472	225
2.95	429	73.4	....	45.7	64.6	455	217
3.00	415	72.8	....	44.5	63.5	440	210
3.05	401	72.0	....	43.1	62.3	425	202
3.10	388	71.4	....	41.8	61.1	410	195
3.15	375	70.6	....	40.4	59.9	396	188
3.20	363	70.0	....	39.1	58.7	383	182
3.25	352	69.3	(110.0)	37.9	57.6	372	176
3.30	341	68.7	(109.0)	36.6	56.4	360	170
3.35	331	68.1	(108.5)	35.5	55.4	350	166
3.40	321	67.5	(108.0)	34.3	54.3	339	160
3.45	311	66.9	(107.5)	33.1	53.3	328	155
3.50	302	66.3	(107.0)	32.1	52.2	319	150
3.55	293	65.7	(106.0)	30.9	51.2	309	145
3.60	285	65.3	(105.5)	29.9	50.3	301	141
3.65	277	64.6	(104.5)	28.8	49.3	292	137

HARDNESS CONVERSION TABLES – continued

BRINELL HARDNESS		ROCKWELL HARDNESS				Diamond Pyramid Hardness Number (Vickers)	Approx. Tensile Stength 1000 psi
Diameter mm 3000 Kg	Tungsten Carbide 10 mm Ball	A-Scale 60 Kg Brale	B-Scale 100 Kg 1/16" Ball	C-Scale 150 Kg Brale	Superficial 30 N		
3.70	269	64.1	(104.0)	27.6	48.3	284	133
3.75	262	63.6	(103.0)	26.6	47.3	276	129
3.80	255	63.0	(102.0)	25.4	46.2	269	126
3.85	248	62.5	(101.0)	24.2	45.1	261	122
3.90	241	61.8	100.0	22.8	43.9	253	118
3.95	235	61.4	99.0	21.7	42.9	247	115
4.00	229	60.8	98.2	20.5	41.9	241	111
4.05	223	59.7	97.3	(18.8)	....	234	....
4.10	217	59.2	96.4	(17.5)	....	228	105
4.15	212	58.5	95.5	(16.0)	....	222	102
4.20	207	57.8	94.6	(15.2)	....	218	100
4.25	201	57.4	93.8	(13.8)	....	212	98
4.30	197	56.9	92.8	(12.7)	....	207	95
4.35	192	56.5	91.9	(11.5)	....	202	93
4.40	187	55.9	90.7	(10.0)	....	196	90
4.45	183	55.5	90.0	(9.0)	....	192	89
4.50	179	55.0	89.0	(8.0)	....	188	87
4.55	174	53.9	87.8	(6.4)	....	182	85
4.60	170	53.4	86.8	(5.4)	....	178	83
4.65	167	53.0	86.0	(4.4)	....	175	81
4.70	163	52.5	85.0	(3.3)	....	171	79
4.80	156	51.0	82.9	(.9)	....	163	76
4.90	149	49.9	80.8	....	....	156	73
5.00	143	48.9	78.7	....	....	150	71
5.10	137	47.4	76.4	....	....	143	67
5.20	131	46.0	74.0	....	....	137	65
5.30	126	45.0	72.0	....	....	132	63
5.40	121	43.9	69.8	....	....	127	60
5.50	116	42.8	67.6	....	....	122	58
5.60	111	41.9	65.7	....	....	117	56

Values in ( ) are beyond normal range and are given for information only.

The Brinell values in this table are based on the use of a 10mm tungsten carbide ball; at hardness levels of 429 Brinell and below, the values obtained with the tungsten carbide ball, the Hultgren ball, and the standard ball are the same.

The Hardness Conversion Tables are based on SAE J417 and ASTM E140.

USEFUL EQUATIONS FOR HARDENABLE ALLOY STEELS

Ae_1 (°F) ~ 1333 − 25 × Mn + 40 × Si + 42 × Cr − 26 × Ni .... (1)

Ae_3 (°F) ~ 1570 − 323 × C − 25 × Mn + 80 × Si − 3 × Cr − 32 × Ni.. (2)

Ac_1 (°C) ~ 723 − 10.7 × Mn + 29.1 × Si + 16.9 × Cr − 16.9 × Ni + 290 × As + 6.38 × W .... (3)

Ac_3 (°C) ~ 910 − 203 × $\sqrt{C}$ + 44.7 × Si − 15.2 × Ni + 31.5 × Mo + 104 × V + 13.1 × W .... (4)

Ms (°F) ~ 930 − 600 × C − 60 × Mn − 20 × Si − 50 × Cr − 30 × Ni − 20 × Mo − 20 × W............ (5)

M_{10} (°F) ~ Ms − 18 .... (6)

M_{50} (°F) ~ Ms − 85 .... (7)

M_{90} (°F) ~ Ms − 185 .... (8)

Mf (°F) ~ Ms − 387............ (9)

Bs (°F) ~ 1526 − 486 × C − 162 × Mn − 126 × Cr − 67 × Ni − 149 × Mo .... (10)

B_{50} (°F) ~ Bs − 108 .... (11)

Bf (°F) ~ Bs − 216 .... (12)

Carburized Case Depth (in.) ~ .025$\sqrt{t}$, for 1700°F .... (13)

Carburized Case Depth (in.) ~ .021$\sqrt{t}$, for 1650°F .... (14)

Carburized Case Depth (in.) ~ .018$\sqrt{t}$, for 1600°F .... (15)

(t = time in hours)

Note: Each equation above is subject to the chemistry limitations under which it was developed.

1 & 2: R. A. Grange, Metal Progress, 79, April 1961, p 73.
3 & 4: K. W. Andrews, JISI, 203, 1965, p 721.
5: E. S. Rowland and S. R. Lyle, Trans. ASM, 37, 1946, p 27.
6-12: W. Steven and A. G. Haynes, JISI, 183, 1956, p 349.
13-15: F. E. Harris, Metal Progress, 44, August 1943, p 265.

GLOSSARY OF METALLURGICAL TERMS

Alloying Elements

ALUMINUM - Al

is used to deoxidize steel and control grain size. Grain size control is effected by forming a fine dispersion with nitrogen and oxygen which restricts austenite grain growth. Aluminum is also an extremely effective nitride former in nitriding steels.

BORON - B

is usually added between .0005-.003% to significantly increase the hardenability, especially for low carbon alloys. It does not affect the strength of ferrite, therefore not sacrificing ductility, formability or machinability in the annealed state.

CALCIUM - Ca

is used in certain steels to control the shape, size and distribution of oxide and/or sulfide inclusions. Benefits may include improved ductility, impact strength and machinability.

CARBON - C

is the most important alloying element which is essential for the formation of cementite, pearlite, spheriodite, bainite, and iron-carbon martensite. Compared to steels with similar microstructures, strength, hardness, hardenability, and ductile-to-brittle transition temperature are increased with increasing carbon content up to approximately .60%. Toughness and ductility of pearlitic steels are decreased with increasing carbon content.

CHROMIUM - Cr

is used in low alloy steels to increase 1) resistance to corrosion and oxidation, 2) high temperature strength, 3) hardenability, and 4) abrasion resistance in high carbon alloys. Straight chromium steels are susceptible to temper embrittlement and can be brittle.

COPPER - Cu

is detrimental to hot workability and subsequent surface quality. It is used in certain steels to improve resistance to atmospheric corrosion.

LEAD - Pb

improves machinability. It does not dissolve in steel but stays as globules. Environmental concerns are resulting in a decreased usage of lead in the steel industry.

MANGANESE - Mn

is important because it deoxidizes the melt and facilitates hot working of the steel by reducing the susceptibility to hot shortness. It combines with sulfur to form MnS stringers which increases machinability. Manganese contributes to the effectiveness of normalizing for strengthening, to the formation of fine pearlite, and lowers the Ms temperature, therefore increasing the probability of retained austenite.

MOLYBDENUM - Mo
increases hardenability of steels and helps maintain a specified hardenability. It increases high temperature tensile and creep strengths. Molybdenum hardened steels require higher tempering temperatures for softening purposes.

NICKEL - Ni
is used in low alloy steels to reduce the sensitivity of the steel to variations in heat treatment and distortion and cracking on quenching. It also improves low temperature toughness and hardenability.

NIOBIUM - Nb (Columbium - Cb)
lowers transition temperature and raises the strength of low carbon steel. Niobium increases strength at elevated temperatures, results in finer grain size and forms stable carbides, lowering the hardenability of the steel.

NITROGEN - N
increases the strength, hardness and machinability of steel, but it decreases the ductility and toughness. In aluminum killed steels, nitrogen combines with the aluminum to provide grain size control, thereby improving both toughness and strength. Nitrogen can reduce the effect of boron on the hardenability of steels.

PHOSPHORUS - P
is generally restricted to below 0.04 weight percent to minimize its detrimental effect on ductility and toughness. Certain steels may contain higher levels to enhance machinability, strength and/or atmospheric corrosion resistance.

SILICON - Si
is one of the principal deoxidizers with the amount used dependent on the deoxidization practice. It slightly increases the strength of ferrite without a serious loss of ductility. In larger quantities, it aids the resistance to scaling up to 500°F in air and decreases magnetic hysteresis loss.

SULFUR - S
is detrimental to transverse strength and impact resistance. It affects longitudinal properties to a lesser degree. Existing primarily in the form of manganese sulfide stringers, sulfur is typically added to improve machinability.

TITANIUM - Ti
is added to boron steels because it combines with oxygen and nitrogen, thus increasing the effectiveness of boron. Titanium, as titanium nitride, also provides grain size control at elevated temperatures in microalloy steels. In excess, titanium is detrimental to machinability and internal cleanness.

TELLURIUM - Te
is added to steel to modify sulfide type inclusion size, morphology and distribution. The resulting sulfide type inclusions are finer and remain ellipsoidal in shape following hot working, thereby improving transverse properties.

VANADIUM - V
inhibits grain growth during heat treating while improving strength and toughness of hardened and tempered steels. Additions up to .05% increase hardenability whereas larger amounts tend to reduce hardenability because of carbide formation. Vanadium is also utilized in ferrite/pearlite microalloy steels to increase hardness through carbonitride precipitation strengthening of the matrix.

Standard Mill Terminology

ANNEALING
A treatment consisting of heating uniformly to a temperature, within or above the critical range, and cooling at a controlled rate to a temperature under the critical range. This treatment is used to produce a definite microstructure, usually one designed for best machinability, and/or to remove stresses, induce softness, and alter ductility, toughness or other mechanical properties.

BILLET
A solid semifinished round or square that has been hot worked usually smaller than a bloom. Also a general term for wrought starting stock for forgings or extrusions.

BLOOM
A semifinished hot rolled rectangular product. The width of the bloom is no more than twice the thickness and the cross-sectional area is usually not less that 36 square inches.

CAPPED STEEL
A type of steel similar to rimmed steel, usually cast in a bottle top ingot, in which the application of a mechanical or chemical cap renders the rimming action incomplete by causing the top metal to solidify.

DI (Ideal Diameter)
The diameter of a round steel bar that will harden at the center to a given percent of martensite when subjected to an ideal quench (i.e., Grossman quench severity H=infinity)

ELONGATION
In tensile testing, the increase in gage length, measured after the fracture of a specimen within the gage length, usually expressed as a percentage of the original gage length.

END-QUENCH HARDENABILITY TEST (Jominy Test)
A laboratory procedure for determining the hardenability of a steel or other ferrous alloy. Hardenability is determined by heating a standard specimen above the upper critical temperature, placing the hot specimen in a fixture so that a stream of cold water impinges on one end, and, after cooling to room temperature is completed, measuring the hardness near the surface of the specimen at regularly spaced intervals along its length. The data are normally plotted as hardness versus distance from the quenched end.

HARDNESS
Resistance of a metal to plastic deformation, usually by indentation. However, this may also refer to stiffness or temper, or to resistance to scratching, abrasion, or cutting.

IMPACT TEST
A test to determine the behavior of materials when subjected to high rates of loading, usually in bending, tension or torsion. The quantity measured is the energy absorbed in breaking the specimen by a single blow, as in the Charpy or Izod tests.

INGOT
A casting of a simple shape which can be used for hot working or remelting.

KILLED STEEL
Steel treated with a strong deoxidizer to reduce oxygen to a level where no reaction occurs between carbon and oxygen during solidification.

LAP
A surface imperfection which appears as a seam. It is caused by the folding over of hot metal, fins, or sharp corners and then rolling or forging them into the surface but not welding them. Laps on tubes can form from seams on piercing mill billets.

MACHINABILITY
This is a generic term for describing the ability of a material to be machined. To be meaningful, machinability must be qualified in terms of tool wear, tool life, chip control, and/or surface finish and integrity. Overall machining performance is affected by a myriad of variables relating to the machining operation and the workpiece. An overall review is provided in the ASM Metals Handbook: Machinability, Ninth Edition, Volume 16, 1989.

NORMALIZING
A treatment consisting of heating uniformly to temperature at least 100°F above the critical range and cooling in still air at room temperature. The treatment produces a recrystallization and refinement of the grain structure and gives uniformity in hardness and structure to the product.

PICKLING
An operation by which surface oxide (scale) is removed by chemical action. Sulfuric acid is typically used for carbon and low-alloy steels. After the acid bath, the steel is rinsed in water.

QUENCHING
A treatment consisting of heating uniformly to a predetermined temperature and cooling rapidly in air or liquid medium to produce a desired crystalline structure.

REDUCTION OF AREA
The difference, expressed as a percentage of original area, between the original cross-sectional area of a tensile test specimen and the minimum cross-sectional area measured after complete separation.

RIMMED STEEL
A low carbon steel having enough iron oxide to give a continuous evolution of carbon monoxide during solidification giving a rim of material virtually free of voids.

SCAB
An imperfection which is a flat piece of metal rolled into the steel surface.

SEAM
A defect on the surface of a metal which appears as a crack. Experience indicates that most seams are created during the cooling or reheating of cast structures.

SEMI-KILLED STEEL
Incompletely deoxidized steel which contains enough dissolved oxygen to react with the carbon to form carbon monoxide to offset solidification shrinkage.

SPHEROIDIZE ANNEAL
A special type of annealing that requires an extremely long cycle. This treatment is used to produce globular carbides and maximum softness for best machinability in some analyses, or to improve cold formability.

STRAND CASTING (Continuous Casting)
Operation in which a cast shape is continuously drawn through the bottom of the mold as it solidifies. The length is not determined by mold dimensions.

STRESS RELIEVE TEMPER
A thermal treatment to restore elastic properties and to minimize distortion on subsequent machining or hardening operations. This treatment is usually applied to material that has been heat treated (quenched and tempered). Normal practice would be to heat to a temperature 100°F lower than the tempering temperatures used to establish mechanical properties and hardness. Ordinarily, no straightening is performed after the stress relieve temper.

TEMPERING
A treatment consisting of heating uniformly to some predetermined temperature under the critical range, holding at that temperature a designated period of time and cooling in air or liquid. This treatment is used to produce one or more of the following end results: A) to soften material for subsequent machining or cold working, B) to improve ductility and relieve stresses resulting from prior treatment or cold working, and C) to produce the desired mechanical properties or structure in the second step of a double treatment.

TENSILE STRENGTH
In tensile testing, the ratio of maximum load to original cross-sectional area.

YIELD POINT
The first stress in a material, usually less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. If there is a decrease in stress after yielding, a distinction may be made between upper and lower yield points.

YIELD STRENGTH
The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of .2% is commonly used.

Information adapted from ASM and/or SAE publications.