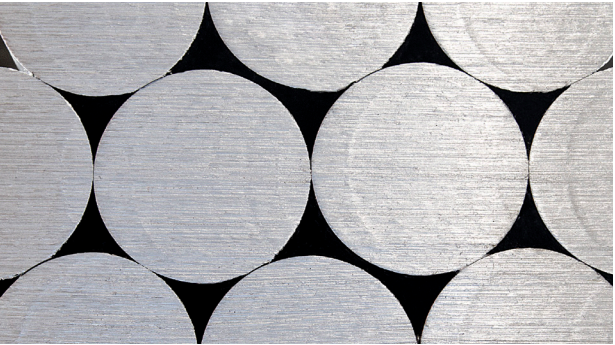
Steel Dynamics, Inc.®
Long Products Group
Engineered Bar Division



BAR DATA HANDBOOK AISI/SAE

Chemical Compositions
and Metallurgical Data

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SECOND EDITION

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STEEL DYNAMICS ENGINEERED BAR PRODUCTS
COMPANY OVERVIEW

Steel Dynamics Incorporated (SDI) Engineered Bar Products Division is a world class supplier of Special Bar Quality steel. The Engineered Bar Products Division is located in Pittsboro, Indiana, which is just west of Indianapolis. The Engineered Bar Products facility offers a wide range of carbon, alloy, and custom designed steel grades to meet exacting customer demands.

The major markets that are served by the Engineered Bar Products Division include off highway construction equipment, agricultural applications, heavy truck, automotive, forging operations, and the gas and oil well industry.

The Engineered Bar Products Division employs approximately 390 employees and has an annual capacity of 625,000 tons.

MISSION STATEMENT

Steel Dynamics is committed to product and process improvement. Our mission statement is:

- To meet or exceed customer expectations with regard to quality, service, and price
- To be a world-class supplier by continually improving our processes, equipment, and systems
- To be a safe working environment for all employees
- To continue to enhance the skills of our employees through ongoing training and education

ISO 9001 CERTIFICATION

Steel Dynamics Engineered Bar Products Division attained ISO 9001:2000 certification in September 2004.

In January 2010, Steel Dynamics achieved ISO 9001:2008 certification.

COMPANY HISTORY

SDI purchased the mill in Pittsboro, Indiana, out of bankruptcy from Qualitech LLC in February 2003. Qualitech declared bankruptcy in 1999 and ceased operations in 2001.

A significant capital investment was undertaken to bring the existing facility up to SDI standards, which included the following:

- Completely rebuilding the ladle metallurgy facility and the addition of new ladle cars
- New carbon and lime system and baghouse upgrades at the Electric Arc Furnace
- The continuous caster was modified to allow for the capacity to cast 7”x7” billets
- An 8 stand Morgardshammar finishing mill was added to the existing Pomini mill
- Upgrades were made to the shipping department, which handles incoming scrap, as well as finished inventory and outgoing products
- An additional 40 acres was purchased for rail infrastructure and scrap storage

The Engineered Bar Products Division made its first shipments of SBQ products in December 2003, and the facility became profitable in April 2004.

An additional upgrade was made in mid 2006 to add a 150,000 square foot bar finishing facility with the capability to offer value added services such as heat treatment, straightening, turning and polishing, bar inspection, and precision cutting. The free-standing facility has the capacity to finish 160,000 tons of bars annually.

PRODUCTS AND SERVICES

SDI produces special bar quality (SBQ) and merchant bar quality (MBQ) steel in rounds ranging in diameter from 1 to 9 inches and round cornered squares (RCS) ranging in diameter from 2-1/2 to 8 inches. The facility also has the ability to produce rebar in sizes 5 through 11. The production and availability of rebar is based on market conditions.

SDI produces a wide range of carbon and low alloy steels, such as:

- Plain carbon steels (AISI series 10xx)
- Resulfurized carbon steels (AISI series 11xx)
- Rephosphorized and Resulfurized carbon steels (AISI series 12xx)
- High Manganese carbon steels (AISI series 13xx and 15xx)
- Cr Alloy Steels (AISI series 51xx and 52xx)
- Cr-Mo Alloy Steels (AISI series 41xx)
- Ni-Cr-Mo Alloy Steels (AISI Series 43xx, 47xx, 86xx, and 88xx)
- Vanadium micro-alloy steels (10V45, 11V41)
- Boron Treated Steels
- Structural Grades ASTM A36 and A572 Grade 50
- Low Alloy Tube and Flange Grades (T2/F2, T11/F11, T22/F22)

The grades listed above are a summary of those produced at the Engineered Bar Products facility. Please inquire for grades not listed above or for custom designed grades.

Hot-Rolled cut lengths are available between 16 and 40 feet. Steel Dynamics can maintain all ASTM tolerances for diameter, length, and straightness on all hot rolled products.

The Engineered Bar Products Rolling Mill metallurgical lab has the capability to provide the full spectrum of metallurgical testing including tensile, hardness, charpy impact, grain size, jominy, microcleanliness, macrocleanliness, and aircraft quality testing.

The Engineered Bar Products Bar Finishing facility is equipped to perform heat treating operations such as Quench and Temper, Normalizing, and Annealing (LP, Spheroidize, Cold Shear, Stress Relieve). In addition to heat treating, the Bar Finishing facility can provide additional services such as:

- Straightening
- Turning and Polishing
- Cutting to Length
- Shot Blasting
- Non Destructive Testing

The Bar Finishing Metallurgical Lab at Steel Dynamics has the capability to provide metallurgical testing such as tensile, hardness, and charpy impact following heat treatment. The lab is also equipped with a scanning electron microscope that is used for research and product evaluation purposes.

PROCESS DESCRIPTION AND CAPABILITIES

MELTING AND CASTING

SDI is equipped with one Electric Arc Furnace (EAF). The EAF is charged with approximately 115 tons of primarily scrap metal in order to yield an aim tapped heat size of 100 tons. Heats are killed following tap with a Silicon-Manganese addition.

Following tap, heats are treated at a Ladle Metallurgy Facility (LMF). At the LMF, slag additions and modifiers are used to work the slag and trap inclusions. Alloy additions are made at the LMF, as well as re-heating the steel for further processing or shipment to the caster.

Heats that require degas treatment have the slag layer removed by means of a mechanical rake. These heats are then treated at the Vacuum Tank Degasser (VTD). Typical gas levels following VTD treatment are 2 ppm H_2, 80 ppm N_2, and 20 ppm O_2.

The continuous caster is a three strand, vertical curved radius machine. Each strand is equipped with automatic mould level control and electromagnetic stirring. Five withdrawal straightener units are used to straighten the strands and also apply soft reduction. The dimensions of the semi-finished bloom are 10.3 x 14.1 inches.

ROLLING

The rolling mill is equipped with a walking beam furnace with a capacity of 125 tons per hour. Blooms are de-scaled after exiting the furnace, and then proceed through a five stand roughing mill, a six stand intermediate mill, and an eight stand finishing mill. Dimensional control is maintained by optical laser gauges and manual micrometer checks. Bars are sheared after reaching their final dimension onto a 125 feet long walking beam cooling bed. Bars are then trimmed to the specified cut length and bundled together for shipment.

HEAT TREATING

The Bar Finishing facility is equipped with five Sauder Energy Car Bottom furnaces. There is one high temperature furnace capable of reaching 2100°F, while the others are capable of reaching 1800°F. The furnaces are limited to a maximum bar length of 33 feet. The quench tank has a 30,000 gallon capacity and is capable of providing agitation and temperature control. Water is the only quench media used at the Bar Finishing facility. The minimum bar diameter that can be quenched is 2.5 inches.

BAR INSPECTION

There are two inspection lines at the Bar Finishing facility, a small bar inspection line (SBIL) and a large bar inspection line (LBIL). The SBIL can accommodate round bars ranging in diameter from one to five inches while the LBIL can accommodate round bars from 2.5 to 9 inches and round cornered squares from 2.5 to 8 inches. Both lines can accommodate bar lengths of 15 to 45 feet.

At the SBIL, bars are rotary straightened and chamfered prior to inspection. Surface inspection is performed via a Forester Magnetic Flux Leakage unit, capable of 100% surface coverage with seam detection of 0.3 mm for smaller bars and 0.5 mm for larger bars. Ultrasonic inspection is performed via a rotary immersion UT inspection unit, capable of 100% volumetric coverage using normal incidence and shear waves. Ultrasonic inspection is capable of detecting 1mm wide defects. The SBIL is also equipped with a 100% Eddy Current grade verification coil.

On the LBIL, bars are shot blasted and pass through an Eddy Current grade verification coil. Surface inspection is performed via an Eddy Current surface inspection unit, capable of 100% surface coverage with seam detection of 0.5mm. Ultrasonic inspection is performed via a Magnetic Analysis Corp 48 channel transducer with four fixed heads, capable of 100% volumetric coverage. Ultrasonic inspection is capable of detecting 1mm wide defects.

TURNING AND POLISHING

The turning line has a capacity of 1.031 inch to 4.25 inch incoming diameter, and is capable of meeting ASTM A108 tolerances. The line can accommodate bar lengths ranging from 14 to 25 feet. The line is equipped with bar chamfering, facing, and etching capabilities. The straightener/polisher is capable of attaining greater than 25Ra surface finish. The turning line is equipped with an Eddy Current tester for surface inspection.

STRAIGHTENING

The bar finishing facility has a Bronx Nine Roll straightener and a #5 Medart Two Roll straightener. The units are capable of meeting both standard and special straightness tolerances as listed in ASTM A29.

MULT CUT-TO-LENGTH SAWING

Cut-to-length sawing is accomplished with two Nishijimax Precision Carbide Rotary Saws, with a capacity of 1.00 to 5.9 inch rounds. The saws can produce cut lengths from 0.5 to 118 inches, with a standard length tolerance of +/- 0.010" or 0.25 mm.

A Hem High Speed Double Column band saw line is also available. It has a capacity of 4 to 25 inch rounds as well as being able to cut bundles. Cut lengths are available from 5 to 24 feet, with a tolerance of -0/+0.25 inches.

NOTES

MAJOR STEEL GROUPS

Carbon Steel
Carbon steel usually contains up to 1.65% manganese, and contains no other added elements to provide any specific alloying effects, except for deoxidation or grain size control. Carbon steels are often classified according to carbon concentration, i.e. low, medium, and high carbon steels. The term 'plain carbon steel' is often used to describe steels which only contain residual concentrations of impurities other than carbon and manganese.

The greatest quantity of steel produced falls into the low-carbon classification, and is typically less than 0.25% carbon. Low-carbon steels are typically unresponsive to heat treatments intended to form martensite and strengthening is usually accomplished through cold working. Low-carbon steels are relatively soft and weak but have excellent ductility and toughness.

Medium-carbon steels have carbon concentrations typically between 0.25% and 0.60%, and may be heat treated by austenitizing, quenching, and tempering to improve their mechanical properties. Medium-carbon steels are stronger than low-carbon steels, but with a reduction in ductility and toughness. High-carbon steels have carbon concentrations typically between 0.60% and 1.4%, and are the hardest and strongest of the carbon steels, but with the least amount of ductility.

Microalloy Steel
Microalloy steels, or High Strength Low Alloy (HSLA) steels, are a group of low-carbon steels which contain a small but deliberate addition of one or more alloying elements such as: vanadium, columbium, and titanium. These steels have increased strength, combined with good ductility in the hot rolled condition. These properties are achieved by a combination of fine grain size and precipitation of finely dispersed particles throughout the steel's microstructure. Some HSLA steels have improved atmospheric corrosion.

Alloy Steel
Steel containing significant quantities of one or more alloying elements (other than carbon and the commonly accepted amounts of manganese, and silicon) added to make changes in mechanical or physical properties. Common alloying elements include nickel, chromium, and molybdenum, among others.

AISI-SAE GRADE DESIGNATIONS

The most widely used system for designating carbon and alloy steels was developed by the American Iron and Steel Institute (AISI) and the Society of Automotive Engineers (SAE). In this system, a particular designation implies the same limits and ranges of chemical composition for both an AISI steel and the corresponding SAE steel. Any differences between AISI and SAE grade designations or limits of chemical composition are unintentional. The fact that a particular steel grade is listed by AISI or SAE implies only that it has been produced in appreciable quantity. It does not imply that other grades are unavailable, nor does it imply that any particular steel producer makes all of the listed grades. All compositions are expressed as weight percents. The SAE designations are published in the annual SAE handbook under various SAE standards. These standards are comprised entirely of listings of SAE designations and the limits and ranges of chemical composition defined by these designations.

UNS DESIGNATIONS

The Unified Numbering System (UNS) has been developed by the AISI, SAE, and several other technical societies, trade associations, and United States government agencies. A UNS number, which is a designation of a chemical composition and *not a specification,* is assigned to each chemical composition of a metallic alloy. Existing systems of designations, including the AISI-SAE system for steels, have been incorporated into the UNS designations.

The UNS designation of a metallic alloy consists of a letter and five numerals. The letters indicate the broad class of alloys, and the numerals define specific alloys and modifications within each class. For practical purposes, carbon and alloy steel bars begin with the letters G or H, the latter describing H-band steels. The first four numerals usually describe the AISI-SAE steel grade designation. The last numeral is typically a zero, unless the steel is modified as follows: a 1 in the last digit signifies boron; a 4 in the last digit signifies lead; a 6 in the last digit indicates Electric Furnace practice with reduced levels of phosphorus and sulfur. The Unified Numbering System is described in greater detail in the latest editions of SAE J1086 and ASTM E 527. The grades in this

manual will be described with the standard AISI-SAE designation instead of the UNS designation.

Certain elements are present in small quantities in most steels. They are not intentionally added, but exist in the steel due to the raw materials used during production. These elements are considered residual or incidental as long as they do not exceed specified maximum limits. The common residual elements of concern are Cu, Ni, Cr, and Mo, with common accepted maximum limits of: 0.35% Cu, 0.25% Ni, 0.20% Cr, and 0.06% Mo according to SAE and ASTM standards. All standard grades listed are subject to these residual maximum limits unless otherwise noted. Any differences in the maximum residual limits must be agreed upon by purchaser and supplier.

AISI-SAE GRADE SERIES OVERVIEW FOR CARBON & ALLOY STEELS

Grade Series Designation	Principal Identifying Elements	Nominal Weight Percentage of Indentifying Elements
10xx	Mn	Mn (0.45, 0.65, 0.75, 0.85) – S (0.050 Max)
11xx	Mn-S	Mn (0.85, 1.15, 1.50) – S (Over 0.050)
12xx	Mn-P-S	Mn (0.85, 0.93, 1.00) – P (0.065, 0.095) – S (0.20, 0.29, 0.31)
13xx	Mn	Mn (1.75)
15xx	Mn	Mn (0.90, 1.00, 1.15, 1.25,1.50)
23xx	Ni	Ni (3.50)
25xx	Ni	Ni (5.00)
31xx	Ni-Cr	Ni (1.25) – Cr (0.65, 0.80)
32xx	Ni-Cr	Ni (1.75) – Cr (1.07)
33xx	Ni-Cr	Ni (3.50) – Cr (1.50, 1.57)
34xx	Ni-Cr	Ni (3.00) – Cr (0.77)
40xx	Mo/Mo-S	Mo (0.20,0.25) or Mo (0.25) – S (0.040)
41xx	Cr-Mo	Cr (0.50, 0.80, 0.95) – Mo (0.12, 0.20, 0.30)
43xx	Ni-Cr-Mo	Ni (1.85) – Cr (0.50, 0.80) – Mo (0.25)
44xx	Mo	Mo (0.50)
46xx	Ni-Mo	Ni (0.85, 1.85) – Mo (0.20, 0.25)
47xx	Ni-Cr-Mo	Ni (1.05) – Cr (0.45) – Mo (0.20, 0.35)
48xx	Ni-Mo	Ni (3.50) – Mo (0.25)
50xx(x)	Cr	Cr (0.30, 0.50)
51xx(x)	Cr	Cr (0.80, 0.90, 1.00)
52xx(x)	Cr	Cr (1.45)
61xx	Cr-V	Cr (0.60, 0.95) – V (0.15)
81xx	Ni-Cr-Mo	Ni (0.30) – Cr (0.40) – Mo (0.12)
86xx	Ni-Cr-Mo	Ni (0.55) – Cr (0.50) – Mo (0.20)
87xx	Ni-Cr-Mo	Ni (0.55) – Cr (0.50) – Mo (0.25)
88xx	Ni-Cr-Mo	Ni (0.55) – Cr (0.50) – Mo (0.35)
92xx	Si/Si-Cr	Si (2.00) or Si (1.40) – Cr (0.70) or Si (1.00) – Cr(0.55)
93xx	Ni-Cr-Mo	Ni (3.25) – Cr (1.25) – Mo (0.12)
94xx	Ni-Cr-Mo	Ni (0.45) – Cr (0.40) – Mo (0.12)
97xx	Ni-Cr-Mo	Ni (0.55) – Cr (0.20) – Mo (0.20)
98xx	Ni-Cr-Mo	Ni (1.00) – Cr (0.80) – Mo (0.25)

Note: xx(x) in the last two (or three) digits indicates that the carbon content, in hundredths of a percent, is to be inserted. (Carbon and Alloy Steels, ASM International, 1996, pg 14)

STANDARD CARBON STEELS

ASTM A 576 – 90b (Reapproved 2006)

Steel Grade	Chemical Composition Limits, Percent[A,B,C]			
	C	Mn	P max	S max
1008	0.10 max	0.30/0.50	0.040	0.050
1010	0.08/0.13	0.30/0.60	0.040	0.050
1012	0.10/0.15	0.30/0.60	0.040	0.050
1015	0.13/0.18	0.30/0.60	0.040	0.050
1016	0.13/0.18	0.60/0.90	0.040	0.050
1017	0.15/0.20	0.30/0.60	0.040	0.050
1018	0.15/0.20	0.60/0.90	0.040	0.050
1019	0.15/0.20	0.70/1.00	0.040	0.050
1020	0.18/0.23	0.30/0.60	0.040	0.050
1021	0.18/0.23	0.60/0.90	0.040	0.050
1022	0.18/0.23	0.70/1.00	0.040	0.050
1023	0.20/0.25	0.30/0.60	0.040	0.050
1025	0.22/0.28	0.30/0.60	0.040	0.050
1026	0.22/0.28	0.60/0.90	0.040	0.050
1029	0.25/0.31	0.60/0.90	0.040	0.050
1030	0.28/0.34	0.60/0.90	0.040	0.050
1035	0.32/0.38	0.60/0.90	0.040	0.050
1037	0.32/0.38	0.70/1.00	0.040	0.050
1038	0.35/0.42	0.60/0.90	0.040	0.050
1039	0.37/0.44	0.70/1.00	0.040	0.050
1040	0.37/0.44	0.60/0.90	0.040	0.050
1042	0.40/0.47	0.60/0.90	0.040	0.050
1043	0.40/0.47	0.70/1.00	0.040	0.050
1044	0.43/0.50	0.30/0.60	0.040	0.050
1045	0.43/0.50	0.60/0.90	0.040	0.050
1046	0.43/0.50	0.70/1.00	0.040	0.050
1049	0.46/0.53	0.60/0.90	0.040	0.050
1050	0.48/0.55	0.60/0.90	0.040	0.050
1053	0.48/0.55	0.70/1.00	0.040	0.050
1055	0.50/0.60	0.60/0.90	0.040	0.050
1060	0.55/0.65	0.60/0.90	0.040	0.050
1070	0.65/0.75	0.60/0.90	0.040	0.050
1078	0.72/0.85	0.30/0.60	0.040	0.050
1080	0.75/0.88	0.60/0.90	0.040	0.050
1084	0.80/0.93	0.60/0.90	0.040	0.050
1090	0.85/0.98	0.60/0.90	0.040	0.050
1095	0.90/1.03	0.30/0.50	0.040	0.050

[A] When Si is required, the following ranges are commonly specified: 0.10% max, 0.10/0.20%, 0.15/0.35%, or 0.20/0.40%. The range of 0.15/0.35% is most common.

[B] Copper can be specified when required as 0.20% minimum.

[C] The elements Bi, Ca, Se, or Te may be added as agreed between purchaser and supplier.

RESULFURIZED CARBON STEELS

ASTM A 576 – 90b (Reapproved 2006)

Steel Grade	Chemical Composition Limits, Percent[A,B]			
	C	Mn	P Max	S
1109	0.08/0.13	0.60/0.90	0.040	0.08/0.13
1110	0.08/0.13	0.30/0.60	0.040	0.08/0.13
1116	0.14/0.20	1.10/1.40	0.040	0.16/0.23
1117	0.14/0.20	1.00/1.30	0.040	0.08/0.13
1118	0.14/0.20	1.30/1.60	0.040	0.08/0.13
1119	0.14/0.20	1.00/1.30	0.040	0.24/0.33
1132	0.27/0.34	1.35/1.65	0.040	0.08/0.13
1137	0.32/0.39	1.35/1.65	0.040	0.08/0.13
1139	0.35/0.43	1.35/1.65	0.040	0.13/0.20
1140	0.37/0.44	0.70/1.00	0.040	0.08/0.13
1141	0.37/0.45	1.35/1.65	0.040	0.08/0.13
1144	0.40/0.48	1.35/1.65	0.040	0.24/0.33
1145	0.42/0.49	0.70/1.00	0.04	0.04/0.07
1146	0.42/0.49	0.70/1.00	0.040	0.08/0.13
1151	0.48/0.55	0.70/1.00	0.040	0.08/0.13

[A] When Si is required, the following ranges are commonly specified: 0.10% max, 0.10/0.20%, 0.15/0.35%, or 0.20/0.40%. The range of 0.15/0.35% is most common.

[B] The elements Bi, Ca, Se, or Te may be added as agreed between purchaser and supplier.

REPHOSPHORIZED AND RESULFURIZED CARBON STEELS

ASTM A 576 – 90b (Reapproved 2006)

Steel Grade	Chemical Composition Limits, Percent[A,B,C]				
	C	Mn	P	S	Pb
1211	0.13 max	0.60/0.90	0.07/0.12	0.10/0.15	...
1212	0.13 max	0.70/1.00	0.07/0.12	0.16/0.23	
1213	0.13 max	0.70/1.00	0.07/0.12	0.24/0.33	...
1215	0.09 max	0.75/1.05	0.04/0.09	0.26/0.35	...
12L14	0.15 max	0.85/1.15	0.04/0.09	0.26/0.35	0.15/0.35

[A] When Pb is required as an added element to a standard steel, a range of 0.15/0.35% is specified. Such a steel is identified by inserting the letter "L" between the second and third numerals of the grade designation.

[B] The elements Bi, Calcium, Se, or Te may be added as agreed between purchaser and supplier.

[C] It is not common practice to produce these steels to specified limits for Si because of the adverse effect on machinability.

Note: SDI does not produce leaded steels. 12L14 is provided for information only.

HIGH MANGANESE CARBON STEELS

ASTM A 576 – 90b (Reapproved 2006)

Steel Grade	Chemical Composition Limits, Percent[A,B,C,D]			
	C	Mn	P max	S max
1513	0.10/0.16	1.10/1.40	0.040	0.050
1518	0.15/0.21	1.10/1.40	0.040	0.050
1522	0.18/0.24	1.10/1.40	0.040	0.050
1524	0.19/0.25	1.35/1.65	0.040	0.050
1525	0.23/0.29	0.80/1.10	0.040	0.050
1526	0.22/0.29	1.10/1.40	0.040	0.050
1527	0.22/0.29	1.20/1.50	0.040	0.050
1536	0.30/0.37	1.20/1.50	0.040	0.050
1541	0.36/0.44	1.35/1.65	0.040	0.050
1547	0.43/0.51	1.35/1.65	0.040	0.050
1548	0.44/0.52	1.10/1.40	0.040	0.050
1551	0.45/0.56	0.85/1.15	0.040	0.050
1552	0.47/0.55	1.20/1.50	0.040	0.050
1561	0.55/0.65	0.75/1.05	0.040	0.050
1566	0.60/0.71	0.85/1.15	0.040	0.050
1572	0.65/0.76	1.00/1.30	0.040	0.050

[A] When Si is required, the following ranges are commonly specified: 0.10% max, 0.10/0.20%, 0.15/0.35%, or 0.20/0.40%. The range of 0.15/0.35% is most common.

[B] Copper can be specified when required as 0.20% minimum.

[C] When B is specified, the typical range is 0.0005 to 0.003%.

[D] The elements Bi, Ca, Se, or Te may be added as agreed between purchaser and supplier.

CARBON AND CARBON BORON STEELS SUBJECT TO END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 304 – 05)

Steel Grade	Chemical Composition Limits, Percent				
	C	Mn	P max	S max	Si
1038 H	0.34/0.43	0.50/1.00	0.040	0.050	0.15/0.30
1045 H	0.42/0.51	0.50/1.00	0.040	0.050	0.15/0.30
1522 H	0.17/0.25	1.00/1.50	0.040	0.050	0.15/0.30
1524 H	0.18/0.26	1.25/1.75	0.040	0.050	0.15/0.30
1526 H	0.21/0.30	1.00/1.50	0.040	0.050	0.15/0.30
1541 H	0.35/0.45	1.25/1.75	0.040	0.050	0.15/0.30
15B21 H[A]	0.17/0.24	0.70/1.20	0.040	0.050	0.15/0.30
15B30 H[A]	0.26/0.34	0.70/1.20	0.040	0.050	0.15/0.30
15B35 H[A]	0.31/0.39	0.70/1.20	0.040	0.050	0.15/0.30
15B37 H[A]	0.30/0.39	1.00/1.50	0.040	0.050	0.15/0.30
15B41 H[A]	0.35/0.45	1.25/1.75	0.040	0.050	0.15/0.30
15B48 H[A]	0.43/0.53	1.00/1.50	0.040	0.050	0.15/0.30
15B62 H[A]	0.54/0.67	1.00/1.50	0.040	0.050	0.40/0.60

[A] Boron treated, with typical range 0.0005 to 0.0030%.

CHEMCAL RANGES & LIMITS OF HOT ROLLED CARBON STEELS

ASTM A 576 – 90b (Reapproved 2006)

Element[A]	When Maximum of Specified Element is:	Chemical Range	Conventional Lowest Maximum
Carbon – (When Mn does NOT exceed 1.10%)	...	...	0.06
	Thru 0.12	...	...
	Over 0.12 thru 0.25	0.05	...
	Over 0.25 thru 0.40	0.06	...
	Over 0.40 thru 0.55	0.07	...
	Over 0.55 thru 0.80	0.10	...
	Over 0.80	0.13	...
Carbon – (When Mn DOES exceed 1.10%)	Over 0.12 thru 0.25	0.06	...
	Over 0.25 thru 0.40	0.07	...
	Over 0.40 thru 0.55	0.08	...
	Over 0.55 thru 0.80	0.11	...
	Over 0.80	0.14	...
Manganese	...	...	0.35
	Thru 0.40	0.15	...
	Over 0.40 thru 0.50	0.20	...
	Over 0.50 thru 1.65	0.30	...
Phosphorus	...	...	0.03
	Thru 0.04	...	...
	Over 0.04 thru 0.08	0.03	...
	Over 0.08 thru 0.13	0.05	...
Sulfur	Thru 0.05	...	0.05
	Over 0.05 thru 0.09	0.03	...
	Over 0.09 thru 0.15	0.05	...
	Over 0.15 thru 0.23	0.07	...
	Over 0.23 thru 0.50	0.09	...
Silicon[B]	Thru 0.10	...	0.10
	Over 0.10 thru 0.15	0.08	...
	Over 0.15 thru 0.20	0.10	...
	Over 0.20 thru 0.30	0.15	...
	Over 0.30 thru 0.60	0.20	...
Copper	When Cu is required as an added element, 0.20% minimum is generally specified		
Lead[C]	Lead is reported only as a range of 0.15 to 0.35% since it is usually added to the mould or ladle stream as the steel is poured		
Boron	Boron treated steels are typically produced to a range of 0.0005 to 0.003%		

[A] The specification for the elements Bi, Ca, Se, and Te will be agreed upon between purchaser and supplier.

[B] It is not common practice to produce a Rephosphorized and Resulfurized carbon steel to specified limits for Si because of its adverse effect on machinability.

[C] A heat analysis for Pb is not determinable, since Pb is added to the ladle stream.

PERMISSIBLE VARIATIONS FOR PRODUCT ANALYSIS OF CARBON STEEL

ASTM A 29/A 29M – 05

Element	Limit, or Maximum of Specified Range (%)	Variance Over the Maximum Limit or Under the Minimum Limit (%)
Carbon[A]	Thru 0.25	0.02
	Over 0.25 thru 0.55	0.03
	Over 0.55	0.04
Manganese	Thru 0.90	0.03
	Over 0.90 thru 1.65	0.06
Phosphorus[A,B]	Basic steels	0.008 over
	Acid Bessemer steel	0.01
Sulfur[A,B]		0.008
Silicon	Thru 0.35	0.02
	Over 0.35 thru 0.60	0.05
Copper	Under minimum only for Cu bearing steels	0.02
Lead[C]	0.15 thru 0.35	0.03

[A] Rimmed and capped steels are not subject to rejection on product analysis unless misapplication is clearly indicated.

[B] Resulfurized or Rephosphorized steels are not subject to rejection on product analysis for these elements unless misapplication is clearly indicated.

[C] Product analysis tolerance for lead applies both over and under to a specified range of 0.15/0.35 %.

STANDARD ALLOY STEELS

(ASTM A 322 – 07)

Steel Grade[C]	Chemical Composition Ranges and Limits, Percent[A,B]					
	C	Mn	Ni	Cr	Mo	Other
1330	0.28/0.33	1.60/1.90	--	--	--	
1335	0.33/0.38	1.60/1.90	--	--	--	
1340	0.38/0.43	1.60/1.90	--	--	--	
1345	0.43/0.48	1.60/1.90	--	--	--	
4023	0.20/0.25	0.70/0.90	--	--	0.20/0.30	
4024	0.20/0.25	0.70/0.90	--	--	0.20/0.30	S 0.035/0.050
4027	0.25/0.30	0.70/0.90	--	--	0.20/0.30	
4028	0.25/0.30	0.70/0.90	--	--	0.20/0.30	S 0.035/0.050
4037	0.35/0.40	0.70/0.90	--	--	0.20/0.30	
4047	0.45/0.50	0.70/0.90	--	--	0.20/0.30	
4118	0.18/0.23	0.70/0.90	--	0.40/0.60	0.08/0.15	
4120	0.18/0.23	0.90/1.20	--	0.40/0.60	0.13/0.20	
4121	0.18/0.23	0.75/1.00	--	0.45/0.65	0.20/0.30	
4130	0.28/0.33	0.40/0.60	--	0.80/1.10	0.15/0.25	
4137	0.35/0.40	0.70/0.90	--	0.80/1.10	0.15/0.25	
4140	0.38/0.43	0.75/1.00	--	0.80/1.10	0.15/0.25	
4142	0.40/0.45	0.75/1.00	--	0.80/1.10	0.15/0.25	
4145	0.43/0.48	0.75/1.00	--	0.80/1.10	0.15/0.25	
4147	0.45/0.50	0.75/1.00	--	0.80/1.10	0.15/0.25	

STANDARD ALLOY STEELS

(ASTM A 322 – 07)

Steel Grade[C]	Chemical Composition Ranges and Limits, Percent[A,B]					
	C	Mn	Ni	Cr	Mo	Other
4150	0.48/0.53	0.75/1.00	--	0.80/1.10	0.15/0.25	
4161	0.56/0.64	0.75/1.00	--	0.70/0.90	0.25/0.35	
4320	0.17/0.22	0.45/0.65	1.65/2.00	0.40/0.60	0.20/0.30	
4340	0.38/0.43	0.60/0.80	1.65/2.00	0.70/0.90	0.20/0.30	
E4340[D]	0.38/0.43	0.65/0.85	1.65/2.00	0.70/0.90	0.20/0.30	
4615	0.13/0.18	0.45/0.65	1.65/2.00	--	0.20/0.30	
4620	0.17/0.22	0.45/0.65	1.65/2.00	--	0.20/0.30	
4621	0.18/0.23	0.70/0.90	1.65/2.00	--	0.20/0.30	
4626	0.24/0.29	0.45/0.65	0.70/1.00	--	0.15/0.25	
4715	0.13/0.18	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60	
4720	0.17/0.22	0.50/0.70	0.90/1.20	0.35/0.55	0.15/0.25	
4815	0.13/0.18	0.40/0.60	3.25/3.75	...	0.20/0.30	
4817	0.13/0.20	0.40/0.60	3.25/3.75	...	0.20/0.30	
4820	0.18/0.23	0.50/0.70	3.25/3.75	...	0.20/0.30	
5117	0.15/0.20	0.70/0.90	...	0.70/0.90	...	
5120	0.17/0.22	0.70/0.90	...	0.70/0.90	...	
5130	0.28/0.33	0.70/0.90	...	0.80/1.10	...	
5132	0.30/0.35	0.60/0.80	...	0.75/1.00	...	
5135	0.33/0.38	0.60/0.80	...	0.80/1.05	...	

STANDARD ALLOY STEELS

(ASTM A 322 – 07)

Steel Grade[C]	Chemical Composition Ranges and Limits, Percent[A,B]					
	C	Mn	Ni	Cr	Mo	Other
5140	0.38/0.43	0.70/0.90	...	0.70/0.90	...	
5150	0.48/0.53	0.70/0.90	...	0.70/0.90	...	
5155	0.51/0.59	0.70/0.90		0.70/0.90	...	
5160	0.56/0.64	0.75/1.00	...	0.70/0.90	...	
E51100[D]	0.98/1.10	0.25/0.45	...	0.90/1.15	...	
E52100[D]	0.98/1.10	0.25/0.45	...	1.30/1.60	...	
6118	0.16/0.21	0.50/0.70	...	0.50/0.70	...	V 0.10/0.15
6150	0.48/0.53	0.70/0.90	...	0.80/1.10	...	V 0.15 min
8615	0.13/0.18	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8617	0.15/0.20	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8620	0.18/0.23	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8622	0.20/0.25	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8625	0.23/0.28	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8627	0.25/0.30	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8630	0.28/0.33	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	
8637	0.35/0.40	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	
8640	0.38/0.43	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	
8642	0.40/0.45	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	
8645	0.43/0.48	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	

STANDARD ALLOY STEELS

(ASTM A 322 – 07)

Steel Grade[C]	Chemical Composition Ranges and Limits, Percent[A,B]					
	C	Mn	Ni	Cr	Mo	Other
8655	0.51/0.59	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	
8720	0.18/0.23	0.70/0.90	0.40/0.70	0.40/0.60	0.20/0.30	
8822	0.20/0.25	0.75/1.00	0.40/0.70	0.40/0.60	0.30/0.40	
9259	0.56/0.64	0.75/1.00	...	0.45/0.65	...	Si 0.70/1.10
9260	0.56/0.64	0.75/1.00	...	...	...	Si 1.80/2.20
Standard Boron Steels[E]						
50B44	0.43/0.48	0.75/1.00	...	0.20/0.60	...	
50B46	0.44/0.49	0.75/1.00	...	0.20/0.35	...	
50B50	0.48/0.53	0.75/1.00	...	0.40/0.60	...	
50B60	0.56/0.64	0.75/1.00	...	0.40/0.60	...	
51B60	0.56/0.64	0.75/1.00	...	0.70/0.90	...	
81B45	0.43/0.48	0.75/1.00	0.20/0.40	0.35/0.55	0.08/0.15	
94B17	0.15/0.20	0.75/1.00	0.30/0.60	0.30/0.50	0.08/0.15	
94B30	0.28/0.33	0.75/1.00	0.30/0.60	0.30/0.50	0.08/0.15	

[A] Unless noted, all grades have a Si range of 0.15 to 0.35%. Silicon may be specified to 0.10% maximum, which generally relates to severely cold-formed parts.

[B] The maximum limits for P and S are 0.035% and 0.040% respectively, unless otherwise agreed upon between purchaser and supplier.

[C] Grade designations correspond to the respective AISI and SAE designations. Grade compositions correspond to the respective AISI compositions.

[D] The max S and P for Electric Furnace Quality Steels (grades preceded by an 'E') is 0.025 max.

[E] These steels can be expected to contain 0.0005 to 0.003% B. If the usual Ti additive is not permitted, these steels can be expected to contain up to 0.005% B.

ALLOY STEEL GRADES SUBJECT TO END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 304 – 05)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
1330 H	0.27/0.33	1.45/2.05	0.15/0.35	...	...	...
1335 H	0.32/0.38	1.45/2.05	0.15/0.35	...	...	...
1340 H	0.37/0.44	1.45/2.05	0.15/0.35	...	...	...
1345 H	0.42/0.49	1.45/2.05	0.15/0.35	...	...	...
4027 H	0.24/0.30	0.60/1.00	0.15/0.35	...	...	0.20/0.30
4028 H[B]	0.24/0.30	0.60/1.00	0.15/0.35	...	...	0.20/0.30
4032 H	0.29/0.35	0.60/1.00	0.15/0.35	...	...	0.20/0.30
4037 H	0.34/0.41	0.60/1.00	0.15/0.35	...	...	0.20/0.30
4042 H	0.39/0.46	0.60/1.00	0.15/0.35	...	...	0.20/0.30
4047 H	0.44/0.51	0.60/1.00	0.15/0.35	...	...	0.20/0.30
4118 H	0.17/0.23	0.60/1.00	0.15/0.35	...	0.30/0.70	0.08/0.15
4130 H	0.27/0.33	0.30/0.70	0.15/0.35	...	0.75/1.20	0.15/0.25
4135 H	0.32/0.38	0.60/1.00	0.15/0.35	...	0.75/1.20	0.15/0.25
4137 H	0.34/0.41	0.60/1.00	0.15/0.35	...	0.75/1.20	0.15/0.25
4140 H	0.37/0.44	0.65/1.10	0.15/0.35	...	0.75/1.20	0.15/0.25
4142 H	0.39/0.46	0.65/1.10	0.15/0.35	...	0.75/1.20	0.15/0.25
4145 H	0.42/0.49	0.65/1.10	0.15/0.35	...	0.75/1.20	0.15/0.25

ALLOY STEEL GRADES SUBJECT TO END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 304 – 05)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
4147 H	0.44/0.51	0.65/1.10	0.15/0.35	...	0.75/1.20	0.15/0.25
4150 H	0.47/0.54	0.65/1.10	0.15/0.35	...	0.75/1.20	0.15/0.25
4161 H	0.55/0.65	0.65/1.10	0.15/0.35	...	0.65/0.95	0.25/0.35
4320 H	0.17/0.23	0.40/0.70	0.15/0.35	1.55/2.00	0.35/0.65	0.20/0.30
4340 H	0.37/0.44	0.55/0.90	0.15/0.35	1.55/2.00	0.65/0.95	0.20/0.30
E4340 H	0.37/0.44	0.60/0.95	0.15/0.35	1.55/2.00	0.65/0.95	0.20/0.30
4419 H	0.17/0.23	0.35/0.75	0.15/0.35	...	...	0.45/0.60
4620 H	0.17/0.23	0.35/0.75	0.15/0.35	1.55/2.00	...	0.20/0.30
4621 H	0.17/0.23	0.60/1.00	0.15/0.35	1.55/2.00	...	0.20/0.30
4626 H	0.23/0.29	0.40/0.70	0.15/0.35	0.65/1.05	...	0.15/0.25
4718 H	0.15/0.21	0.60/0.95	0.15/0.35	0.85/1.25	0.30/0.60	0.30/0.40
4720 H	0.17/0.23	0.45/0.75	0.15/0.35	0.85/1.25	0.30/0.60	0.15/0.25
4815 H	0.12/0.18	0.30/0.70	0.15/0.35	3.20/3.80	...	0.20/0.30
4817 H	0.14/0.20	0.30/0.70	0.15/0.35	3.20/3.80	...	0.20/0.30
4820 H	0.17/0.23	0.40/0.80	0.15/0.35	3.20/3.80	...	0.20/0.30
50B40 H[C]	0.37/0.44	0.65/1.10	0.15/0.35	...	0.30/0.70	...
50B44 H[C]	0.42/0.49	0.65/1.10	0.15/0.35	...	0.30/0.70	...

ALLOY STEEL GRADES SUBJECT TO END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 304 – 05)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
5046 H	0.43/0.50	0.65/1.10	0.15/0.35	...	0.13/0.43	...
50B46 H[C]	0.43/0.50	0.65/1.10	0.15/0.35	...	0.13/0.43	...
50B50 H[C]	0.47/0.54	0.65/1.10	0.15/0.35	...	0.30/0.70	...
50B60 H[C]	0.55/0.65	0.65/1.10	0.15/0.35	...	0.30/0.70	...
5120 H	0.17/0.23	0.60/1.00	0.15/0.35	...	0.60/1.00	...
5130 H	0.27/0.33	0.60/1.00	0.15/0.35	...	0.75/1.20	...
5132 H	0.29/0.35	0.50/0.90	0.15/0.35	...	0.65/1.10	...
5135 H	0.32/0.38	0.50/0.90	0.15/0.35	...	0.70/1.15	...
5140 H	0.37/0.44	0.60/1.00	0.15/0.35	...	0.60/1.00	...
5145 H	0.42/0.49	0.60/1.00	0.15/0.35	...	0.60/1.00	...
5147 H	0.45/0.52	0.60/1.05	0.15/0.35	...	0.80/1.25	...
5150 H	0.47/0.54	0.60/1.00	0.15/0.35	...	0.60/1.00	...
5155 H	0.50/0.60	0.60/1.00	0.15/0.35	...	0.60/1.00	...
5160 H	0.55/0.65	0.65/1.10	0.15/0.35	...	0.60/1.00	...
51B60 H[C]	0.55/0.65	0.65/1.10	0.15/0.35	...	0.60/1.00	...
6118 H[D]	0.15/0.21	0.40/0.80	0.15/0.35	...	0.40/0.80	...
6150 H[E]	0.47/0.54	0.60/1.00	0.15/0.35	...	0.75/1.20	...

ALLOY STEEL GRADES SUBJECT TO END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 304 – 05)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
81B45 H[C]	0.42/0.49	0.70/1.05	0.15/0.35	0.15/0.45	0.30/0.60	0.08/0.15
8617 H	0.14/0.20	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8620 H	0.17/0.23	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8622 H	0.19/0.25	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8625 H	0.22/0.28	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8627 H	0.24/0.30	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8630 H	0.27/0.33	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
86B30 H[C]	0.27/0.33	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8637 H	0.34/0.41	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8640 H	0.37/0.44	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8642 H	0.39/0.46	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8645 H	0.42/0.49	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
86B45 H[C]	0.42/0.49	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8650 H	0.47/0.54	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8655 H	0.50/0.60	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8660 H	0.55/0.65	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8720 H	0.17/0.23	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.20/0.30

ALLOY STEEL GRADES SUBJECT TO END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 304 – 05)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
8740 H	0.37/0.44	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8822 H	0.19/0.25	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.30/0.40
9260 H	0.55/0.65	0.65/1.10	1.70/2.20	...	...	...
9310 H	0.07/0.13	0.40/0.70	0.15/0.35	2.95/3.55	1.00/1.45	0.08/0.15
94B15 H[C]	0.12/0.18	0.70/1.05	0.15/0.35	0.25/0.65	0.25/0.55	0.08/0.15
94B17 H[C]	0.14/0.20	0.70/1.05	0.15/0.35	0.25/0.65	0.25/0.55	0.08/0.15
94B30 H[C]	0.27/0.33	0.70/1.05	0.15/0.35	0.25/0.65	0.25/0.55	0.08/0.15

[A] P and S in open-hearth steel is 0.035% and 0.040% respectively, while the P and S in electric furnace steel is 0.025% max (Grade preceded by an 'E').

[B] S range is 0.035 to 0.050%.

[C] These steels can be expected to have a 0.0005% minimum B content.

[D] V range is 0.10 to 0.15%.

[E] Minimum V content is 0.15%.

STEEL GRADES SUBJECT TO RESTRICTED END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 914/A 914M – 92; Reapproved 2005)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
15B21 RH[B]	0.17/0.22	0.80/1.10	0.15/0.35	...	...	...
15B35 RH[B]	0.33/0.38	0.80/1.10	0.15/0.35	...	...	...
3310 RH	0.08/0.13	0.40/0.60	0.15/0.35	3.25/3.75	1.40/1.75	...
4027 RH	0.25/0.30	0.70/0.90	0.15/0.35	...	...	0.20/0.30
4118 RH	0.18/0.23	0.70/0.90	0.15/0.35	...	0.40/0.60	0.08/0.15
4120 RH	0.18/0.23	0.90/1.20	0.15/0.35	...	0.40/0.60	0.13/0.20
4130 RH	0.28/0.33	0.40/0.60	0.15/0.35	...	0.80/1.10	0.15/0.25
4140 RH	0.38/0.43	0.75/1.00	0.15/0.35	...	0.80/1.10	0.15/0.25
4145 RH	0.43/0.48	0.75/1.00	0.15/0.35	...	0.80/1.10	0.15/0.25
4161 RH	0.56/0.64	0.75/1.00	0.15/0.35	...	0.70/0.90	0.25/0.35
4320 RH	0.17/0.22	0.45/0.65	0.15/0.35	1.65/2.00	0.40/0.60	0.20/0.30
4620 RH	0.17/0.22	0.45/0.65	0.15/0.35	1.65/2.00	...	0.20/0.30
4820 RH	0.18/0.23	0.50/0.70	0.15/0.35	3.25/3.75	...	0.20/0.30
50B40 RH[B]	0.38/0.43	0.75/1.00	0.15/0.35	...	0.40/0.60	...
5130 RH	0.28/0.33	0.70/0.90	0.15/0.35	...	0.80/1.10	...
5140 RH	0.38/0.43	0.70/0.90	0.15/0.35	...	0.70/0.90	...
5160 RH	0.56/0.64	0.75/1.00	0.15/0.35	...	0.70/0.90	...

STEEL GRADES SUBJECT TO RESTRICTED END QUENCH HARDENABILITY REQUIREMENTS

(ASTM A 914/A 914M – 92; Reapproved 2005)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]					
	C	Mn	Si	Ni	Cr	Mo
8620 RH	0.18/0.23	0.70/0.90	0.15/0.35	0.40/0.70	0.40/0.60	0.15/0.25
8622 RH	0.20/0.25	0.70/0.90	0.15/0.35	0.40/0.70	0.40/0.60	0.15/0.25
8720 RH	0.18/0.23	0.70/0.90	0.15/0.35	0.40/0.70	0.40/0.60	0.20/0.30
8822 RH	0.20/0.25	0.75/1.00	0.15/0.35	0.40/0.70	0.40/0.60	0.30/0.40
9310 RH	0.08/0.13	0.45/0.65	0.15/0.35	3.00/3.50	1.00/1.40	0.08/0.15

[A] P and S in open-hearth steel is 0.035% and 0.040% max respectively, while P and S in electric furnace steel is 0.025% max.

[B] These steels can be expected to have 0.0005 to 0.003% B.

SAE POTENTIAL STANDARD STEELS

(SAE J1081 – NOV 2000)

PS No.[A]	Chemical Composition Ranges and Limits, Percent[B]					
	C	Mn	Ni	Cr	Mo	Other
PS 10	0.19/0.24	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10	
PS 16	0.20/0.25	0.90/1.20	...	0.40/0.60	0.13/0.20	
PS 17	0.23/0.28	0.90/1.20	...	0.40/0.60	0.13/0.20	
PS 18	0.25/0.30	0.90/1.20	...	0.40/0.60	0.13/0.20	
PS 19	0.18/0.23	0.90/1.20	...	0.40/0.60	0.08/0.15	B 0.0005/0.003
PS 20	0.13/0.18	0.90/1.20	...	0.40/0.60	0.13/0.20	
PS 21	0.15/0.20	0.90/1.20	...	0.40/0.60	0.13/0.20	
PS 31	0.15/0.20	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60	
PS 32	0.18/0.23	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60	
PS 33[C]	0.17/0.24	0.85/1.25	0.20 min	0.20 min	0.05 min	
PS 34	0.28/0.33	0.90/1.20	...	0.40/0.60	0.13/0.20	
PS 36	0.38/0.43	0.90/1.20	...	0.45/0.65	0.13/0.20	
PS 38	0.43/0.48	0.90/1.20	...	0.45/0.65	0.13/0.20	
PS 39	0.48/0.53	0.90/1.20	...	0.45/0.65	0.13/0.20	
PS 40	0.51/0.59	0.90/1.20	...	0.45/0.65	0.13/0.20	
PS 54	0.19/0.25	0.70/1.05	...	0.40/0.70	0.05 min	

SAE POTENTIAL STANDARD STEELS

(SAE J1081 – NOV 2000)

PS No.[A]	Chemical Composition Ranges and Limits, Percent[B]					
	C	Mn	Ni	Cr	Mo	Other
PS 55	0.15/0.20	0.70/1.00	1.65/2.00	0.45/0.65	0.65/0.80	
PS 56	0.08/0.13	0.70/1.00	1.65/2.00	0.45/0.65	0.65/0.80	
PS 57	0.08 max	1.25 max	...	17.00/19.00	1.75/2.25	S 0.15/0.35, P 0.040 max
PS 58	0.16/0.21	1.00/1.30	...	0.45/0.65	...	
PS 59	0.18/0.23	1.00/1.30	...	0.70/0.90	...	
PS 61	0.23/0.28	1.00/1.30	...	0.70/0.90	...	
PS 63	0.31/0.38	0.75/1.10	...	0.45/0.65	...	B 0.0005/0.003
PS 64	0.16/0.21	1.00/1.30	...	0.70/0.90	...	
PS 65	0.21/0.26	1.00/1.30	...	0.70/0.90	...	
PS 66	0.16/0.21	0.40/0.70	1.65/2.00	0.45/0.75	0.08/0.15	V 0.10/0.15
PS 67	0.42/0.49	0.80/1.20	...	0.85/1.20	0.25/0.35	
PS 68[D]	0.15 max	0.85/1.15	...	...	...	P 0.04/0.09, S 0.26/0.35

[A] Some PS steels may be supplied to a hardenability requirement.

[B] Unless specified, Si = 0.15/0.35, P = 0.025 max, and S = 0.025 max.

[C] Supplied to a hardenability requirement of 15 HRC points within the range of HRC 23/43 at J4, subject to agreement between producer and user.

[D] PS 68 has Sn content of 0.04/0.08.

FORMER SAE EX AND PS STEELS

(SAE J1249 JUN 2000)

Former Number	Aprox SAE Grade	Chemical Composition Ranges and Limits, Percent						Deletion Date
		C	Mn	Ni	Cr	Mo	Other	
PS 10	...	0.19/0.24	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1993
PS 19	...	0.18/0.23	0.90/1.20	...	0.40/0.60	0.08/0.15	B 0.0005/0.003	1993
PS 21	...	0.15/0.20	0.90/1.20	...	0.40/0.60	0.13/0.20		1993
PS 31	...	0.15/0.20	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60		1993
PS 32	...	0.18/0.23	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60		1993
PS 34	...	0.28/0.33	0.90/1.20	...	0.40/0.60	0.13/0.20		1993
PS 36	...	0.38/0.43	0.90/1.20	...	0.45/0.65	0.13/0.20		1993
PS 38	...	0.43/0.48	0.90/1.20	...	0.45/0.65	0.13/0.20		1993
PS 39	...	0.48/0.53	0.90/1.20	...	0.45/0.65	0.13/0.20		1993
PS 40	...	0.51/0.59	0.90/1.20	...	0.45/0.60	0.13/0.20		1993
PS 56	...	0.08/0.13	0.70/1.00	1.65/2.00	0.45/0.65	0.65/0.80		1993
PS 57	...	0.08 max	1.25 max	...	17.00/19.00	1.75/2.25	S 0.15/0.35, Si 1.00 max	1993
PS 58	...	0.16/0.21	1.00/1.30	...	0.45/0.65	...		1993
PS 59	...	0.18/0.23	1.00/1.30	...	0.70/0.90	...		1993
PS 61	...	0.23/0.28	1.00/1.30	...	0.70/0.90	...		1993
PS 63	...	0.31/0.38	0.75/1.10	...	0.70/0.90	...	B 0.0005/0.003	1993

FORMER SAE EX AND PS STEELS

(SAE J1249 JUN 2000)

Former Number	Aprox. SAE Grade	Chemical Composition Ranges and Limits, Percent						Deletion Date
		C	Mn	Ni	Cr	Mo	Other	
PS 64	...	0.16/0.21	1.00/1.30	...	0.70/0.90	...		1993
PS 65	...	0.21/0.26	1.00/1.30	...	0.70/0.90	...		1993
PS 66	...	0.16/0.21	0.40/0.70	1.65/2.00	0.45/0.75	0.08/0.15	V 0.10/0.15	1993
PS 67	...	0.42/0.49	0.85/1.20	...	0.85/1.20	0.25/0.35		1993
EX 1	9310	0.15/0.21	0.35/0.60	4.80/5.30	...	0.20/0.30	P 0.040 max	1976
EX 2	...	0.64/0.75	0.25/0.45	0.70/1.00	0.15/0.30	0.08/0.15	P & S 0.025 max each	1971
EX 3	5060	0.56/0.64	0.75/1.00	...	0.40/0.60	...		standard
EX 4	4118	0.18/0.23	0.75/1.00	...	0.45/0.65	0.05/0.10		1973
EX 5	8620	0.18/0.23	0.75/1.00	0.40/0.70	0.45/0.65	0.08/0.15		1971
EX 6	8622	0.20/0.25	0.75/1.00	0.40/0.70	0.45/0.65	0.08/0.15		1971
EX 7	8625	0.23/0.28	0.75/1.00	0.40/0.70	0.45/0.65	0.08/0.15		1971
EX 8	8627	0.25/0.30	0.75/1.00	0.40/0.70	0.45/0.65	0.08/0.15		1971
EX 9	8620	0.19/0.24	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10	Si 0.050 max	1976
EX 11	8640	0.38/0.43	0.75/1.00	0.20/0.40	0.25/0.40	0.05/0.10	B 0.0005/0.003, Si 0.050 max	1976
EX 12	8640	0.38/0.43	0.75/1.00	0.20/0.40	0.25/0.40	0.05/0.10	B 0.0005/0.003	1976

FORMER SAE EX AND PS STEELS

(SAE J1249 JUN 2000)

Former Number	Aprox. SAE Grade	Chemical Composition Ranges and Limits, Percent						Deletion Date
		C	Mn	Ni	Cr	Mo	Other	
EX 13	...	0.66/0.75	0.80/1.05	0.20/0.40	0.25/0.40	0.05/0.10	P & S both 0.025 max, Si 0.050 max	1976
EX 14	...	0.66/0.75	0.80/1.05	0.20/0.40	0.25/0.40	0.05/0.10	P & S both 0.025 max	1976
EX 15	4120	0.18/0.23	0.90/1.20	...	0.40/0.60	0.13/0.20		
EX 22	8615	0.13/0.18	0.75/1.00	...	0.45/0.65	0.20/0.30		1973
EX 23	8617	0.15/0.20	0.75/1.00	...	0.45/0.65	0.20/0.30		1973
EX 24	...	0.18/0.23	0.75/1.00	...	0.45/0.65	0.20/0.30		1973
EX 25	8622	0.20/0.25	0.75/1.00	...	0.45/0.65	0.20/0.30		1973
EX 26	8625	0.23/0.28	0.75/1.00	...	0.45/0.65	0.20/0.30		1973
EX 27	8627	0.25/0.30	0.75/1.00	...	0.45/0.65	0.20/0.30		1976
EX 28	4718	0.16/0.21	0.75/1.00	0.40/0.70	0.45/0.65	0.30/0.40		1973
EX 29	4320	0.18/0.23	0.75/1.00	0.40/0.70	0.45/0.65	0.30/0.40		1976
EX 30	...	0.13/0.18	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60		
EX 35	8637	0.35/0.40	0.90/1.20	...	0.45/0.65	0.13/0.20		1976
EX 37	8642	0.40/0.45	0.90/1.20	...	0.45/0.65	0.13/0.20		1976
EX 41	8660	0.56/0.64	0.90/1.20	...	0.45/0.65	0.13/0.20		1976

FORMER SAE EX AND PS STEELS

(SAE J1249 JUN 2000)

Former Number	Aprox. SAE Grade	Chemical Composition Ranges and Limits, Percent						Deletion Date
		C	Mn	Ni	Cr	Mo	Other	
EX 42	8615	0.13/0.18	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 43	...	0.13/0.18	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10	B 0.0005/0.003	1976
EX 44	8617	0.15/0.20	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 45	...	0.15/0.20	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10	B 0.0005/0.003	1976
EX 46	8622	0.20/0.25	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 47	8625	0.23/0.28	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 48	8627	0.25/0.30	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 49	8630	0.28/0.33	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 50	8635	0.33/0.38	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 51	8637	0.35/0.40	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 52	8640	0.38/0.43	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 53	8642	0.40/0.45	0.95/1.25	0.20/0.40	0.25/0.40	0.05/0.10		1976
EX 60	...	0.20/0.25	1.00/1.30	...	0.70/0.90	...		1983
EX 62	...	0.25/0.30	1.00/1.30	...	0.70/0.90	...		1983

Note 1: All steels contain 0.035% max P and 0.040% max S, except as noted.

Note 2: All steels contain 0.15/0.35% Si, except as noted.

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]				
	C	Mn	P max	S max	Last Date
1009	0.15 max	0.60 max	0.04	0.05	1965
1011	0.09/0.14	0.60/0.90	0.04	0.05	1993
1019	0.15/0.20	0.70/1.00	0.04	0.05	
1033	0.30/0.36	0.70/1.00	0.04	0.05	1965
1034	0.32/0.38	0.50/0.80	0.04	0.05	1968
1037	0.32/0.38	0.70/1.00	0.04	0.05	
1059	0.55/0.65	0.50/0.80	0.04	0.05	1968
1062	0.54/0.65	0.85/1.15	0.04	0.05	1993
1064	0.60/0.70	0.50/0.80	0.04	0.05	1953
1069	0.65/0.75	0.40/0.70	0.04	0.05	
1074	0.70/0.80	0.50/0.80	0.04	0.05	1993
1075	0.70/0.80	0.40/0.70	0.04	0.05	
1084	0.80/0.93	0.60/0.90	0.04	0.05	
1085	0.80/0.93	0.70/1.00	0.04	0.05	
1086	0.80/0.94	0.30/0.50	0.04	0.05	1977

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]				
	C	Mn	P max	S max	Last Date
1108	0.08/0.13	0.50/0.80	0.04	0.08/0.13	
1109	0.08/0.13	0.60/0.90	0.04	0.08/0.13	1977
1110	0.08/0.13	0.30/0.60	0.04	0.08/0.13	1993
1111	0.13 max	0.60/0.90	0.07/0.12	0.10/0.15	1969
1112	0.13 max	0.70/1.00	0.07/0.12	0.16/0.23	1969
1113	0.13 max	0.70/1.00	0.07/0.12	0.24/0.33	1969
1114	0.10/0.16	1.00/1.30	0.04	0.08/0.13	1952
1115	0.13/0.18	0.60/0.90	0.04	0.08/0.13	1965
1116	0.14/0.20	1.10/1.40	0.04	0.16/0.23	1952
1119	0.14/0.20	1.00/1.30	0.04	0.24/0.33	1977
1120	0.18/0.23	0.70/1.00	0.04	0.08/0.13	1965
1123	0.20/0.27	1.20/1.50	0.04	0.06/0.09	1993
1139	0.35/0.43	1.35/1.65	0.04	0.13/0.20	
1145	0.42/0.49	0.70/1.00	0.04	0.04/0.07	1977
1152	0.48/0.55	0.70/1.00	0.04	0.06/0.09	1993
1211	0.13 max	0.60/0.90	0.07/0.12	0.10/0.15	

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]				
	C	Mn	P max	S max	Last Date
1513	0.10/0.16	1.10/1.40	0.04	0.05	1993
1518	0.15/0.21	1.10/1.40	0.04	0.05	1977
1525	0.23/0.29	0.80/1.10	0.04	0.05	1977
1533	0.30/0.37	1.10/1.40	0.04	0.05	1993
1534	0.30/0.37	1.20/1.50	0.04	0.05	1993
1536	0.30/0.37	1.20/1.50	0.04	0.05	
1544	0.40/0.47	0.80/1.10	0.04	0.05	1993
1545	0.43/0.50	0.80/1.10	0.04	0.05	1993
1546	0.44/0.52	1.00/1.30	0.04	0.05	1993
1551	0.45/0.56	0.85/1.15	0.04	0.05	
1553	0.48/0.55	0.80/1.10	0.04	0.05	1993
1561	0.55/0.65	0.75/1.05	0.04	0.05	
1570	0.65/0.75	0.80/1.10	0.04	0.05	1993
1572	0.65/0.76	1.00/1.30	0.04	0.05	1977
1580	0.75/0.88	0.80/1.10	0.04	0.05	1993
1590	0.85/0.98	0.80/1.10	0.04	0.05	1993

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent						Last Date
	C	Mn	Ni	Cr	Mo	Other	
1320	0.18/0.23	1.60/1.90	...	...	...	Si 0.20/0.35	1956
1330	0.28/0.33	1.60/1.90	...	...	...		1993
1345	0.43/0.48	1.60/1.90	...	...	0.15/0.25		
2317	0.15/0.20	0.40/0.60	3.25/3.75	...	...	Si 0.20/0.35	1956
2330	0.28/0.33	0.60/0.80	3.25/3.76	...	...	Si 0.20/0.35	1953
2340	0.38/0.43	0.70/0.90	3.25/3.77	...	...	Si 0.20/0.35	1953
2345	0.43/0.48	0.70/0.90	3.25/3.78	...	...	Si 0.20/0.35	1952
2512	0.09/0.14	0.45/0.60	4.75/5.25	...	...	Si 0.20/0.35, P&S 0.025 max	1953
2515	0.12/0.17	0.40/0.60	4.75/5.25	...	...	Si 0.20/0.35	1956
2517	0.15/0.20	0.45/0.60	4.75/5.25	...	...	Si 0.20/0.35, P&S 0.025 max	1959
3115	0.13/0.18	0.40/0.60	3.25/3.75	...	...	Si 0.20/0.35	1956
3120	0.17/0.22	0.60/0.80	1.10/1.40	0.55/0.75	...	Si 0.20/0.35	1956
3130	0.28/0.33	0.60/0.80	1.10/1.40	0.55/0.75	...	Si 0.20/0.35	1956
3135	0.33/0.38	0.60/0.80	1.10/1.40	0.55/0.75	...	Si 0.20/0.35	1960
X3140	0.38/0.43	0.70/0.90	1.10/1.40	0.70/0.90	...	Si 0.20/0.35	1947

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent						Last Date
	C	Mn	Ni	Cr	Mo	Other	
3140	0.38/0.43	0.70/0.90	1.10/1.40	0.55/0.75	...	Si 0.20/0.35	1964
3145	0.43/0.48	0.70/0.90	1.10/1.40	0.70/0.90	...	Si 0.20/0.35	1952
3150	0.48/0.53	0.70/0.90	1.10/1.40	0.70/0.90	...	Si 0.20/0.35	1952
3215	0.10/0.20	0.30/0.60	1.50/2.00	0.90/1.25	...	Si 0.15/0.30	1941
3220	0.15/0.25	0.30/0.60	1.50/2.00	0.90/1.25	...	Si 0.15/0.30	1941
3230	0.25/0.35	0.30/0.60	1.50/2.00	0.90/1.25	...	Si 0.15/0.30	1941
3240	0.35/0.45	0.30/0.60	1.50/2.00	0.90/1.25	...	Si 0.15/0.30	1941
3245	0.40/0.50	0.30/0.60	1.50/2.00	0.90/1.25	...	Si 0.15/0.30	1941
3250	0.45/0.55	0.30/0.60	1.50/2.00	0.90/1.25	...	Si 0.15/0.30	1941
3310	0.08/0.13	0.45/0.60	3.25/3.75	1.40/1.75	...	Si 0.20/0.35, P&S 0.025 max	1964
3312	0.08/0.13	0.45/0.60	3.25/3.75	1.40/1.75	...	Si 0.20/0.35, P&S 0.025 max	1948
3316	0.14/0.19	0.45/0.60	3.25/3.75	1.40/1.75	...	Si 0.20/0.35, P&S 0.025 max	1956
3325	0.20/0.30	0.30/0.60	3.25/3.75	1.25/1.75	...	Si 0.15/0.30	1936
3335	0.30/0.40	0.30/0.60	3.25/3.75	1.25/1.75	...	Si 0.15/0.30	1936
3340	0.35/0.45	0.30/0.60	3.25/3.75	1.25/1.75	...	Si 0.15/0.30	1936

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
3415	0.10/0.20	0.30/0.60	2.75/3.25	0.60/0.95	...	Si 0.15/0.30	1941
3435	0.30/0.40	0.30/0.60	2.75/3.25	0.60/0.95	...	Si 0.15/0.30	1936
3450	0.45/0.55	0.30/0.60	2.75/3.25	0.60/0.95	...	Si 0.15/0.30	1936
4012	0.09/0.14	0.75/1.00	...	...	0.20/0.30	Si 0.15/0.30	1977
4024	0.20/0.25	0.70/0.90	...	...	0.20/0.30	S 0.035/0.050	
4028	0.25/0.30	0.70/0.90	...	...	0.20/0.30	S 0.035/0.050	1993
4032	0.30/0.35	0.70/0.90	...	...	0.20/0.30		
4042	0.40/0.45	0.70/0.90	...	...	0.20/0.30		
4053	0.50/0.56	0.75/1.00	...	...	0.20/0.30	Si 0.20/0.35	1956
4063	0.60/0.67	0.75/1.00	...	...	0.20/0.30	Si 0.20/0.35	1964
4068	0.63/0.70	0.75/1.00	...	...	0.20/0.30	Si 0.20/0.35	1957
4119	0.17/0.22	0.70/0.90	...	0.40/0.60	0.20/0.30	Si 0.20/0.35	1956
4121	0.18/0.23	0.75/1.00	...	0.45/0.65	0.20/0.30		1993
4125	0.23/0.28	0.70/0.90	...	0.40/0.60	0.20/0.30	Si 0.20/0.35	1950

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
4131	0.28/0.23	0.50/0.70	...	0.90/1.20	0.15/0.25		1993
4135	0.33/0.38	0.70/0.90	...	0.80/1.10	0.15/0.25		
4147	0.45/0.50	0.75/1.00	...	0.80/1.10	0.15/0.25		1993
4161	0.56/0.64	0.75/1.00	...	0.70/0.90	0.25/0.35		
4317	0.15/0.20	0.45/0.60	1.65/2.00	0.40/0.60	0.20/0.30	Si 0.20/0.35	1953
4337	0.35/0.40	0.60/0.80	1.65/2.00	0.70/0.90	0.20/0.30	Si 0.20/0.35	1964
4419	0.18/0.23	0.45/0.65	...	...	0.45/0.60	Si 0.15/0.30	1977
4419 H	0.17/0.23	0.35/0.75	...	...	0.45/0.60	Si 0.15/0.30	1977
4422	0.20/0.25	0.70/0.90	...	...	0.35/0.45		
4427	0.24/0.29	0.70/0.90	...	...	0.35/0.45		
4608	0.06/0.11	0.25/0.45	1.40/1.75	...	0.15/0.25	Si 0.25 max	1956
46B12[B]	0.10/0.15	0.45/0.65	1.65/2.00	...	0.20/0.30		1957
4615	0.13/0.18	0.45/0.65	1.65/2.00	...	0.20/0.30		
4617	0.15/0.20	0.45/0.65	1.65/2.00	...	0.20/0.30		
X4620	0.18/0.23	0.50/0.70	1.65/2.00	...	0.20/0.30	Si 0.20/0.35	1956

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
4621	0.18/0.23	0.70/0.90	1.65/2.00	...	0.20/0.30	Si 0.15/0.30	1977
4621 H	0.17/0.23	0.60/1.00	1.55/2.00	...	0.20/0.30	Si 0.15/0.30	1977
4626	0.24/0.29	0.45/0.65	0.70/1.00	...	0.15/0.25		
4640	0.38/0.43	0.60/0.80	1.65/2.00	...	0.20/0.30	Si 0.20/0.35	1952
4715	0.13/0.18	0.70/0.90	0.70/1.00	0.45/0.65	0.45/0.60		1993
4718	0.16/0.21	0.70/0.90	0.90/1.20	0.35/0.55	0.30/0.40		
4720	0.17/0.22	0.50/0.70	0.90/1.20	0.35/0.55	0.15/0.25		1993
4812	0.10/0.15	0.50/0.70	3.25/3.75	...	0.20/0.30	Si 0.20/0.35	1956
4815	0.13/0.18	0.40/0.60	3.25/3.75	...	0.20/0.30		1993
4817	0.15/0.20	0.40/0.60	3.25/3.75	...	0.20/0.30		
5015	0.12/0.17	0.40/0.60	...	0.30/0.50	...	Si 0.15/0.30	1977
50B40[B]	0.38/0.43	0.75/1.00	...	0.40/0.60	...		
50B44[B]	0.43/0.48	0.75/1.00	...	0.40/0.60	...		
5045	0.43/0.48	0.70/0.90	...	0.55/0.75	...	Si 0.20/0.35	1953
5046	0.43/0.48	0.75/1.00	...	0.20/0.35	...		

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
50B50[B]	0.48/0.53	0.75/1.00	...	0.40/0.60	...		
5060	0.56/0.64	0.75/1.00	...	0.40/0.60	...		
50B60[B]	0.56/0.64	0.75/1.00	...	0.40/0.60	...		
5115	0.13/0.18	0.70/0.90	...	0.40/0.60	...		
5117	0.15/0.20	0.70/0.90	...	0.70/0.90	...		
5135	0.33/0.38	0.60/0.80	...	0.80/1.05	...		
5145	0.43/0.48	0.70/0.90	...	0.70/0.90	...	Si 0.15/0.30	1977
5145H	0.42/0.49	0.60/1.00	...	0.60/1.00	...	Si 0.15/0.30	1977
5147	0.46/0.51	0.70/0.95	...	0.85/1.15	...		
5152	0.48/0.55	0.70/0.90	...	0.90/1.20	...	Si 0.20/0.35	1956
5155	0.51/0.59	0.70/0.90	...	0.70/0.90	...		
50100	0.98/1.10	0.25/0.45	...	0.40/0.60	...		
E51100[C]	0.98/1.10	0.25/0.45	...	0.90/1.15	...		1993
6115	0.10/0.20	0.30/0.60	...	0.80/1.10	...	V 0.15 min	1936
6117	0.15/0.20	0.70/0.90	...	0.70/0.90	...	V 0.10 min	1956

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
6118	0.16/0.21	0.50/0.70	...	0.50/0.70	...	V 0.10/0.15	
6120	0.17/0.22	0.70/0.90	...	0.70/0.90	...	V 0.10 min	1961
6125	0.20/0.30	0.60/0.90	...	0.80/1.10	...	V 0.15 min	1936
6130	0.25/0.35	0.60/0.90	...	0.80/1.10	...	V 0.15 min	1936
6135	0.30/0.40	0.60/0.90	...	0.80/1.10	...	V 0.15 min	1941
6140	0.35/0.45	0.60/0.90	...	0.80/1.10	...	V 0.15 min	1936
6145	0.43/0.48	0.70/0.90	...	0.80/1.10	...	V 0.15 min	1956
6195	0.90/1.05	0.20/0.45	...	0.80/1.10	...	V 0.15 min	1936
8115	0.13/0.18	0.70/0.90	0.20/0.40	0.30/0.50	0.08/0.15		
81B45[B]	0.43/0.48	0.75/1.00	0.20/0.40	0.35/0.55	0.08/0.15		
8625	0.23/0.28	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25		
8627	0.25/0.30	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25		
8632	0.30/0.35	0.70/0.90	0.40/0.70	0.40/0.60	0.15/0.25	Si 0.20/0.35	1951
8635	0.33/0.38	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	Si 0.20/0.35	1956
8637	0.35/0.40	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25		1993

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
8641	0.38/0.43	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	S 0.04/0.06	1956
8642	0.40/0.45	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25		
86B45[B]	0.43/0.48	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25		
8647	0.45/0.50	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25	Si 0.20/0.35	1948
8650	0.48/0.53	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25		
8653	0.50/0.56	0.75/1.00	0.40/0.70	0.50/0.80	0.15/0.25	Si 0.20/0.35	1956
8655	0.51/0.59	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25		
8660	0.56/0.64	0.75/1.00	0.40/0.70	0.40/0.60	0.15/0.25		
8715	0.13/0.18	0.70/0.90	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1956
8717	0.15/0.20	0.70/0.90	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1956
8719	0.18/0.23	0.60/0.80	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1952
8735	0.33/0.38	0.75/1.00	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1952
8740	0.38/0.43	0.75/1.00	0.40/0.70	0.40/0.60	0.20/0.30		
8742	0.40/0.45	0.75/1.00	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1964
8745	0.43/0.48	0.75/1.00	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1953

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
8750	0.48/0.53	0.75/1.00	0.40/0.70	0.40/0.60	0.20/0.30	Si 0.20/0.35	1956
9250	0.45/0.55	0.60/0.90	...	...	...	Si 1.80/2.20	1941
9254	0.51/0.59	0.60/0.80	...	0.60/0.80	...	Si 1.20/1.60	
9255	0.51/0.59	0.70/0.95	...	...	...	Si 1.80/2.20	1977
9261	0.55/0.65	0.75/1.00	...	0.10/0.25	...	Si 1.80/2.20	1956
9262	0.55/0.65	0.75/1.00	...	0.25/0.40	...	Si 1.80/2.20	1961
9310	0.08/0.13	0.45/0.65	3.00/3.50	1.00/1.40	0.08/0.15		
9315	0.13/0.18	0.45/0.65	3.00/3.50	1.00/1.40	0.08/0.15	Si 0.20/0.35	1959
9317	0.15/0.20	0.45/0.65	3.00/3.50	1.00/1.40	0.08/0.15	Si 0.20/0.35	1959
94B15[B]	0.13/0.18	0.75/1.00	0.30/0.60	0.30/0.50	0.08/0.15		
94B17[B]	0.15/0.20	0.75/1.00	0.30/0.60	0.30/0.50	0.08/0.15		
94B30[B]	0.28/0.33	0.75/1.00	0.30/0.60	0.30/0.50	0.08/0.15		
9437	0.35/0.40	0.90/1.20	0.30/0.60	0.30/0.50	0.08/0.15	Si 0.20/0.35	1950
9440	0.38/0.43	0.90/1.20	0.30/0.60	0.30/0.50	0.08/0.15	Si 0.20/0.35	1950
94B40[B]	0.38/0.43	0.75/1.00	0.30/0.60	0.30/0.50	0.08/0.15		1964

FORMER STANDARD SAE STEELS

(SAE J1249 JUN 2000)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]						Last Date
	C	Mn	Ni	Cr	Mo	Other	
9442	0.40/0.45	0.90/1.20	0.30/0.60	0.30/0.50	0.08/0.15	Si 0.20/0.35	1950
9445	0.43/0.48	0.90/1.20	0.30/0.60	0.30/0.50	0.08/0.15	Si 0.20/0.35	1950
9447	0.45/0.50	0.90/1.20	0.30/0.60	0.30/0.50	0.08/0.15	Si 0.20/0.35	1950
9747	0.45/0.50	0.50/0.80	0.40/0.70	0.10/0.25	0.15/0.25	Si 0.20/0.35	1950
9763	0.60/0.67	0.50/0.80	0.40/0.70	0.10/0.25	0.15/0.25	Si 0.20/0.35	1950
9840	0.38/0.43	0.70/0.90	0.85/1.15	0.70/0.90	0.20/0.30	Si 0.20/0.35	1964
9845	0.43/0.48	0.70/0.90	0.85/1.15	0.70/0.90	0.20/0.30	Si 0.20/0.35	1950
9850	0.48/0.53	0.70/0.90	0.85/1.15	0.70/0.90	0.20/0.30	Si 0.20/0.35	1961
43BV12[D]	0.08/0.13	0.75/1.00	1.65/2.00	0.40/0.60	0.20/0.30	Si 0.20/0.35	
43BV14[D]	0.10/0.15	0.45/0.65	1.65/2.00	0.40/0.60	0.08/0.15	Si 0.20/0.35	

[A] Standard alloy steels usually contain 0.035% maximum P and 0.040% S, unless noted otherwise. Standard alloy steels usually contain 0.15/0.35% Si, unless noted otherwise.

[B] Boron content 0.0005/0.003%

[C] Letter "E" preceding the grade indicates electric arc furnace steel. P and S are each 0.025% maximum.

[D] Boron content 0.0005/0.003% and V content is 0.03% min.

CARBURIZING BEARING QUALITY STEELS

(ASTM A 534 – 04)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A,B,C,D]							
	C	Mn	P (max)	S (max)	Si	Cr	Ni	Mo
4118H	0.17/0.23	0.60/1.00	0.025	0.015	0.15/0.35	0.30/0.70	...	0.08/0.15
4320H	0.17/0.23	0.40/0.70	0.025	0.015	0.15/0.35	0.35/0.65	1.55/2.00	0.20/0.30
4620H	0.17/0.23	0.35/0.75	0.025	0.015	0.15/0.35	...	1.55/2.00	0.20/0.30
4720H	0.17/0.23	0.45/0.75	0.025	0.015	0.15/0.35	0.30/0.60	0.85/1.25	0.15/0.25
4817H	0.14/0.20	0.30/0.70	0.025	0.015	0.15/0.35	...	3.20/3.80	0.20/0.30
4820H	0.17/0.23	0.40/0.80	0.025	0.015	0.15/0.35	...	3.20/3.80	0.20/0.30
5120H	0.17/0.23	0.60/1.00	0.025	0.015	0.15/0.35	0.60/1.00	...	...
8617H	0.14/0.20	0.60/0.95	0.025	0.015	0.15/0.35	0.35/0.65	0.35/0.75	0.15/0.25
8620H	0.17/0.23	0.60/0.95	0.025	0.015	0.15/0.35	0.35/0.65	0.35/0.75	0.15/0.25
9310H	0.07/0.13	0.40/0.70	0.025	0.015	0.15/0.35	1.00/1.45	2.95/3.55	0.08/0.15
20Cr3	0.17/0.23	0.60/1.00	0.025	0.015	0.40 max	0.60/1.00	...	...
20Cr4	0.17/0.23	0.60/0.90	0.025	0.015	0.40 max	0.90/1.20	...	...
20MnCr4-2	0.17/0.23	0.65/1.10	0.025	0.015	0.40 max	0.40/0.75	...	...
17MnCr5	0.14/0.19	1.00/1.30	0.025	0.015	0.40 max	0.80/1.10	...	...
19MnCr5	0.17/0.22	1.10/1.40	0.025	0.015	0.40 max	1.00/1.30	...	...
15CrMo4	0.12/0.18	0.60/0.90	0.025	0.015	0.40 max	0.90/1.20	...	0.15/0.25

CARBURIZING BEARING QUALITY STEELS

(ASTM A 534 – 04)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A,B,C,D]							
	C	Mn	P (max)	S (max)	Si	Cr	Ni	Mo
20CrMo4	0.17/0.23	0.60/0.90	0.025	0.015	0.40 max	0.90/1.20	...	0.15/0.25
20MnCrMo4-2	0.17/0.23	0.65/1.10	0.025	0.015	0.40 max	0.40/0.75	...	0.10/0.20
20NiCrMo2	0.17/0.23	0.60/0.95	0.025	0.015	0.40 max	0.35/0.65	0.40/0.70	0.15/0.25
20NiCrMo7	0.17/0.23	0.40/0.70	0.025	0.015	0.40 max	0.35/0.65	1.60/2.00	0.20/0.30
18CrNiMo7-6	0.15/0.21	0.50/0.90	0.025	0.015	0.40 max	1.50/1.80	1.40/1.70	0.25/0.35
18NiCrMo14-6	0.15/0.20	0.40/0.70	0.025	0.015	0.40 max	1.30/1.60	3.25/3.75	0.15/0.25
16NiCrMo16-5	0.14/0.18	0.25/0.55	0.025	0.015	0.40 max	1.00/1.40	3.80/4.30	0.20/0.30

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.

[B] Intentional additions of Ca or Ca alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.

[C] All grades have the following maximum limits: 0.30% max Cu, 0.0020% max O, and 0.050% max Al.

[D] For machinability purposes, S may be specified as 0.015-0.030%.

Microcleanliness Requirements (ASTM E45)			
Thin		Heavy	
A	2.5	A	1.5
B	2	B	1
C	0.5	C	0.5
D	1	D	1
Macrostructure Requirements (ASTM E381): S2 R2 C2			

MEDIUM CARBON BEARING QUALITY STEELS

(ASTM A 866 – 01)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A,B]									
	C	Mn	P[C]	S[C]	Si	Cr	Mo	Cu (max)	O (max)[D]	Al (max)
1030	0.28/0.34	0.60/0.90	0.025	0.025	0.15/0.35	…	…	0.30	0.0020	0.050
1040	0.37/0.44	0.60/0.90	0.025	0.025	0.15/0.35	…	…	0.30	0.0020	0.050
1050	0.48/0.55	0.60/0.90	0.025	0.025	0.15/0.35	…	…	0.30	0.0020	0.050
1541	0.36/0.44	1.35/1.65	0.025	0.025	0.15/0.35	…	…	0.30	0.0020	0.050
1552	0.47/0.55	1.20/1.50	0.025	0.025	0.15/0.35	…	…	0.30	0.0020	0.050
4130	0.28/0.33	0.40/0.60	0.025	0.025	0.15/0.35	0.80/1.10	0.15/0.25	0.30	0.0020	0.050
4140	0.38/0.43	0.75/1.00	0.025	0.025	0.15/0.35	0.80/1.10	0.15/0.25	0.30	0.0020	0.050
4150	0.48/0.53	0.75/1.00	0.025	0.025	0.15/0.35	0.80/1.10	0.15/0.25	0.30	0.0020	0.050
5140	0.38/0.43	0.70/0.95	0.025	0.025	0.15/0.35	0.70/0.90	…	0.30	0.0020	0.050
5150	0.48/0.53	0.70/0.90	0.025	0.025	0.15/0.35	0.70/0.90	…	0.30	0.0020	0.050
6150[E]	0.48/0.53	0.70/0.90	0.025	0.025	0.15/0.35	0.80/1.10	…	0.30	0.0020	0.050

MEDIUM CARBON BEARING QUALITY STEELS

(ASTM A 866 – 01)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A,B]									
	C	Mn	P[C]	S[C]	Si	Cr	Mo	Cu (max)	O (max)[D]	Al (max)
C56E2[F]	0.52/0.60	0.60/0.90	0.025	0.015	0.40 max	...	...	0.30	0.0020	0.050
56Mn4[F]	0.52/0.60	0.90/1.20	0.025	0.015	0.40 max	...	...	0.30	0.0020	0.050
43CrMo4[F]	0.40/0.46	0.60/0.90	0.025	0.015	0.40 max	0.90/1.20	0.15/0.30	0.30	0.0020	0.050

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.

[B] Intentional additions of Ca or Ca alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.

[C] P and S are maximum limits.

[D] Oxygen content applies to product analysis and shall be determined in accordance with Test Method ASTM E 1019.

[E] Requires 0.15 min V.

[F] Specified element ranges meet the requirements of ISO 683, Part 17, Table 3, NO. B1, 100CR6.

Note: The same inclusion and macrostructure requirements apply as are specified in ASTM A 534 – 04.

HIGH CARBON BEARING QUALITY STEELS

(ASTM A 295/A 295M – 05)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A,B,C]									
	C	Mn	P[D]	S[D]	Cr	Ni (max)	Mo	Cu (max)	O (max)[E]	Al (max)[F]
52100[G]	0.93/1.05	0.25/0.45	0.025	0.015	1.35/1.60	0.25	0.10 max	0.30	0.0015	0.050
5195	0.90/1.03	0.75/1.00	0.025	0.015	0.70/0.90	0.25	0.10 max	0.30	0.0015	0.050
5090M	0.89/1.01	0.50/0.80	0.025	0.015	0.40/0.60	0.25	0.08/0.15	0.30	0.0015	0.050
1070M	0.65/0.75	0.80/1.10	0.025	0.015	0.20 max	0.25	0.10 max	0.30	0.0015	0.050
5160	0.56/0.64	0.75/1.00	0.025	0.015	0.70/0.90	0.25	0.10 max	0.30	0.0015	0.050

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.

[B] Intentional additions of Ca or Ca alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.

[C] The Si range for all grades is 0.15/0.35%.

[D] P and S are maximum limits.

[E] Oxygen content applies to product analysis and shall be determined in accordance with Test Method ASTM E 1019.

[F] Total Al content.

[G] Specified element ranges meet the requirements of ISO 683, Part 17, Table 3, NO. B1, 100CR6.

Note: The same inclusion and macrostructure requirements apply as are specified in ASTM A 534 – 04.

CARBON STEEL FORGINGS FOR PIPING APPLICATIONS

(ASTM A 105/A 105M – 09)

Element	Composition, %
C	0.35 max
Mn	0.60/1.05
P	0.035 max
S	0.040 max
Si	0.10/0.35
Cu	0.40 max[A]
Ni	0.40 max[A]
Cr	0.30 max[A,B]
Mo	0.12 max[A,B]
V	0.08 max
C Equivalence[C]	0.47 or 0.48

[A] The sum of C, Ni, Cr, Mo, and V shall not exceed 1.00%.

[B] The sum of Cr and Mo shall not exceed 0.32%.

[C] The max C equivalence (Ceq) only applies when specified by the PO. The Ceq shall be 0.47 for forgings with a max section thickness of 2 in. or less, and 0.48 for forgings with a max section thickness greater than 2 in. A lower max Ceq may be agreed upon between the supplier and purchaser. The Ceq is determined as follows:

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$$

Note: For each reduction of 0.01% below the specified carbon max (0.35%), an increase of 0.06% Mn above the specified max (1.05%) will be permitted up to a max of 1.35%.

ALLOY STEELS FOR HIGH/LOW TEMPERATURE FLANGES

(ASTM A 182/A 182M – 09a)

Symbol	Chemical Ranges and Limits, Percent[A]								
	C	Mn	P	S	Si	Ni	Cr	Mo	Other Elements[B]
F 1	0.28	0.60/0.90	0.045	0.045	0.15/0.35	...	...	0.44/0.65	
F 2	0.05/0.21	0.30/0.80	0.030	0.030	0.10/0.60	...	0.50/0.81	0.44/0.65	
F 5	0.15	0.30/0.60	0.030	0.030	0.50	0.50	4.0/6.0	0.44/0.65	
F 5a	0.25	0.60	0.040	0.030	0.50	0.50	4.0/6.0	0.44/0.65	
F 9	0.15	0.30/0.60	0.030	0.030	0.50/1.00	...	8.0/10.0	0.90/1.10	
F 10	0.10/0.20	0.50/0.80	0.040	0.030	1.00/1.40	19.0/22.0	7.0/9.0	...	
F 91[C]	0.08/0.12	0.30/0.60	0.02	0.01	0.20/0.50	0.40	8.0/9.5	0.85/1.05	N 0.03/0.07, V 0.18/0.25, Nb 0.06/0.10
F 92[C]	0.07/0.13	0.30/0.60	0.02	0.01	0.50	0.40	8.50/9.50	0.30/0.60	V 0.15/0.25, N 0.03/0.07, W 1.50/2.00, B 0.001/0.006, Nb 0.04/0.09
F 122[C]	0.07/0.14	0.70	0.02	0.01	0.50	0.50	10.00/11.50	0.25/0.60	V 0.15/0.30,B 0.005, N 0.04/0.10, Cu 0.3/1.7, W 1.5/2.5, Nb 0.04/0.10
F 911[C]	0.09/0.13	0.30/0.60	0.02	0.01	0.10/0.50	0.40	8.5/9.5	0.90/1.10	W 0.90/1.10, N 0.04/0.09,V 0.18/0.25, B 0.0003/0.006, Nb 0.06/0.10
F11 CL 1	0.05/0.15	0.30/0.60	0.030	0.30	0.50/1.00	...	1.00/1.50	0.44/0.65	
F11 CL 2	0.10/0.20	0.30/0.80	0.040	0.040	0.50/1.00	...	1.00/1.50	0.44/0.65	
F11 CL 3	0.10/0.20	0.30/0.80	0.040	0.040	0.50/1.00	...	1.00/1.50	0.44/0.65	
F12 CL 1	0.05/0.15	0.30/0.60	0.045	0.045	0.50	...	0.80/1.25	0.44/0.65	
F12 CL 2	0.10/0.20	0.30/0.80	0.040	0.040	0.10/0.60	...	0.80/1.25	0.44/0.65	
F 21	0.05/0.15	0.30/0.60	0.040	0.040	0.50	...	2.70/3.30	0.80/1.06	

ALLOY STEELS FOR HIGH/LOW TEMPERATURE FLANGES

(ASTM A 182/A 182M – 09a)

Symbol	Chemical Ranges and Limits, Percent[A]								
	C	Mn	P	S	Si	Ni	Cr	Mo	Other Elements[B]
F 3V	0.05/0.18	0.30/0.60	0.020	0.020	0.10	...	2.80/3.20	0.90/1.10	Ti 0.015/0.035, V 0.20/0.30, B 0.001/0.003
F 3VCb	0.10/0.15	0.30/0.60	0.020	0.010	0.10	0.25	2.70/3.30	0.90/1.10	Ti 0.015, V 0.20/0.30, Cu 0.25, Ca 0.0005/0.0150, Nb 0.015/0.070
F22 CL 1	0.05/0.15	0.30/0.60	0.040	0.040	0.50	...	2.00/2.50	0.87/1.13	
F22 CL 3	0.05/0.15	0.30/0.60	0.040	0.040	0.50	...	2.00/2.50	0.87/1.13	
F22V[D]	0.11/0.15	0.30/0.60	0.015	0.010	0.10	0.25	2.00/2.50	0.90/1.10	Ti 0.030, Cu 0.20, V 0.25/0.35, B 0.002, Ca 0.015, Nb 0.07
F 23	0.04/0.10	0.10/0.60	0.030	0.010	0.50	...	1.90/2.60	0.05/0.30	V 0.20/0.30, B 0.0005/0.006, N 0.030, Al 0.030, W 1.45/1.75, Nb 0.02/0.08
F 24	0.05/0.10	0.30/0.70	0.020	0.010	0.15/0.45	...	2.20/2.60	0.90/1.10	Ti 0.06/0.10, V 0.20/0.30, N 0.12, Al 0.020, B 0.0015/0.007
FR	0.20	0.40/1.06	0.045	0.050	...	1.60/2.24	...	...	Cu 0.75/1.25
F 36	0.10/0.17	0.80/1.20	0.030	0.025	0.25/0.50	1.00/1.30	0.30	0.25/0.50	N 0.020, Al 0.050, Cu 0.50/0.80, V 0.02, Nb 0.015/0.045

[A] Maximum unless otherwise stated.

[B] For the elements Al, Ti, and Zr, the requirement applies to both heat and product analyses.

[C] These grades require 0.02 max Al, 0.01 max Ti, and 0.01 max Zr.

[D] For grade F22V, rare earth metals (REM) may be added in place of calcium, subject to agreement between the producer and the purchaser. In that case, the total amount of REM shall be determined and reported.

ALLOY STEEL FOR BOLTING APPLICATIONS

(ASTM A193/A193M – 09)

Grade	Description	Chemical Composition Ranges and Limits, Percent[A]							
		C	Mn	P (max)	S (max)	Si	Cr	Mo	V
B5	5% Cr	0.10 min	1.00 max	0.040	0.030	1.00 max	4.00/6.00	0.40/0.65	...
B6 and B6X	12% Cr	0.08/0.15	1.00 max	0.040	0.030	1.00 max	11.5/13.5	...	...
B7 and B7M[B]	Cr-Mo	0.37/0.49	0.65/1.10	0.035	0.040	0.15/0.35	0.75/1.20	0.15/0.25	...
B16[C]	Cr-Mo-V	0.36/0.47	0.45/0.70	0.035	0.040	0.15/0.35	0.80/1.15	0.50/0.65	0.25/0.35

[A] The intentional addition of Bi, Se, Te, and Pb is not permitted.

[B] Typical steel compositions used for this grade include 4140, 4142, 4145, 4140H, 4142H, and 4145H.

[C] Grade B16 has a requirement of 0.015 max Al, total of soluble and insoluble.

FERRITIC ALLOY-STEELS FOR SEAMLESS TUBES

(ASTM A 213/A 213M – 09a)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]									
	C	Mn	P	S	Si	Ni	Cr	Mo	V	Other
T2[B]	0.10/0.20	0.30/0.61	0.025	0.025[B]	0.10/0.30	...	0.50/0.81	0.44/0.65		...
T5	0.15	0.30/0.60	0.025	0.025	0.50	...	4.00/6.00	0.45/0.65		...
T5b	0.15	0.30/0.60	0.025	0.025	1.00/2.00	...	4.00/6.00	0.45/0.65		...
T5c	0.12	0.30/0.60	0.025	0.025	0.50	...	4.00/6.00	0.45/0.65		Ti 4xC/0.70
T9	0.15	0.30/0.60	0.025	0.025	0.25/1.00	...	8.00/10.00	0.90/1.10		...
T11	0.05/0.15	0.30/0.60	0.025	0.025	0.50/1.00	...	1.00/1.50	0.44/0.65		...
T12[B]	0.05/0.15	0.30/0.61	0.025	0.025[B]	0.50	...	0.80/1.25	0.44/0.65		...
T17	0.15/0.25	0.30/0.61	0.025	0.025	0.15/0.35	...	0.80/1.25	...	0.15	
T21	0.05/0.15	0.30/0.60	0.025	0.025	0.50/1.00	...	2.65/3.35	0.80/1.06	0.80/1.06	...
T22	0.05/0.15	0.30/0.60	0.025	0.025	0.50	...	1.90/2.60	0.87/1.13	0.87/1.13	...
T23	0.04/0.10	0.10/0.60	0.030	0.010	0.50	...	1.90/2.60	0.05/0.30	0.20/0.30	B 0.0005/0.006, Nb 0.02/0.08, N 0.03 max, Al 0.030 max, W 1.45/1.75
T24	0.05/0.10	0.30/0.70	0.020	0.010	0.15/0.45	...	2.20/2.60	0.90/1.10	0.20/0.30	B 0.0015/0.007, N 0.012 max, Al 0.02 max, Ti 0.06/0.10

FERRITIC ALLOY-STEELS FOR SEAMLESS TUBES

(ASTM A 213/A 213M – 09a)

Steel Grade	Chemical Composition Ranges and Limits, Percent[A]									
	C	Mn	P	S	Si	Ni	Cr	Mo	V	Other
T36	0.10/0.17	0.80/1.20	0.030	0.025	0.25/0.50	1.00/1.30	0.30	0.25/0.50	0.02	Nb 0.015/0.045, N 0.02, Al 0.05, Cu 0.50/0.80
T91[C]	0.07/0.14	0.30/0.60	0.020	0.010	0.20/0.50	0.40	8.0/9.5	0.85/1.05	0.18/0.25	Nb 0.06/0.10, N 0.03/0.07
T92[C]	0.07/0.13	0.30/0.60	0.020	0.010	0.50	0.40	8.5/9.5	0.30/0.60	0.15/0.25	B 0.001/0.006, Nb 0.04/0.09, W 1.50/2.00
T122[C]	0.07/0.14	0.70	0.020	0.010	0.50	0.50	10.0/11.5	0.25/0.60	0.15/0.30	B 0.0005/0.005, N 0.04/0.10, W 1.50/2.50, Cu 0.30/1.70
T911[C]	0.09/0.13	0.30/0.60	0.020	0.010	0.10/0.50	0.40	8.5/9.5	0.90/1.10	0.18/0.25	B 0.0003/0.006, Nb 0.06/0.10, N 0.04/0.09, W 0.90/1.10

[A] Maximum, unless range or minimum is indicated. Where ellipses (...) appear in this table, there is no requirement, and analysis for the element need not be determined or reported.

[B] It is permissible to ordered T2 and T12 with a S content of 0.045 max.

[C] These grades require 0.02 max Al, 0.01 max Ti, and 0.01 max Zr.

CARBON AND LOW-ALLOY STEEL FORGINGS, REQUIRING NOTCH TOUGHNESS TESTING FOR PIPING COMPONENTS

(ASTM A 350/A 350M – 07)

Element	Composition, wt%						
	Grade LF1	Grade LF2	Grade LF3	Grade LF5	Grade LF6	Grade LF9	Grade LF787
C, max	0.30	0.30	0.20	0.30	0.22	0.20	0.07
Mn	0.60/1.35	0.60/1.35	0.90 max	0.60/1.35	1.15/1.50	0.40/1.06	0.40/0.70
P, max	0.035	0.035	0.035	0.035	0.025	0.035	0.025
S, max	0.040	0.040	0.040	0.040	0.025	0.040	0.025
Si[A]	0.15/0.30	0.15/0.30	0.20/0.35	0.20/0.35	0.15/0.30	...	0.40 max
Ni	0.40 max[B]	0.40 max[B]	3.3/3.7	1.0/2.0	0.40 max[B]	1.60/2.24	0.70/1.00
Cr	0.30 max[B,C]	0.30 max[B,C]	0.30 max[C]	0.30 max[C]	0.30 max[B,C]	0.30 max[C]	0.60/0.90
Mo	0.12 max[B,C]	0.12 max[B,C]	0.12 max[C]	0.12 max[C]	0.12 max[B,C]	0.12 max[C]	0.15/0.25
Cu	0.40 max[B]	0.40 max[B]	0.40 max[C]	0.40 max[C]	0.40 max[B]	0.75/1.25	1.00/1.30
Nb	0.02 max[D]	0.02 max[D]	0.02 max	0.02 max	0.02 max	0.02 max	0.02 min
V	0.08 max	0.08 max	0.03 max	0.03 max	0.04/0.11	0.03 max	0.03 max
N	...	...	...	...	0.01/0.030	...	...

[A] When vacuum carbon-deoxidation is required, the Si content shall be 0.12% max.

[B] The sum of Cu, Ni, Cr, Mo, and V shall not exceed 1.00% on heat analysis.

[C] The sum of Cr and Mo shall not exceed 0.32% on heat analysis.

[D] By agreement, the limit for Nb may be increased up to 0.05% on heat analysis and 0.08% on product analysis.

HSLA COLUMBIUM-VANADIUM STRUCTURAL STEEL

(ASTM A 572/A 572M – 07)

Grade	Chemical Ranges and Limits, Percent[A]				
	C[D]	Mn[B,D]	P max	S max	Si max[C]
42 [290]	0.21 max	1.35 max[D]	0.040	0.050	0.40
50 [345]	0.23 max	1.35 max[D]	0.040	0.050	0.40
55 [380]	0.25 max	1.35 max[D]	0.040	0.050	0.40
60 [415]	0.26 max	1.35 max[D]	0.040	0.050	0.40
65 [450]	0.23 max	1.65 max	0.040	0.050	0.40
65 [450]	0.26 max	1.35 max	0.040	0.050	0.40

[A] Cu when specified shall have a minimum content of 0.20% by heat analysis.

[B] Mn minimum of 0.50% for bars is required. The Mn/C ratio shall not be less than 2:1.

[C] Bars over 1.5" in diameter or thickness shall be made by a killed steel practice.

[D] For each reduction of 0.01% below the specified C maximum, an increase of 0.06% Mn above the specified maximum is permitted, up to 1.60%.

Type[A]	Elements	Heat Analysis (%)
1	Cb[B]	0.005/0.05[C]
2	V	0.01/0.15
3	Cb[B]	0.005/0.05[C]
	V	0.01/0.15
	Cb + V	0.02/0.15[D]
5	Ti	0.006/0.04
	N	0.003/0.015
	V	0.06 max

[A] Alloy content shall be in accordance with Type 1, 2, 3, or 5 and contents of the applicable elements shall be reported on the test report.

[B] Cb shall be restricted unless killed steel is furnished. Killed steel shall be confirmed by a statement of killed steel on the test report, or by the presence of a sufficient quantity of a strong deoxidizing element, such as Si at 0.10% or higher, or Al at 0.015% or higher.

[C] Product analysis limit 0.004/0.06

[D] Product analysis limit 0.01/0.16

HSLA STRUCTURAL STEEL WITH ATMOSPHERIC CORROSION RESISTANCE

(ASTM A 588/A 588M – 05)

Element	Chemical Composition Ranges and Limits, Percent			
	Grade A	Grade B	Grade C	Grade K
C[A]	0.19 max	0.20 max	0.15 max	0.17 max
Mn[A]	0.80/1.25	0.75/1.35	0.80/1.35	0.50/1.20
P	0.04 max	0.04 max	0.04 max	0.04 max
S	0.05 max	0.05 max	0.05 max	0.05 max
Si	0.30/0.65	0.15/0.50	0.15/0.40	0.25/0.50
Ni	0.40 max	0.50 max	0.25/0.50	0.40 max
Cr	0.40/0.65	0.40/0.70	0.30/0.50	0.40/0.70
Mo	...	...	...	0.10 max
Cu	0.25/0.40	0.20/0.40	0.20/0.50	0.30/0.50
V	0.02/0.10	0.01/0.10	0.01/0.10	...
Cb	...	...	...	0.005/0.05

[A] For each reduction of 0.01% below the specified maximum for C, an increase of 0.06% Mn is permitted, up to a maximum of 1.50%.

Note: The atmospheric corrosion resistance index, calculated on the basis of the heat analysis of the steel, as described in ASTM G101, shall be 6.0 or higher.

MICROALLOY STEEL GRADES

(ASTM A 920/A 920M – 07)

Grade	C %	Mn %	P %	S %	V %
10V40	0.37/0.44	0.60/0.90	0.040 max	0.050 max	0.02/0.20
10V45	0.43/0.50	0.60/0.90	0.040 max	0.050 max	0.02/0.20
11V37	0.32/0.39	1.35/1.65	0.040 max	0.08/0.13	0.02/0.20
11V41	0.37/0.45	1.35/1.65	0.040 max	0.08/0.13	0.02/0.20
15V24	0.19/0.25	1.35/1.65	0.040 max	0.050 max	0.02/0.20
15V41	0.36/0.44	1.35/1.65	0.040 max	0.050 max	0.02/0.20

Note 1: These compositions are identical to those listed In ASTM A576 with the exception of the addition of V.

Note 2: Si content shall be 0.15/0.35% (up to 0.80% may be furnished upon agreement).

Note 3: V, Nb, or Mo may be specified singly or in combination, subject to the following limits: V .02/.20, Nb .005/.07, Mo .01/.30.

Note 4: Ti may be added when specified for refinement of the ferritic-pearlitic (or bainitic) or austenitic grain size.

Note 5: N may be specified as a supplement to V, Nb, or Ti. If specified, N content shall not exceed 0.03%.

Three strength classes are available, designated 75, 80, and 100 corresponding to the minimum yield strength (ksi).

Class	Yield Strength, min		Tensile Strength, min		Elongation, %, min	
	ksi	MPa	ksi	MPa	in 8 in. (200mm)	in 2 in. (50mm)
75	75	520	100	690	7	10
80	80	550	100	690	6	9
100	100	690	115	790	5	7

HEAT CHEMICAL RANGES AND LIMITS OF ALLOY STEEL BARS

(ASTM A 29/A 29M – 05)

Element	When Maximum of Specified Element is:	Chemical Range
Carbon	Thru 0.55	0.05
	Over 0.55 thru 0.70	0.07
	Over 0.70 thru 0.80	0.09
	Over 0.80 thru 0.95	0.11
	Over 0.95 thru 1.35	0.12
Manganese	Thru 0.60	0.15
	Over 0.60 thru 0.90	0.20
	Over 0.90 thru 1.05	0.25
	Over 1.05 thru 1.90	0.30
	Over 1.90 thru 2.10	0.35
Phosphorus	EAF Steel	0.025 max
Sulfur	Thru 0.050	0.015
	EAF Steel	0.025 max
Silicon	Thru 0.15	0.08
	Over 0.15 thru 0.20	0.10
	Over 0.20 thru 0.40	0.15
	Over 0.40 thru 0.60	0.20
	Over 0.60 thru 1.00	0.30
	Over 1.00 thru 2.20	0.35
Nickel	Thru 0.50	0.20
	Over 0.50 thru 1.50	0.30
	Over 1.50 thru 2.00	0.35
	Over 2.00 thru 3.00	0.40
	Over 3.00 thru 5.30	0.50
Chromium	Thru 0.40	0.15
	Over 0.40 thru 0.90	0.20
	Over 0.90 thru 1.05	0.25
	Over 1.05 thru 1.60	0.30
Molybdenum	Thru 0.10	0.05
	Over 0.10 thru 0.20	0.07
	Over 0.20 thru 0.50	0.10
Vanadium	Thru 0.25	0.05
	Over 0.25 thru 0.50	0.10
Aluminum	Thru 0.10	0.05
	Over 0.10 thru 0.20	0.10
Copper	Thru 0.60	0.20
	Over 0.60 thru 1.50	0.30

PERMISSIBLE VARIATIONS FOR PRODUCT ANALYSIS OF ALLOY STEEL

(ASTM A 29/A 29M – 05)

Element	Limit, or Maximum of Specified Range	Variation Over the Maximum Limit or Under the Minimum Limit
Carbon	Thru 0.30	0.01
	Over 0.30 thru 0.75	0.02
	Over 0.75	0.03
Manganese	Thru 0.90	0.03
	Over 0.90 thru 2.10	0.04
Phosphorus	Over maximum only	0.005
Sulfur	Thru 0.060	0.005
Silicon	Thru 0.40	0.02
	Over 0.40 thru 2.20	0.05
Nickel	Thru 1.00	0.03
	Over 1.00 thru 2.00	0.05
	Over 2.00 thru 5.30	0.07
Chromium	Thru 0.90	0.03
	Over 0.90 thru 2.10	0.05
	Over 2.10 thru 3.99	0.10
Molybdenum	Thru 0.20	0.01
	Over 0.20 thru 0.40	0.02
	Over 0.40 thru 1.15	0.03
Vanadium	Thru 0.10	0.01
	Over 0.10 thru 0.25	0.02
	Over 0.25 thru 0.50	0.03
Aluminum	Thru 0.10	0.03
	Over 0.10 thru 0.20	0.04
Copper	Thru 1.00	0.03
	Over 1.00 thru 2.00	0.05
Lead	0.15 thru 0.35	0.03
Titanium	Thru 0.10	0.01
Columbium	Thru 0.10	0.01
Nitrogen	Thru 0.030	0.005

AMS Designation	SAE or Other Equivalent	Chemical Composition and Ranges, Percent							
		C	Mn	Si	P (max)	S (max)	Cr	Ni	Mo
6260[A]	9310	0.07/0.13	0.40/0.70	0.15/0.35	0.025	0.025	1.00/1.40	3.00/3.50	0.08/0.15
6263	9315	0.11/0.17	0.40/0.70	0.15/0.35	0.025	0.025	1.00/1.40	3.00/3.50	0.08/0.15
6264	9317	0.14/0.20	0.40/0.70	0.15/0.35	0.025	0.025	1.00/1.40	3.00/3.50	0.08/0.15
6265	CV9310	0.07/0.13	0.40/0.70	0.15/0.35	0.015	0.015	1.00/1.40	3.00/3.50	0.08/0.15
6266[B]	43BV12	0.08/0.13	0.75/1.00	0.20/0.40	0.025	0.025	0.40/0.60	1.65/2.00	0.20/0.30
6270	8615	0.13/0.18	0.70/0.90	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.15/0.25
6272	8617	0.15/0.20	0.70/0.90	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.15/0.25
6274	8620	0.17/0.23	0.60/0.95	0.15/0.35	0.025	0.025	0.35/0.65	0.35/0.75	0.15/0.25
6275[C]	94B17	0.15/0.20	0.60/0.95	0.15/0.35	0.025	0.025	0.30/0.50	0.30/0.60	0.08/0.15
6280	8630	0.28/033	0.70/0.90	0.15/0.25	0.025	0.025	0.40/0.60	0.40/0.70	0.15/0.25
6281	8630	0.28/033	0.70/0.90	0.15/0.25	0.025	0.025	0.40/0.60	0.40/0.70	0.15/0.25
6282	8735	0.33/0.38	0.75/1.00	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.20/0.30
6290	4615	0.11/0.17	0.45/0.65	0.15/0.35	0.025	0.025	0.20 max	1.65/2.00	0.20/0.30
6292	4617	0.15/0.20	0.45/0.65	0.15/0.35	0.025	0.025	0.20 max	1.65/2.00	0.20/0.30
6294	4620	0.17/0.22	0.45/0.65	0.15/0.35	0.025	0.025	0.20 max	1.65/2.00	0.20/0.30
6299	4320H	0.17/0.23	0.40/0.70	0.15/0.35	0.025	0.025	0.35/0.65	1.55/2.00	0.20/0.30

[A] Requires 0.001 max B

[B] Requires B range of 0.0005/0.005 and V range of 0.03/0.08

[C] Requires B range of 0.0005/0.005

SELECT AEROSPACE SPECIFICATIONS

AMS Designation	SAE or Other Equivalent	Chemical Composition and Ranges, Percent							
		C	Mn	Si	P (max)	S (max)	Cr	Ni	Mo
6300	4037	0.35/0.40	0.70/0.90	0.15/0.35	0.040	0.040	0.20 max	0.25 max	0.20/0.30
6304[A]	--	0.40/0.50	0.40/0.70	0.15/0.35	0.025	0.025	0.80/1.10	0.25 max	0.45/0.65
6312	4640	0.38/0.43	0.60/0.80	0.15/0.35	0.025	0.025	0.20 max	1.65/2.00	0.20/0.30
6320	8735	0.33/0.38	0.75/1.00	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.20/0.30
6321[B]	81B40	0.38/0.43	0.75/1.00	0.15/0.35	0.025	0.025	0.30/0.55	0.20/0.40	0.08/0.15
6322	8740	0.38/0.43	0.75/1.00	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.20/0.30
6323	8740	0.38/0.43	0.75/1.00	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.20/0.30
6324	8740 Mod	0.38/0.43	0.75/1.00	0.15/0.35	0.025	0.025	0.55/0.75	0.55/0.85	0.20/0.30
6328	8750	0.48/0.53	0.75/1.00	0.15/0.35	0.025	0.025	0.40/0.60	0.40/0.70	0.20/0.30
6342	9840	0.38/0.43	0.70/0.90	0.15/0.35	0.025	0.025	0.70/0.90	0.85/1.15	0.20/0.30
6348	4130	0.25/0.33	0.40/0.60	0.15/0.35	0.025	0.025	0.80/1.10	0.25 max	0.15/0.25
6371	4130	0.28/0.33	0.40/0.60	0.15/0.35	0.025	0.025	0.80/1.10	0.25 max	0.15/0.25
6372	4135	0.33/0.38	0.70/0.90	0.15/0.35	0.025	0.025	0.80/1.10	0.25 max	0.15/0.25
6381	4140	0.38/0.43	0.75/1.00	0.15/0.35	0.025	0.025	0.80/1.10	0.25 max	0.15/0.25
6382	4140	0.38/0.43	0.75/1.00	0.15/0.35	0.025	0.025	0.80/1.10	0.25 max	0.15/0.25
6412	4337	0.35/0.40	0.65/0.85	0.15/0.35	0.025	0.025	0.70/0.90	1.65/2.00	0.20/0.30

[A] Requires V range of 0.25/0.35

[B] Requires B range of 0.0005/0.005

SELECT AEROSPACE SPECIFICATIONS

AMS Designation	SAE or Other Equivalent	Chemical Composition and Ranges, Percent							
		C	Mn	Si	P (max)	S (max)	Cr	Ni	Mo
6414	CV4340	0.38/0.43	0.65/0.90	0.15/0.35	0.015	0.015	0.70/0.90	1.65/2.00	0.20/0.30
6415	E4340 MIL S-5000	0.38/0.43	0.65/0.85	0.15/0.35	0.025	0.025	0.70/0.90	1.65/2.00	0.20/0.30
6418	4625M4 MIL S-7108	0.23/0.28	1.20/1.50	1.30/1.70	0.025	0.025	0.20/0.40	1.65/2.00	0.35/0.45
6427[A]	4330M4V2	0.28/0.33	0.75/1.00	0.15/0.35	0.025	0.025	0.75/1.00	1.65/2.00	0.35/0.50
6440	52100	0.93/1.05	0.25/0.45	0.15/0.35	0.025	0.025	1.35/1.60	0.25 max	0.10 max
6448[B]	6150	0.48/0.53	0.70/0.90	0.15/035	0.025	0.025	0.80/1.10	0.25 max	0.06 max

[A] Requires V range of 0.05/0.10

[B] Requires V range of 0.15/0.30

DIN SPECIFICATION FOR QUENCHED AND TEMPERED SPECIAL STEELS

(DIN 10083 – 1:2006)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]								
Name	**Number**	**C[D]**	**Si max**	**Mn**	**P max**	**S**	**Cr**	**Mo**	**Ni**	**Cr+Mo+Ni[D,E]**
C22E	**1.1151**	0.17/0.24	0.40	0.40/0.70	0.035	0.035 max	0.40	0.10	0.40	0.63
C22R	**1.1149**					0.020/0.040	max	max	max	
C25E	**1.1158**	0.22/0.29	0.40	0.40/0.70	0.035	0.035 max	0.40	0.10	0.40	0.63
C25R	**1.1163**					0.020/0.040	max	max	max	
C30E	**1.1178**	0.27/0.34	0.40	0.50/0.80	0.035	0.035 max	0.40	0.10	0.40	0.63
C30R	**1.1179**					0.020/0.040	max	max	max	
C35E	**1.1181**	0.32/0.39	0.40	0.50/0.80	0.035	0.035 max	0.40	0.10	0.40	0.63
C35R	**1.1180**					0.020/0.040	max	max	max	
C40E	**1.1186**	0.37/0.44	0.40	0.50/0.80	0.035	0.035 max	0.40	0.10	0.40	0.63
C40R	**1.1189**					0.020/0.040	max	max	max	
C45E	**1.1191**	0.42/0.80	0.40	0.50/0.80	0.035	0.035 max	0.40	0.10	0.40	0.63
C45R	**1.1201**					0.020/0.040	max	max	max	
C50E	**1.1206**	0.47/0.55	0.40	0.60/0.90	0.035	0.035 max	0.40	0.10	0.40	0.63
C50R	**1.1241**					0.020/0.040	max	max	max	
C55E	**1.1203**	0.52/0.60	0.40	0.60/0.90	0.035	0.035 max	0.40	0.10	0.40	0.63
C55R	**1.1209**					0.020/0.040	max	max	max	
C60E	**1.221**	0.57/0.65	0.40	0.60/0.90	.035	0.035 max	0.40	.10	0.40	0.63
C60R	**1.223**					0.020/0.040				

DIN SPECIFICATION FOR QUENCHED AND TEMPERED SPECIAL STEELS

(DIN 10083 – 1:2006)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]								
Name	**Number**	**C[D]**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Cr+Mo+Ni[D,E]**
28Mn6	**1.1170**	0.25/0.32	0.40	1.30/1.65	.035	0.035 max	0.40	.10	0.40	0.63
38Cr2	**1.7003**	0.35/0.42	0.40	0.50/0.80	.035	0.035 max	0.40/0.60	…	…	…
38CrS2	**1.7023**					0.020/0.040				
46Cr2	**1.7006**	0.42/0.50	0.40	0.50/0.80	.035	0.035 max	0.40/0.60	…	…	…
46CrS2	**1.7025**					0.020/0.040				
34Cr4	**1.7033**	0.30/0.37	0.40	0.60/0.90	.035	0.035 max	0.90/1.20	…	…	…
34CrS4	**1.7037**					0.020/0.040				
37Cr4	**1.7034**	0.34/0.41	0.40	0.60/0.90	.035	0.035 max	0.90/1.20	…	…	…
37CrS4	**1.7038**					0.020/0.040				
41Cr4	**1.7035**	0.38.45	0.40	0.60/0.90	.035	0.035 max	0.90/1.20	…	…	…
41CrS4	**1.7039**					0.020/0.040				
25CrMo4	**1.7218**	0.22/0.29	0.40	0.60/0.90	.035	0.035 max	0.90/1.20	.15/.30	…	…
25CrMoS4	**1.7213**					0.020/0.040				
34CrMo4	**1.7220**	0.30/0.37	0.40	0.60/0.90	.035	0.035 max	0.90/1.20	.15/.30	…	…
34CrMoS4	**1.7226**					0.020/0.040				
42CrMo4	**1.7225**	0.38/0.45	0.40	0.60/0.90	.035	0.035 max	0.90/1.20	.15/.30	…	…
42CrMoS4	**1.7227**					0.020/0.040				

DIN SPECIFICATION FOR QUENCHED AND TEMPERED SPECIAL STEELS

(DIN 10083 – 1:2006)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]								
Name	Number	C[D]	Si	Mn	P	S	Cr	Mo	Ni	Cr+Mo+Ni[D,E]
50CrMo4	**1.7228**	0.46/0.54	0.40	0.50/0.80	.035	0.035 max	0.90/1.20	.15/.30	…	…
36CrNiMo4	**1.6511**	0.32/0.40	0.40	0.50/0.80	.035	0.035 max	0.90/1.20	.15/.30	0.90/1.20	…
34CrNiMo6	**1.6582**	0.30/0.38	0.40	0.50/0.80	.035	0.035 max	1.30/1.70	.15/.30	1.30/1.70	…
30CrNiMo8	**1.6580**	0.26/0.34	0.40	0.30/0.60	.035	0.035 max	1.80/2.20	.30/.50	1.80/2.20	…
36NiCrMo16	**1.6773**	0.32/0.39	0.40	0.30/0.60	.030	0.025 max	1.60/2.00	.25/.45	3.60/4.10	…
51CrV4[F]	**1.8159**	0.47/0.55	0.40	0.70/1.10	.035	0.035 max	0.90/1.20	…	…	…

[A] Elements not quoted in this table shall not be intentionally added to the steel without the agreement of the purchaser, other than for the purpose of finishing the heat. All reasonable precautions shall be taken to prevent the addition of such elements which affect the hardenability, mechanical properties, and applicability.

[B] Where requirements are made on hardenability of special steels, slight deviations from the limits for the cast analysis are permissible, except for the elements C (see footnote D), P, and S; the deviations shall not exceed those specified.

[C] Steels with improved machinability as a result of the addition of higher S contents up to around 0.10% S (including resulfurized steels with controlled inclusion contents, i.e. Ca treated) may be supplied upon request. In this case, the upper limit for Mn content may be increased by 0.15%.

[D] If special steels are ordered without hardenability requirements (symbols +H, +HH, +HL) or without mechanical property requirements in the quenched and tempered or normalized condition, a restriction in the C range to 0.05% and/or the total sum of the elements Cr, Mo, and Ni to ≤ 0.45% may be agreed upon at the time of ordering.

[E] The individual limits for residual elements are as follows: Cr 0.40%, Mo 0.10%, and Ni 0.40%.

[F] Requires V range of 0.10/0.25

DIN SPECIFICATION FOR QUENCHED AND TEMPERED UNALLOYED QUALITY STEELS

(DIN 10083 – 2:2006)

Steel Designation		Chemical Ranges and Limits, Percent[A,B]								
Name	Number	C[C]	Si	Mn	P	S	Cr	Mo	Ni	Cr+Mo+Ni[C]
C22	1.0402	0.17/0.24	0.40	0.40/0.70	0.045	0.045	0.40	0.10	0.40	0.63
C25[4]	1.0406[4]	0.22/0.29	0.40	0.40/0.70	0.045	0.045	0.40	0.10	0.40	0.63
C30[4]	1.0528[4]	0.27/0.34	0.40	0.50/0.80	0.045	0.045	0.40	0.10	0.40	0.63
C35	1.0501	0.32/0.39	0.40	0.50/0.80	0.045	0.045	0.40	0.10	0.40	0.63
C40[4]	1.0511[4]	0.37/0.44	0.40	0.50/0.80	0.045	0.045	0.40	0.10	0.40	0.63
C45	1.0503	0.42/0.50	0.40	0.50/0.80	0.045	0.045	0.40	0.10	0.40	0.63
C50[D]	1.0540[D]	0.47/0.55	0.40	0.60/0.90	0.045	0.045	0.40	0.10	0.40	0.63
C55[D]	1.0535[D]	0.52/0.60	0.40	0.60/0.90	0.045	0.045	0.40	0.10	0.40	0.63
C60	1.0501	0.57/0.65	0.40	0.60/0.90	0.045	0.045	0.40	0.10	0.40	0.63

[A] Elements not quoted in this table shall not be intentionally added to the steel without the agreement of the purchaser, other than for the purpose of finishing the heat. All reasonable measures should be taken to prevent the addition of such elements which affect the hardenability, mechanical properties and applicability.

[B] Steels with improved machinability as a result of the addition of lead or higher sulfur contents up to around 0.100% S (including controlled sulfide and oxide formation (e.g. Ca treatment)) may be supplied on request.

[C] If the steels are ordered without mechanical property requirements in the quenched and tempered or normalized condition, a restriction in the carbon range to 0.05% and/or of the total sum of the elements Cr, Mo and Ni to <= 0.45% may be agreed at the time of ordering.

[D] These steel grades have been included in this European Standard for the first time; they are not available from stock in all countries.

DIN SPECIFICATION FOR QUENCHED AND TEMPERED BORON STEELS

(DIN 10083 – 3:2006)

Steel Designation		Chemical Ranges and Limits, Percent						
Name	**Number**	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**B**
20MnB5	**1.5530**	0.17/0.23	0.40	1.10/1.40	0.035	0.040	…	0.0008/0.0050
30MnB5	**1.5531**	0.27/0.33	0.40	1.15/1.45	0.035	0.040	…	0.0008/0.0050
38MnB5	**1.5532**	0.36/0.42	0.40	1.15/1.45	0.035	0.040	…	0.0008/0.0050
27MnCrB5-2	**1.7182**	0.24/0.30	0.40	1.10/1.40	0.035	0.040	0.30/0.60	0.0008/0.0050
33MnCrB5-2	**1.7185**	0.30/0.36	0.40	1.20/1.50	0.035	0.040	0.30/0.60	0.0008/0.0050
39MnCrB6-2	**1.7189**	0.36/0.42	0.40	1.40/1.70	0.035	0.040	0.30/0.60	0.0008/0.0050

[A] Elements not listed in this table should not be intentionally added to the steel without the agreement of the purchaser other than for the purpose of finishing the cast and For boron to have its effect on the hardenability. All reasonable precautions shall be taken to prevent the addition of such elements which affect the hardenability, Mechanical properties and applicability.

[B] When requirements are made on hardenability or on the mechanical properties in the quenched and tempered condition, slight deviations from the limits on the cast Analysis are permissible except for the elements carbon, phosphorous and sulfur; the deviations shall not exceed the values given in DIN 10083.

DIN SPECIFICATION FOR CASE HARDENING STEELS

(EN 10084 – 1998)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]							
Name	Number	C	Mn	Si	P	S	Cr	Mo	Ni
C10E	1.1121	0.07/0.13	0.30/0.60	0.40	0.035	0.035 max	...	...	...
C10R	1.1207					0.020/0.040			
C15E	1.1141	0.12/0.18	0.30/0.60	0.40	0.035	0.035 max	...	...	...
C15R	1.1140					0.020/0.040			
C16E	1.1148	0.12/0.18	0.60/0.90	0.40	0.035	0.035 max	...	...	...
C16R	1.1208					0.020/0.040			
17Cr3	1.7016	0.14/0.20	0.60/0.90	0.40	0.035	0.035 max	0.70/1.00	...	...
17CrS3	1.7014					0.020/0.040			
28Cr4	1.7030	0.24/0.31	0.60/0.90	0.40	0.035	0.035 max	0.90/1.20	...	...
28CrS4	1.7036					0.020/0.040			
16MnCr5	1.7131	0.14/0.19	1.00/1.30	0.40	0.035	0.035 max	0.80/1.10	...	...
16MnCrS5	1.7139					0.020/0.040			
16MnCrB5[D]	1.7160	0.14/0.19	1.00/1.30	0.40	0.035	0.035 max	0.80/1.10	...	...
20MnCr5	1.7147	0.17/0.22	1.10/1.40	0.40	0.035	0.035 max	1.00/1.30	...	...
20MnCrS5	1.7149					0.020/0.040			
18CrMo4	1.7243	0.15/0.21	0.60/0.90	0.40	0.035	0.035 max	0.90/1.20	.15/.25	...
18CrMoS4	1.7244					0.020/0.040			

DIN SPECIFICATION FOR CASE HARDENING STEELS

(EN 10084 – 1998)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]							
Name	**Number**	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Mo**	**Ni**
22CrMoS3-5	**1.7333**	0.19/0.24	0.70/1.00	0.040	0.035	0.020/0.040	0.70/1.00	.40/.50	…
20MoCr3	**1.7320**	0.17/0.23	0.60/0.90	0.40	0.035	0.035 max	0.40/0.70	.30/.40	…
20MoCrS3	**1.7319**					0.020/0.040			
20MoCr4	**1.7321**	0.17/0.23	0.70/1.00	0.40	0.035	0.035 max	0.30/0.60	.40/.50	…
20MoCrS4	**1.7323**					0.020/0.040			
16NiCr4	**1.5714**	0.13/0.19	0.70/1.00	0.40	0.035	0.035 max	0.60/1.00	…	0.80/1.10
16NiCrS4	**1.5715**					0.020/0.040			
10NiCr5-4	**1.5805**	0.07/0.12	0.60/0.90	0.40	0.035	0.035 max	0.90/1.20	…	1.20/1.50
18NiCr5-4	**1.5810**	0.16/0.21	0.60/0.90	0.40	0.035	0.035 max	0.90/1.20	…	1.20/1.50
17CrNi6-6	**1.5918**	0.14/0.20	0.50/0.90	0.40	0.035	0.035 max	1.40/1.70	…	1.40/1.70
15NiCr13	**1.5752**	0.14/0.20	0.40/0.70	0.40	0.035	0.035 max	0.60/0.90	…	3.00/3.50
20NiCrMo2-2	**1.6523**	0.17/0.23	0.65/0.95	0.40	0.035	0.035 max	0.35/0.70	.15/.25	0.40/0.70
20NiCrMoS2-2	**1.6526**					0.020/0.040			
17NiCrMo6-4	**1.6566**	0.14/0.20	0.60/0.90	0.40	0.035	0.035 max	0.80/1.10	.15/.25	1.20/1.50
17NiCrMoS6-4	**1.6569**					0.020/0.040			

DIN SPECIFICATION FOR CASE HARDENING STEELS

(EN 10084 – 1998)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]							
Name	**Number**	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Mo**	**Ni**
20NiCrMoS6-4	**1.6571**	0.16/0.23	0.50/0.90	0.40	0.035	0.020/0.040	0.60/0.90	.25/.35	1.40/1.70
18CrNiMo7-6	**1.6587**	0.15/0.21	0.50/0.90	0.40	0.035	0.035 max	1.50/1.80	.25/.35	1.40/1.70
14NiCrMo13-4	**1.6657**	0.11/0.17	0.30/0.60	0.40	0.035	0.035 max	0.80/1.10	.10/.25	3.00/3.50

[A] Elements not quoted in this table shall not be intentionally added to the steel without the agreement of the purchaser, other than for the purpose of finishing the heat. All reasonable precautions should be taken to prevent the addition of such elements which affect the hardenability, mechanical properties, and applicability.

[B] Where requirements are made on hardenability, slight deviations from the limits for the cast analysis are permitted, except for P and S; these deviations shall, however, not exceed in the case of carbon +/- 0.01% and in all other cases the values according to DIN 10084.

[C] Steels with improved machinability as a result of the addition of Pb or higher S contents, depending on the manufacturing process up to around 0.100% S (including controlled sulfide and oxide formation, e.g. Ca treatment), may be supplied on request. In this case, the upper limit of the Mn content may be increased by 0.15%.

[D] Requires B addition of 0.0008/0.0050. B is added not for an increase in hardenability, but to improve the toughness of the case hardened zone.

DIN SPECIFICATION FOR NITRIDING STEELS

(EN 10085 – 2001)

Steel Designation		Chemical Ranges and Limits, Percent[A,B]							
Name	**Number**	**C**	**Mn**	**Si**	**Al**	**Cr**	**Mo**	**Ni**	**V**
24CrMo13-6	**1.8516**	0.20/0.27	0.40/0.70	0.40	…	3.00/3.50	0.50/0.70	…	…
31CrMo12	**1.8515**	0.28/0.35	0.40/0.70	0.40	…	2.80/3.30	0.30/0.50	…	…
32CrAlMo7-10	**1.8505**	0.28/0.35	0.40/0.70	0.40	0.80/1.20	1.50/1.80	0.20/0.40	…	…
31CrMoV9	**1.8519**	0.27/0.34	0.40/0.70	0.40	…	2.30/2.70	0.15/0.25	…	.10/.20
33CrMoV12-9	**1.8522**	0.29/0.36	0.40/0.70	0.40	…	2.80/3.30	0.70/1.00	…	.15/.25
34CrAlNi7-10	**1.8550**	0.30/0.37	0.40/0.70	0.40	0.80/1.20	1.50/1.80	0.15/0.25	.85/1.15	…
41CrAlMo7-10	**1.8509**	0.38/0.45	0.40/0.70	0.40	0.80/1.20	1.50/1.80	0.20/0.35	…	…
40CrMoV13-9	**1.8523**	0.36/0.43	0.40/0.70	0.40	…	3.00/3.50	0.80/1.10	…	.15/.25
34CrAlMo5-10	**1.8507**	0.30/0.37	0.40/0.70	0.40	0.80/1.20	1.00/1.30	0.15/0.25	…	…

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser, other than for the purpose of finishing the heat. All reasonable precautions shall be taken to prevent the addition of such elements which affect the mechanical properties and applicability.

[B] All grades require 0.025 max P and 0.035 max S. The steel may be ordered with an upper limit of sulfur less than 0.035% if agreed upon by purchaser and manufacturer.

DIN SPECIFICATION FOR QUENCHED AND TEMPERED SPRINGS

(EN 10089 – 2002)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]								
Name	**Number**	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**V**
38Si7	**1.5023**	0.35/0.42	0.50/0.80	1.50/1.80	.025	.025	...	...	...	...
46Si7	**1.5024**	0.42/0.50	0.50/0.80	1.50/2.00	.025	.025	...	...	...	...
56Si7	**1.5026**	0.52/0.60	0.60/0.90	1.60/2.00	.025	.025	...	...	...	...
55Cr3	**1.7176**	0.52/0.59	0.70/1.00	0.40 max	.025	.025	0.70/1.00	...	...	...
60Cr3	**1.7177**	0.55/0.65	0.70/1.00	0.40 max	.025	.025	0.60/0.90	...	...	...
54SiCr6	**1.7102**	0.51/0.59	0.50/0.80	1.20/1.60	.025	.025	0.50/0.80	...	...	...
56SiCr7	**1.7106**	0.52/0.60	0.70/1.00	1.60/2.00	.025	.025	0.20/0.45	...	...	...
61SiCr7	**1.7108**	0.57/0.65	0.70/1.00	1.60/2.00	.025	.025	0.20/0.45	...	...	...
51CrV4	**1.8159**	0.47/0.55	0.70/1.00	0.40 max	.025	.025	0.90/1.20	...	...	0.10/0.25
45SiCrV6-2	**1.8151**	0.40/0.50	0.60/0.90	1.30/1.70	.025	.025	0.40/0.80	...	...	0.10/0.20
54SiCrV6	**1.8152**	0.51/0.59	0.50/0.80	1.20/1.60	.025	.025	0.50/0.80	...	...	0.10/0.20
60SiCrV7	**1.8153**	0.56/0.64	0.70/1.00	1.50/2.00	.025	.025	0.20/0.40	...	...	0.10/0.20
46SiCrMo6	**1.8062**	0.42/0.50	0.50/0.80	1.30/1.70	.025	.025	0.50/0.80	...	.20/.30	...
50SiCrMo6	**1.8063**	0.46/0.54	0.70/1.00	1.40/1.80	.025	.025	0.80/1.10	...	.20/.35	...
52SiCrNi5	**1.7117**	0.49/0.56	0.70/1.00	1.20/1.50	.025	.025	0.70/1.00	.50/.70	...	...

DIN SPECIFICATION FOR QUENCHED AND TEMPERED SPRINGS

(EN 10089 – 2002)

Steel Designation		Chemical Ranges and Limits, Percent[A,B,C]								
Name	**Number**	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**V**
52CrMoV4	**1.7701**	0.48/0.56	0.70/1.10	0.40 max	.025	.025	0.90/1.20	...	.15/.30	0.10/0.20
60CrMo3-1	**1.7239**	0.56/0.64	0.70/1.00	0.40 max	.025	.025	0.70/1.00	...	.06/.15	...
60CrMo3-2	**1.7240**	0.56/0.64	0.70/1.00	0.40 max	.025	.025	0.70/1.00	...	.15/.25	...
60CrMo3-3	**1.7241**	0.56/0.64	0.70/1.00	0.40 max	.025	.025	0.70/1.00	...	.25/.35	...

[A] Elements which are not mentioned shall not be intentionally added to the steel without the agreement of the purchaser, other than for the purpose of finishing the heat. All reasonable precautions shall be taken to prevent the addition of elements which could affect the hardenability, mechanical properties and application.

[B] In the case of the grades specified hardenability requirements, except for P and S, insignificant deviations from the limits for cast analysis are permissible. These deviations shall, however, not exceed ± 0.01% in the case of carbon, and the values according to DIN 10089.

[C] All grades require that the sum of Cu + 10 x Sn be less than or equal to 0.60.

DIN SPECIFICATION FOR FERRITIC-PEARLITIC STEELS FOR PRECIPITATION HARDENING FROM HOT-WORKING TEMPERATURES

(EN 10267 – 1998)

Steel Designation		Chemical Ranges and Limits, Percent[A,D]								
Name	Number	C	Mn	Si	P	S[B]	N	Cr	Mo	V[C]
19MnVS6	**1.1301**	0.15/0.22	1.20/1.60	0.15/0.80	0.025	0.020/0.060	0.010/0.020	0.30	0.08	0.08/0.20
30MnVS6	**1.1302**	0.26/0.33	1.20/1.60	0.15/0.80	0.025	0.020/0.060	0.010/0.020	0.30	0.08	0.08/0.20
38MnVS6	**1.1303**	0.34/0.41	1.20/1.60	0.15/0.80	0.025	0.020/0.060	0.010/0.020	0.30	0.08	0.08/0.20
46MnVS6	**1.1304**	0.42/0.49	1.20/1.60	0.15/0.80	0.025	0.020/0.060	0.010/0.020	0.30	0.08	0.08/0.20
46MnVS3	**1.1305**	0.42/0.49	0.15/0.80	0.15/0.80	0.025	0.020/0.060	0.010/0.020	0.30	0.08	0.08/0.20

[A] Elements not quoted should not be intentionally added to the steel without the agreement of the purchaser, other than for purpose of finishing the heat. All reasonable Precautions should be taken to prevent the addition of elements which affect the hardenability, mechanical properties and application.

[B] Other elements may be added to improve machinability (or to control sulfide morphology and oxide formation), subject to agreement. The sulfur range may also be subject to agreement.

[C] Some or all of the vanadium content may be replaced by niobium, subject to agreement. In this case, the lower limit of vanadium shall also be subject to agreement.

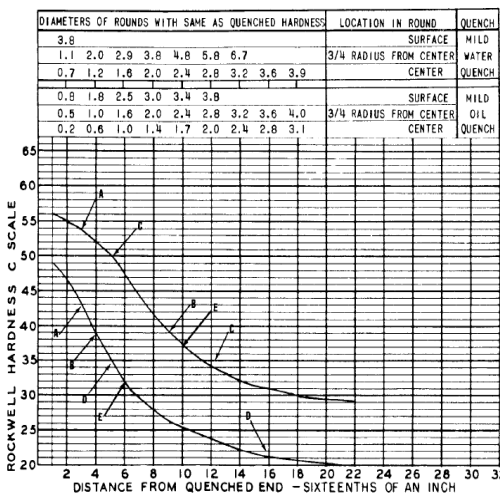
[D] Titanium additions shall be subject to agreement.

NOTES

HARDENABILITY

EXAMBLES ILLUSTRATING ALTERNATE METHODS OF SPECIFYING HARDENABILITY REQUIREMENTS FOR CARBON AND ALLOY H STEELS

1. The minimum and maximum hardness values at any desired distance, illustrated as points A-A.
2. The minimum and maximum distance at which any hardness value occurs. The method is illustrated as points B-B. If the desired hardness does not fall on an exact sixteenth (or mm) position, the minimum distance selected should be the nearest sixteenth (or mm) position toward the quenched end and the maximum should be the nearest sixteenth (or mm) position away from the quenched end.



3. Two maximum hardness values at two desired locations (C-C).
4. Two minimum hardness values at two desired locations (D-D).
5. Any minimum hardness plus any maximum hardness (E-E).

END QUENCH HARDENABILITY BAND DATA

(ASTM A 304 – 05)

"J" Distance (Sixteenths of an inch)	Grade							
	1038 H		1045 H		1522 H		1524 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1.0	58	51	62	55	50	41	51	42
1.5	56	42	61	52	48	41	49	42
2.0	55	34	59	42	47	32	48	38
2.5	53	29	56	34	46	27	47	34
3.0	49	26	52	31	45	22	45	29
3.5	43	24	46	29	42	21	43	25
4.0	37	23	38	28	39	20	39	22
4.5	33	22	34	27	37	--	38	20
5.0	30	22	33	26	34	--	35	--
5.5	29	21	32	26	32	--	34	--
6.0	28	21	32	25	30	--	32	--
6.5	27	20	31	25	28	--	30	--
7.0	27	--	31	25	27	--	29	--
7.5	26	--	30	24	--	--	28	--
8.0	26	--	30	24	--	--	27	--
9.0	25	--	29	23	--	--	26	--
10.0	25	--	29	22	--	--	25	--
12.0	24	--	28	21	--	--	23	--
14.0	23	--	27	20	--	--	22	--
16.0	21	--	26	--	--	--	20	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade					
	1526 H		1541 H		15B21 H	
	Max	Min	Max	Min	Max	Min
1.0	53	44	60	53	48	41
1.5	50	42	59	52	48	41
2.0	49	38	59	50	47	40
2.5	47	33	58	47	47	39
3.0	46	26	57	44	46	38
3.5	42	25	56	41	45	36
4.0	39	21	55	38	44	30
4.5	37	20	53	35	42	23
5.0	33	--	52	32	40	20
5.5	31	--	50	29	38	--
6.0	30	--	48	27	35	--
6.5	28	--	46	26	32	--
7.0	27	--	44	25	27	--
7.5	26	--	41	24	22	--
8.0	26	--	39	23	20	--
9.0	24	--	35	22	--	--
10.0	24	--	33	22	--	--
12.0	23	--	32	21	--	--
14.0	22	--	31	20	--	--
16.0	21	--	30	--	--	--
18.0	20	--	30	--	--	--
20.0	--	--	29	--	--	--
24.0	--	--	28	--	--	--
28.0	--	--	26	--	--	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	15B28 H		15B30 H		15B35 H		15B37 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	53	47	55	48	58	51	58	50
2	53	47	53	47	56	50	56	50
3	52	46	52	46	55	49	55	49
4	51	45	51	44	54	48	54	48
5	51	42	50	32	53	39	53	43
6	50	32	48	22	51	28	52	37
7	49	25	43	20	47	24	51	33
8	48	21	38	--	41	22	50	26
9	46	20	33	--	--	--	--	--
10	43	--	29	--	30	20	45	22
11	40	--	27	--	--	--	--	--
12	37	--	26	--	27	--	40	21
13	34	--	25	--	--	--	--	--
14	31	--	24	--	26	--	33	20
15	30	--	23	--	--	--	--	--
16	29	--	22	--	25	--	29	--
18	27	--	20	--	--	--	--	--
20	25	--	--	--	24	--	27	--
22	25	--	--	--	--	--	--	--
24	24	--	--	--	22	--	25	--
26	23	--	--	--	--	--	--	--
28	22	--	--	--	20	--	23	--
30	21	--	--	--	--	--	--	--
32	20	--	--	--	--	--	21	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade					
	15B41 H		15B48 H		15B62H	
	Max	Min	Max	Min	Max	Min
1	60	53	63	56	--	60
2	59	52	62	56	--	60
3	59	52	62	55	--	60
4	58	51	61	54	--	60
5	58	51	60	53	65	59
6	57	50	59	52	65	58
7	57	49	58	42	64	57
8	56	48	57	34	64	52
9	55	44	56	31	64	43
10	55	37	55	30	63	39
11	54	32	53	29	63	37
12	53	28	51	28	63	35
13	52	26	48	27	62	35
14	51	25	45	27	62	34
15	50	25	41	26	61	33
16	49	24	38	26	60	33
18	46	23	34	25	58	32
20	42	22	32	24	54	31
22	39	21	31	23	48	30
24	36	21	30	22	43	30
26	34	20	29	21	40	29
28	33	--	29	20	37	28
30	31	--	28	--	35	27
32	31	--	28	--	34	26

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	1330 H		1335 H		1340 H		1345 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	56	49	58	51	60	53	63	56
2	56	47	57	49	60	52	63	56
3	55	44	56	47	59	51	62	55
4	53	40	55	44	58	49	61	54
5	52	35	54	38	57	46	61	51
6	50	31	52	34	56	40	60	44
7	48	28	50	31	55	35	60	38
8	45	26	48	29	54	33	59	35
9	43	25	46	27	52	31	58	33
10	42	23	44	26	51	29	57	32
11	40	22	42	25	50	28	56	31
12	39	21	41	24	48	27	55	30
13	38	20	40	23	46	26	54	29
14	37	--	39	22	44	25	53	29
15	36	--	38	22	42	25	52	28
16	35	--	37	21	41	24	51	28
18	34	--	35	20	39	23	49	27
20	33	--	34	--	38	23	48	27
22	32	--	33	--	37	22	47	26
24	31	--	32	--	36	22	46	26
26	31	--	31	--	35	21	45	25
28	31	--	31	--	35	21	45	25
30	30	--	30	--	34	20	45	24
32	30	--	30	--	34	20	45	24

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4027 H/4028 H		4032 H		4037 H		4042 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	52	45	57	50	59	52	62	55
2	50	40	54	45	57	49	60	52
3	46	31	51	36	54	42	58	48
4	40	25	46	29	51	35	55	40
5	34	22	39	25	45	30	50	33
6	30	20	34	23	38	26	45	29
7	28	--	31	22	34	23	39	27
8	26	--	29	21	32	22	36	26
9	25	--	28	20	30	21	34	25
10	25	--	26	--	29	20	33	24
11	24	--	25	--	28	--	32	24
12	23	--	25	--	27	--	31	23
13	23	--	24	--	26	--	30	23
14	22	--	24	--	26	--	30	23
15	22	--	23	--	26	--	29	22
16	21	--	23	--	25	--	29	22
18	21	--	23	--	25	--	28	22
20	20	--	22	--	25	--	28	21
22	--	--	22	--	25	--	28	20
24	--	--	21	--	24	--	27	20
26	--	--	21	--	24	--	27	--
28	--	--	20	--	24	--	27	--
30	--	--	--	--	23	--	26	--
32	--	--	--	--	23	--	26	--

END QUENCH HARDENABILITY BAND DATA

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

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4137 H		4140 H		4142 H		4145 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	59	52	60	53	62	55	63	56
2	59	51	60	53	62	55	63	55
3	58	50	60	52	62	54	62	55
4	58	49	59	51	61	53	62	54
5	57	49	59	51	61	53	62	53
6	57	48	58	50	61	52	61	53
7	56	45	58	48	60	51	61	52
8	55	43	57	47	60	50	61	52
9	55	40	57	44	60	49	60	51
10	54	39	56	42	59	47	60	50
11	53	37	56	40	59	46	60	49
12	52	36	55	39	58	44	59	48
13	51	35	55	38	58	42	59	46
14	50	34	54	37	57	41	59	45
15	49	33	54	36	57	40	58	43
16	48	33	53	35	56	39	58	42
18	46	32	52	34	55	37	57	40
20	45	31	51	33	54	36	57	38
22	44	30	49	33	53	35	56	37
24	43	30	48	32	53	34	55	36
26	42	30	47	32	52	34	55	35
28	42	29	46	31	51	34	55	35
30	41	29	45	31	51	33	55	34
32	41	29	44	30	50	33	54	34

END QUENCH HARDENABILITY BAND DATA

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

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4340 H		E4340 H		4419 H		4620 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	60	53	60	53	48	40	48	41
2	60	53	60	53	45	33	45	35
3	60	53	60	53	41	27	42	27
4	60	53	60	53	34	23	39	24
5	60	53	60	53	30	21	34	21
6	60	53	60	53	28	20	31	--
7	60	53	60	53	27	--	29	--
8	60	52	60	53	25	--	27	--
9	60	52	60	53	25	--	26	--
10	60	52	60	53	24	--	25	--
11	59	51	60	53	24	--	24	--
12	59	51	60	52	23	--	23	--
13	59	50	60	52	23	--	22	--
14	58	49	59	52	22	--	22	--
15	58	49	59	52	22	--	22	--
16	58	48	59	51	21	--	21	--
18	58	47	58	51	21	--	21	--
20	57	46	58	50	20	--	20	--
22	57	45	58	49	--	--	--	--
24	57	44	57	48	--	--	--	--
26	57	43	57	47	--	--	--	--
28	56	42	57	46	--	--	--	--
30	56	41	57	45	--	--	--	--
32	56	40	57	44	--	--	--	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4621 H		4626 H		4718 H		4720 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	48	41	51	45	47	40	48	41
2	47	38	48	36	47	40	47	39
3	46	34	41	29	45	38	43	31
4	44	30	33	24	43	33	39	27
5	41	27	29	21	40	29	35	23
6	37	25	27	--	37	27	32	21
7	34	23	25	--	35	25	29	--
8	32	22	24	--	33	24	28	--
9	30	20	23	--	32	23	27	--
10	28	--	22	--	31	22	26	--
11	27	--	22	--	30	22	25	--
12	26	--	21	--	29	21	24	--
13	26	--	21	--	29	21	24	--
14	25	--	20	--	28	21	23	--
15	25	--	--	--	27	20	23	--
16	24	--	--	--	27	20	22	--
18	24	--	--	--	27	--	21	--
20	23	--	--	--	26	--	21	--
22	23	--	--	--	26	--	21	--
24	22	--	--	--	25	--	20	--
26	22	--	--	--	25	--	--	--
28	22	--	--	--	24	--	--	--
30	21	--	--	--	24	--	--	--
32	21	--	--	--	24	--	--	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4815 H		4817 H		4820 H		50B40 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	45	38	46	39	48	41	60	53
2	44	37	46	38	48	40	60	53
3	44	34	45	35	47	39	59	52
4	42	30	44	32	46	38	59	51
5	41	27	42	29	45	34	58	50
6	39	24	41	27	43	31	58	48
7	37	22	39	25	42	29	57	44
8	35	21	37	23	40	27	57	39
9	33	20	35	22	39	26	56	34
10	31	--	33	21	37	25	55	31
11	30	--	32	20	36	24	53	29
12	29	--	31	20	35	23	51	28
13	28	--	30	--	34	22	49	27
14	28	--	29	--	33	22	47	26
15	27	--	28	--	32	21	44	25
16	27	--	28	--	31	21	41	25
18	26	--	27	--	29	20	38	23
20	25	--	26	--	28	20	36	21
22	24	--	25	--	28	--	35	--
24	24	--	25	--	27	--	34	--
26	24	--	25	--	27	--	33	--
28	23	--	25	--	26	--	32	--
30	23	--	24	--	26	--	30	--
32	23	--	24	--	25	--	29	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	50B44 H		5046 H		50B46 H		50B50 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	63	56	63	56	63	56	65	59
2	63	56	62	55	62	54	65	59
3	62	55	60	45	61	52	64	58
4	62	55	56	32	60	50	64	57
5	61	54	52	28	59	41	63	56
6	61	52	46	27	58	32	63	55
7	60	48	39	26	57	31	62	52
8	60	43	35	25	56	30	62	47
9	59	38	34	24	54	29	61	42
10	58	34	33	24	51	28	60	37
11	57	31	33	23	47	27	60	35
12	56	30	32	23	43	26	59	33
13	54	29	32	22	40	26	58	32
14	52	29	31	22	38	25	57	31
15	50	28	31	21	37	25	56	30
16	48	27	30	21	36	24	54	29
18	44	26	29	20	35	23	50	28
20	40	24	28	--	34	22	47	27
22	38	23	27	--	33	21	44	26
24	37	21	26	--	32	20	41	25
26	36	20	25	--	31	--	39	24
28	35	--	24	--	30	--	38	22
30	34	--	23	--	29	--	37	21
32	33	--	23	--	28	--	36	20

END QUENCH HARDENABILITY BAND DATA

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

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	5135 H		5140 H		5145 H		5147 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	58	51	60	53	63	56	64	57
2	57	49	59	52	62	55	64	56
3	56	47	58	50	61	53	63	55
4	55	43	57	48	60	51	62	54
5	54	38	56	43	59	48	62	53
6	52	35	54	38	58	42	61	52
7	50	32	52	35	57	38	61	49
8	47	30	50	33	56	35	60	45
9	45	28	48	31	55	33	60	40
10	43	27	46	30	53	32	59	37
11	41	25	45	29	52	31	59	35
12	40	24	43	28	50	30	58	34
13	39	23	42	27	48	30	58	33
14	38	22	40	27	47	29	57	32
15	37	21	39	26	45	28	57	32
16	37	21	38	25	44	28	56	31
18	36	20	37	24	42	26	55	30
20	35	--	36	23	41	25	54	29
22	34	--	35	21	39	24	53	27
24	33	--	34	20	38	23	52	26
26	32	--	34	--	37	22	51	25
28	32	--	33	--	37	21	50	24
30	31	--	33	--	36	--	49	22
32	30	--	32	--	35	--	48	21

END QUENCH HARDENABILITY BAND DATA

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

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	6118 H		6150 H		81B45 H		8617 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	46	39	65	59	63	56	46	39
2	44	36	65	58	63	56	44	33
3	38	28	64	57	63	56	41	27
4	33	24	64	56	63	56	38	24
5	30	22	63	55	63	55	34	20
6	28	20	63	53	63	54	31	--
7	27	--	62	50	62	53	28	--
8	26	--	61	47	62	51	27	--
9	26	--	61	43	61	48	26	--
10	25	--	60	41	60	44	25	--
11	25	--	59	39	60	41	24	--
12	24	--	58	38	59	39	23	--
13	24	--	57	37	58	38	23	--
14	23	--	55	36	57	37	22	--
15	23	--	54	35	57	36	22	--
16	22	--	52	35	56	35	21	--
18	22	--	50	34	55	34	21	--
20	21	--	48	32	53	32	20	--
22	21	--	47	31	52	31	--	--
24	20	--	46	30	50	30	--	--
26	--	--	45	29	49	29	--	--
28	--	--	44	27	47	28	--	--
30	--	--	43	26	45	28	--	--
32	--	--	42	25	43	27	--	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	8620 H		8622 H		8625 H		8627 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	48	41	50	43	52	45	54	47
2	47	37	49	39	51	41	52	43
3	44	32	47	34	48	36	50	38
4	41	27	44	30	46	32	48	35
5	37	23	40	26	43	29	45	32
6	34	21	37	24	40	27	43	29
7	32	--	34	22	37	25	40	27
8	30	--	32	20	35	23	38	26
9	29	--	31	--	33	22	36	24
10	28	--	30	--	32	21	34	24
11	27	--	29	--	31	20	33	23
12	26	--	28	--	30	--	32	22
13	25	--	27	--	29	--	31	21
14	25	--	26	--	28	--	30	21
15	24	--	26	--	28	--	30	20
16	24	--	25	--	27	--	29	20
18	23	--	25	--	27	--	28	--
20	23	--	24	--	26	--	28	--
22	23	--	24	--	26	--	28	--
24	23	--	24	--	26	--	27	--
26	23	--	24	--	26	--	27	--
28	22	--	24	--	25	--	27	--
30	22	--	24	--	25	--	27	--
32	22	--	24	--	25	--	27	--

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	8630 H		86B30 H		8637 H		8640 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	56	49	56	49	59	52	60	53
2	55	46	55	49	58	51	60	53
3	54	43	55	48	58	50	60	52
4	52	39	55	48	57	48	59	51
5	50	35	54	48	56	45	59	49
6	47	32	54	48	55	42	58	46
7	44	29	53	48	54	39	57	42
8	41	28	53	47	53	36	55	39
9	39	27	52	46	51	34	54	36
10	37	26	52	44	49	32	52	34
11	35	25	52	42	47	31	50	32
12	34	24	51	40	46	30	49	31
13	33	23	51	39	44	29	47	30
14	33	22	50	38	43	28	45	29
15	32	22	50	36	41	27	44	28
16	31	21	49	35	40	26	42	28
18	30	21	48	34	39	25	41	26
20	30	20	47	32	37	25	39	26
22	29	20	45	31	36	24	38	25
24	29	--	44	29	36	24	38	25
26	29	--	43	28	35	24	37	24
28	29	--	41	27	35	24	37	24
30	29	--	40	26	35	23	37	24
32	29	--	39	25	35	23	37	24

END QUENCH HARDENABILITY BAND DATA

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

END QUENCH HARDENABILITY BAND DATA

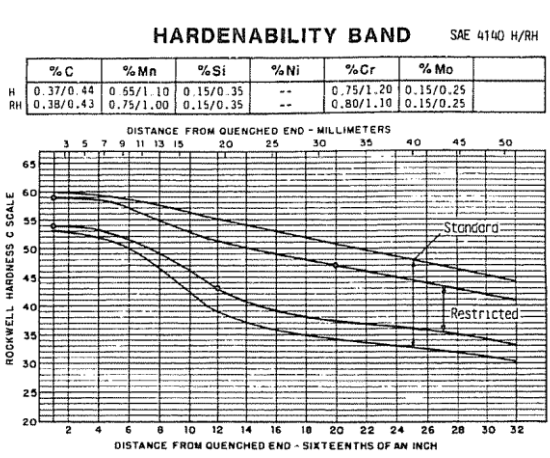
"J" Distance (Sixteenths of an inch)	Grade							
	8655 H		8660 H		8720 H		8740 H	
	Max	Min	Max	Min	Max	Min	Max	Min
1	--	60	--	60	48	41	60	53
2	--	59	--	60	47	38	60	53
3	--	59	--	60	45	35	60	52
4	--	58	--	60	42	30	60	51
5	--	57	--	60	39	26	59	49
6	--	56	--	59	35	24	58	46
7	--	55	--	58	33	22	57	43
8	--	54	--	57	31	21	56	40
9	--	52	--	55	30	20	55	37
10	65	49	--	53	29	--	53	35
11	65	46	--	50	28	--	52	34
12	64	43	--	47	27	--	50	32
13	64	41	--	45	26	--	49	31
14	63	40	--	44	26	--	48	31
15	63	39	--	43	25	--	46	30
16	62	38	65	42	25	--	45	29
18	61	37	64	40	24	--	43	28
20	60	35	64	39	24	--	42	28
22	59	34	63	38	23	--	41	27
24	58	34	62	37	23	--	40	27
26	57	33	62	36	23	--	39	27
28	56	33	61	36	23	--	39	27
30	55	32	60	35	22	--	38	26
32	53	32	60	35	22	--	38	26

END QUENCH HARDENABILITY BAND DATA

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

END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade			
	94B17 H		94B30 H	
	Max	Min	Max	Min
1	46	39	56	49
2	46	39	56	49
3	45	38	55	48
4	45	37	55	48
5	44	34	54	47
6	43	29	54	46
7	42	26	53	44
8	41	24	53	42
9	40	23	52	39
10	38	21	52	37
11	36	20	51	34
12	34	--	51	32
13	33	--	50	30
14	32	--	49	29
15	31	--	48	28
16	30	--	46	27
18	28	--	44	25
20	27	--	42	24
22	26	--	40	23
24	25	--	38	23
26	24	--	37	22
28	24	--	35	21
30	23	--	34	21
32	23	--	34	20



Restricted hardenability (RH) steels are desirable to provide more controlled heat treatment response and dimensional control for critical parts. In general, RH steels will exhibit a hardness range not greater than 5 HRC at the initial position on the end-quench hardenability bar and not greater than 65% of the hardness range for standard H-band steels in the inflection region. Generally, the RH-band follows the middle of the corresponding standard H-band. An example of the RH-band compared with the standard H-band is given for a standard SAE 4140 in the figure to the left.

RH-band steels shall be within the minimum and maximum HRC range specified at the J1 position and shall meet one additional minimum and one additional maximum HRC value. In the following tables, the two additional hardness values shall represent the approximate hardness for 50% martensite for the minimum and maximum specified carbon content, respectively (except where hardenability is too high to exhibit 50% martensite hardness; then the two points shall be 5 HRC below the minimum and maximum hardness specified at the J1 position. These points are outlined in boxes in the following tables.

RESTRICTED END QUENCH HARDENABILITY BAND DATA

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

RESTRICTED END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4118 RH		4120 RH		4130 RH		4140 RH	
	Max	Min	Max	Min	Max	Min	Max	Min
1	47	42	47	42	55	50	59	54
2	44	38	45	39	54	48	59	54
3	38	30	41	35	52	44	59	54
4	33	25	38	30	49	40	59	53
5	29	22	34	26	46	36	58	52
6	27	20	31	24	44	34	57	51
7	25	--	29	22	41	32	56	50
8	24	--	28	21	39	30	55	49
9	23	--	26	20	37	28	54	48
10	22	--	25	--	35	27	53	46
11	21	--	24	--	33	26	52	44
12	20	--	23	--	32	26	52	43
13	--	--	23	--	32	26	51	42
14	--	--	22	--	31	25	50	41
15	--	--	22	--	31	25	50	40
16	--	--	21	--	31	25	49	39
18	--	--	20	--	30	24	48	38
20	--	--	--	--	30	23	47	37
22	--	--	--	--	30	23	46	37
24	--	--	--	--	29	22	45	36
26	--	--	--	--	29	22	44	35
28	--	--	--	--	28	21	43	35
30	--	--	--	--	28	21	42	34
32	--	--	--	--	27	20	41	33

RESTRICTED END QUENCH HARDENABILITY BAND DATA

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

RESTRICTED END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade							
	4820 RH		50B40 RH		5130 RH		5140 RH	
	Max	Min	Max	Min	Max	Min	Max	Min
1	47	42	59	54	55	50	59	54
2	47	42	59	54	53	47	58	53
3	46	41	58	53	51	44	57	51
4	45	40	58	53	49	41	55	49
5	43	36	57	52	46	37	53	45
6	41	33	56	50	44	35	51	41
7	40	32	55	47	42	33	48	38
8	38	30	54	43	39	31	46	36
9	36	28	52	38	37	29	44	34
10	35	27	50	35	35	27	43	33
11	34	26	49	33	34	26	41	32
12	33	25	47	32	33	25	40	31
13	32	24	45	31	32	24	39	30
14	31	24	44	30	31	23	37	29
15	30	23	41	29	30	22	36	28
16	29	23	38	28	29	21	35	27
18	28	22	36	26	28	20	34	26
20	27	22	34	24	27	--	33	25
22	26	21	33	23	26	--	32	24
24	25	20	32	22	25	--	31	23
26	25	20	31	21	24	--	30	22
28	25	--	30	20	23	--	30	21
30	24	--	29	--	22	--	29	20
32	23	--	28	--	21	--	29	--

RESTRICTED END QUENCH HARDENABILITY BAND DATA

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

RESTRICTED END QUENCH HARDENABILITY BAND DATA

"J" Distance (Sixteenths of an inch)	Grade			
	8822 RH		9310 RH	
	Max	Min	Max	Min
1	49	44	42	37
2	48	43	42	36
3	47	40	42	36
4	43	35	41	35
5	40	31	41	34
6	37	29	40	33
7	35	27	40	32
8	33	26	39	31
9	32	25	38	30
10	31	25	37	29
11	30	24	37	29
12	30	23	36	28
13	29	23	35	28
14	28	23	34	28
15	28	22	34	28
16	27	22	33	27
18	27	21	33	27
20	26	20	32	26
22	26	--	32	26
24	26	--	32	26
26	26	--	32	26
28	25	--	32	26
30	25	--	31	25
32	25	--	31	25

LIMITING VALUES FOR STEEL GRADES WITH (NORMAL) HARDNESS REQUIRMENTS (+H GRADES)

(EN 10083-1:1996)

Steel Designation		Distance, in mm, from Quenched End, in HRC															
Name	**Symbol**	**Limit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**13**	**15**	**20**	**25**	**30**
C35E	+H	max	58	57	55	53	49	41	34	31	28	27	26	25	24	23	20	…
C35R		min	48	40	33	24	22	20	…	…	…	…	…	…	…	…	…	…
C40E	+H	max	60	60	59	57	53	47	39	34	31	30	29	28	27	26	25	24
C40R		min	51	46	35	27	25	24	23	22	21	20	…	…	…	…	…	…
C45E	+H	max	62	61	61	60	57	51	44	37	34	33	32	31	30	29	28	27
C45R		min	55	51	37	30	28	27	26	25	24	23	22	21	20	…	…	…
C50E	+H	max	63	62	61	60	58	55	50	43	36	35	34	33	32	31	29	28
C50R		min	56	53	44	34	31	30	30	29	28	27	26	25	24	23	20	…
C55E	+H	max	65	64	63	62	60	57	52	45	37	36	35	34	33	32	30	29
C55R		min	58	55	47	37	33	32	31	30	29	28	27	26	25	24	22	20
C60E	+H	max	67	66	65	63	62	59	54	47	39	37	36	35	34	33	31	30
C60R		min	60	57	50	39	35	33	32	31	30	29	28	27	26	25	23	21

LIMITING VALUES FOR STEEL GRADES WITH (NORMAL) HARDNESS REQUIRMENTS (+H GRADES)

(EN 10083-1:1996)

Steel Designation		Distance, in mm, from Quenched End, in HRC															
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
28Mn6	+H	max	54	53	51	48	44	41	38	35	31	29	27	26	25	25	24
		min	45	42	37	27	21	...	...	...	...	...	...	...	...	...	...
38Cr2	+H	max	59	57	54	49	43	39	37	35	32	30	27	25	24	23	22
38CrS2		min	51	46	37	29	25	22	20	...	...	...	...	...	...	...	...
46Cr2	+H	max	63	61	59	57	53	47	42	39	36	33	32	31	30	29	29
46CrS2		min	54	49	40	32	28	25	23	22	20	...	...	...	...	...	...
34Cr4	+H	max	57	57	56	54	52	49	46	44	39	37	35	34	33	32	31
34CrS4		min	49	48	45	41	35	32	29	27	23	21	20	...	...	...	...
37Cr4	+H	max	59	59	58	57	55	52	50	48	42	39	37	36	35	34	33
37CrS4		min	51	50	48	44	39	36	33	31	26	24	22	20	...	...	...
41Cr4	+H	max	61	61	60	59	58	56	54	52	46	42	40	38	37	36	35
41CrS4		min	53	52	50	47	41	37	34	32	29	26	23	21	...	...	...
25CrMo4	+H	max	52	52	51	50	48	46	43	41	37	35	33	32	31	31	31
25CrMoS4		min	44	43	40	37	34	32	29	27	23	21	20	...	...	...	...
34CrMo4	+H	max	57	57	57	56	55	54	53	52	48	45	43	41	40	40	39
34CrMoS4		min	49	49	48	45	42	39	36	34	30	28	27	26	25	24	24

LIMITING VALUES FOR STEEL GRADES WITH (NORMAL) HARDNESS REQUIRMENTS (+H GRADES)

(EN 10083-1:1996)

Steel Designation			Distance, in mm, from Quenched End, in HRC														
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
42CrMo4	+H	max	61	61	61	60	60	59	59	58	56	53	51	48	47	46	45
42CrMoS4		min	53	53	52	51	49	43	40	37	34	32	31	30	30	29	29
50CrMo4	+H	max	65	65	64	64	63	63	63	62	61	60	58	57	55	54	54
		min	58	58	57	55	54	53	51	48	45	41	39	38	37	36	36
36CrNiMo4	+H	max	59	59	58	58	57	57	57	56	55	54	53	52	51	50	49
		min	51	50	49	49	48	47	46	45	43	41	39	38	36	34	33
34CrNiMo6	+H	max	58	58	58	58	57	57	57	57	57	57	57	57	57	57	57
		min	50	50	50	50	49	48	48	48	48	47	47	47	46	45	44
30CrNiMo8	+H	max	56	56	56	56	55	55	55	55	55	54	54	54	54	54	54
		min	48	48	48	48	47	47	47	46	46	45	45	44	44	43	43
36NiCrMo16	+H	max	57	56	56	56	56	56	55	55	55	55	55	55	55	55	55
		min	50	49	48	48	48	48	47	47	47	47	47	47	47	47	47
51CrV4	+H	max	65	65	64	64	63	63	63	62	62	62	61	60	60	59	58
		min	57	56	56	55	53	52	50	48	44	41	37	35	34	33	32

[1] The hardenability values for the unalloyed steels are provisional and may be reviewed as more information becomes available. If the hardenability scatter for the H grade of the relevant steel of a manufacturer exceeds the limits given above, the manufacturer shall inform the purchaser accordingly at the time of ordering.

LIMITING VALUES FOR HIGH MN AND ALLOY STEELS WITH RESTRICTED SCATTERBANDS

(EN 10083-1:1996)

Steel Designation		Distance (mm) from Quenched End Hardness, in HRC															
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
28Mn6	**+HH**	max	54	53	51	48	44	41	38	35	31	29	27	26	25	25	24
		min	48	46	42	34	30	27	24	21	…	…	…	…	…	…	…
	+HL	max	51	49	46	41	35	32	29	26	22	20	…	…	…	…	…
		min	45	42	37	27	21	…	…	…	…	…	…	…	…	…	…
38Cr2 38CrS2	**+HH**	max	59	57	54	49	43	39	37	35	32	30	27	25	24	23	22
		min	54	50	43	36	31	28	26	24	21	…	…	…	…	…	…
	+HL	max	56	53	48	42	37	33	31	29	26	24	21	…	…	…	…
		min	51	46	37	29	25	22	20	…	…	…	…	…	…	…	…
46Cr2 46CrS2	**+HH**	max	63	61	59	57	53	47	42	39	36	33	32	31	30	29	29
		min	57	53	46	40	36	32	29	28	25	22	21	20	…	…	…
	+HL	max	60	57	53	49	45	40	36	33	31	28	27	26	25	24	24
		min	54	49	40	32	28	25	23	22	20	…	…	…	…	…	…
34Cr4 34CrS4	**+HH**	max	57	57	56	54	52	49	46	44	39	37	35	34	33	32	31
		min	52	51	49	45	41	38	35	33	28	26	25	24	23	22	21
	+HL	max	54	54	52	50	46	43	40	38	34	32	30	29	28	27	26
		min	49	48	45	41	35	32	29	27	23	21	20	…	…	…	…

LIMITING VALUES FOR HIGH MN AND ALLOY STEELS WITH RESTRICTED SCATTERBANDS

(EN 10083-1:1996)

Steel Designation		Distance (mm) from Quenched End Hardness, in HRC															
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
37Cr4 37CrS4	**+HH**	max	59	59	58	57	55	52	50	48	42	39	37	36	35	34	33
		min	54	53	51	48	44	41	39	37	31	29	27	25	24	23	22
	+HL	max	56	56	55	53	50	47	44	42	37	34	32	31	30	29	28
		min	51	50	48	44	39	36	33	31	26	24	22	20	...	...	...
41Cr4 41CrS4	**+HH**	max	61	61	60	59	58	56	54	52	46	42	40	38	37	36	35
		min	56	55	53	51	47	43	41	39	35	31	29	27	26	25	24
	+HL	max	58	58	57	55	52	50	47	45	40	37	34	32	31	30	29
		min	53	52	50	47	41	37	34	32	29	26	23	21	...	...	...
25CrMo4 25CrMoS4	**+HH**	max	52	52	51	50	48	46	43	41	37	35	33	32	31	31	31
		min	47	46	44	41	39	37	344	32	28	26	24	23	22	22	22
	+HL	max	49	49	47	46	43	41	38	36	32	30	29	28	27	27	27
		min	44	43	40	37	34	32	29	27	23	21	20	**...**	**...**	**...**	**...**
34CrMo4 34CrMoS4	**+HH**	max	57	57	57	56	55	54	53	52	48	45	43	41	40	40	39
		min	52	52	51	49	46	44	42	40	36	34	32	31	30	29	29
	+HL	max	54	54	54	52	51	49	47	46	42	39	38	36	35	35	34
		min	49	49	48	45	42	39	36	34	30	28	27	26	25	24	24

LIMITING VALUES FOR HIGH MN AND ALLOY STEELS WITH RESTRICTED SCATTERBANDS

(EN 10083-1:1996)

Steel Designation		Distance (mm) from Quenched End Hardness, in HRC															
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
42CrMo4 42CrMoS4	**+HH**	max	61	61	61	60	60	59	59	58	56	53	51	48	47	46	45
		min	56	56	55	54	52	48	46	44	41	39	38	36	36	35	34
	+HL	max	58	58	58	57	56	54	53	51	49	46	44	42	41	40	40
		min	53	53	52	51	49	43	40	37	34	32	31	30	30	29	29
50CrMo4	**+HH**	max	65	65	64	64	63	63	63	62	61	60	58	57	55	54	54
		min	60	60	59	58	57	56	55	53	50	47	45	44	43	42	42
	+HL	max	63	63	62	61	60	60	59	57	56	54	52	51	49	48	48
		min	58	58	57	55	54	53	51	48	45	41	39	38	37	36	36
36CrNiMo4	**+HH**	max	59	59	58	58	57	57	57	56	55	54	53	52	51	50	49
		min	54	53	52	52	51	50	50	49	47	45	44	43	41	39	38
	+HL	max	56	56	55	55	54	54	53	52	51	50	48	47	46	45	44
		min	51	50	49	49	48	47	46	45	43	41	39	38	36	34	33
34CrNiMo6	**+HH**	max	58	58	58	58	57	57	57	57	57	57	57	57	57	57	57
		min	53	53	53	53	52	51	51	51	51	50	50	50	50	49	48
	+HL	max	55	55	55	55	54	54	54	54	54	54	54	54	53	53	53
		min	50	50	50	50	49	48	48	48	48	47	47	47	46	45	44

LIMITING VALUES FOR HIGH MN AND ALLOY STEELS WITH RESTRICTED SCATTERBANDS

(EN 10083-1:1996)

Steel Designation		Distance (mm) from Quenched End Hardness, in HRC															
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
30CrNiMo8	**+HH**	max	56	56	56	56	55	55	55	55	55	54	54	54	54	54	54
		min	51	51	51	51	50	50	50	49	49	48	48	47	47	47	47
	+HL	max	53	53	53	53	52	52	52	52	52	51	51	51	51	50	50
		min	48	48	48	48	47	47	47	46	46	45	45	44	44	43	43
36NiCrMo16	**+HH**	max	57	56	56	56	56	56	56	55	55	55	55	55	55	55	55
		min	52	51	51	51	51	51	51	50	50	50	50	50	50	50	50
	+HL	max	55	54	53	53	53	53	53	52	52	52	52	52	52	52	52
		min	50	49	48	48	48	48	48	47	47	47	47	47	47	47	47
51CrV4	**+HH**	max	65	65	64	64	63	63	63	62	62	62	61	60	60	59	58
		min	60	59	59	58	56	56	54	53	50	48	45	43	43	42	41
	+HL	max	62	62	61	61	60	59	59	57	56	55	53	52	51	50	49
		min	57	56	56	55	53	52	50	48	44	41	37	35	34	33	32

LIMITING VALUES FOR STEEL GRADES WITH (NORMAL) HARDENABILITY REQUIREMENTS

(EN 10083-3:1995)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece												
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
20MnB5	**+H**	max	50	49	49	49	47	45	43	41	33	27	…	…	…
		min	42	41	40	37	30	22	20	…	…	…	…	…	…
30MnB5	**+H**	max	56	55	55	54	53	51	50	47	40	37	33	…	…
		min	47	46	45	44	42	39	36	31	22	…	…	…	…
38MnB5	**+H**	max	60	60	59	58	57	57	55	53	48	41	37	33	31
		min	52	51	50	49	47	44	41	35	28	24	20	…	…
27MnCrB5-2	**+H**	max	55	55	55	54	54	53	52	51	47	44	40	37	…
		min	47	46	45	44	43	41	39	36	30	24	20	…	…
33MnCrB5-2	**+H**	max	57	57	57	57	57	56	55	54	53	50	47	45	…
		min	48	47	47	46	45	44	43	41	36	31	25	20	…
39MnCrB6-2	**+H**	max	59	59	59	59	58	58	58	58	57	57	56	55	54
		min	51	51	51	51	50	50	50	49	47	45	40	35	32

HARDNESS LIMITS FOR STEEL TYPES WITH SPECIFIED (NORMAL) HARDENABILITY

(EN 10084-1998)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece												
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
17C3	**+H**	max	47	44	40	33	29	27	25	24	23	21	...	...	...
17CrS3		min	39	35	25	20	...	...	...	...	...	...	...	...	...
28Cr4	**+H**	max	53	52	51	49	45	42	39	36	33	30	29	28	27
28CrS4		min	45	43	39	29	25	22	20	...	...	...	...	...	...
16MnCr5	**+H**	max	47	46	44	41	39	37	35	33	31	30	29	28	27
16MnCrS5		min	39	36	31	28	24	21	...	...	...	...	...	...	...
16MnCrB5	**+H**	max	47	46	44	41	39	37	35	33	31	30	29	28	27
		min	39	36	31	28	24	21	...	...	...	...	...	...	...
20MnCr5	**+H**	max	49	49	48	46	43	42	41	39	37	35	34	33	32
20MnCr5S		min	41	39	36	33	30	28	26	25	23	21	...	...	...
18CrMo4	**+H**	max	47	46	45	42	39	37	35	34	31	29	28	27	26
18CrMoS4		min	39	37	34	30	27	24	22	21	...	...	...	...	...
22CrMoS3-5	**+H**	max	50	49	48	47	45	43	41	40	37	35	34	33	32
		min	42	41	37	33	31	28	26	25	23	22	21	20	...
20MoCr3	**+H**	max	49	47	45	40	35	32	31	30	28	26	25	24	23
20MoCrS3		min	41	38	34	28	22	20	...	...	...	...	...	...	...

HARDNESS LIMITS FOR STEEL TYPES WITH SPECIFIED (NORMAL) HARDENABILITY

(EN 10084-1998)

Steel Designation			Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece												
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
20MoCr4	**+H**	max	49	47	44	41	38	35	33	31	28	26	25	24	24
20MoCrS4		min	41	37	31	27	24	22	...	...	...	...	...	...	...
16NiCr4	**+H**	max	47	46	44	42	40	38	36	34	32	30	29	28	28
16NiCrS4		min	39	36	33	29	27	25	23	22	20	...	...	...	...
10NiCr5-4	**+H**	max	41	39	37	34	32	30	...	...	...	...	...	...	...
		min	33	27	24	22	...	...	...	...	...	...	...	...	...
18NiCr5-4	**+H**	max	49	48	46	44	42	39	37	35	34	32	31	31	30
		min	41	39	35	32	29	27	25	24	21	20	...	...	...
17CrNi6-6	**+H**	max	47	47	46	45	43	42	41	39	37	35	34	34	33
		min	39	38	36	35	32	30	28	26	24	22	21	20	20
15NiCr13	**+H**	max	48	48	48	47	45	44	42	41	38	35	34	34	33
		min	41	41	41	40	38	36	33	30	24	22	22	21	21
20NiCrMo2-2	**+H**	max	49	48	45	42	36	33	31	30	27	25	24	24	23
20NiCrMoS2-2		min	41	37	31	25	22	20	...	...	...	...	...	...	...
17NiCrMo6-4	**+H**	max	48	48	47	46	45	44	42	41	38	36	35	34	33
17NiCrMo6-4		min	40	40	37	34	30	28	27	26	24	23	22	21	...

HARDNESS LIMITS FOR STEEL TYPES WITH SPECIFIED (NORMAL) HARDENABILITY

(EN 10084-1998)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece												
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
20NiCrMoS6-4	**+H**	max	49	49	48	48	47	47	46	44	41	39	38	37	36
		min	41	40	39	36	33	30	28	26	23	21	…	…	…
18CrNiMo7-6	**+H**	max	48	48	48	48	47	47	46	46	44	43	42	41	41
		min	40	40	39	38	37	36	35	34	32	31	30	29	29
14NiCrMo13-4	**+H**	max	47	47	46	46	46	46	46	45	43	42	40	39	38
		min	39	39	37	36	36	36	35	33	31	30	28	27	26

HARDNESS LIMITS FOR STEEL TYPES WITH RESTRICTED HARDENABILITY SCATTERBANDS (HH AND HL GRADES)

(EN 10084-1998)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece													
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
17Cr3 17Cr3S	**+HH**	max	47	44	40	33	29	27	25	24	23	21	…	…	…
		min	42	38	30	24	20	…	…	…	…	…	…	…	…
	+HL	max	44	41	35	29	25	23	21	20	…	…	…	…	…
		min	39	35	25	20	…	…	…	…	…	…	…	…	…
28Cr4 28CrS4	**+HH**	max	53	52	51	49	45	42	39	36	33	30	29	28	27
		min	48	46	43	36	32	29	26	23	20	…	…	…	…
	+HL	max	50	49	47	42	38	35	33	30	27	24	23	22	21
		min	45	43	39	29	25	22	20	…	…	…	…	…	…
16MnCr5 16MnCrS5	**+HH**	max	47	46	44	41	39	37	35	33	31	30	29	28	27
		min	42	39	35	32	29	26	24	22	20	…	…	…	…
	+HL	max	44	43	40	37	34	32	30	28	26	25	24	23	22
		min	39	36	31	28	24	21	…	…	…	…	…	…	…
16MnCrB5	**+HH**	max	47	46	44	41	39	37	35	33	31	30	29	28	27
		min	42	39	35	32	29	26	24	22	20	…	…	…	…
	+HL	max	44	43	40	37	34	32	30	28	26	25	24	23	22
		min	39	36	31	28	24	21	…	…	…	…	…	…	…

HARDNESS LIMITS FOR STEEL TYPES WITH RESTRICTED HARDENABILITY SCATTERBANDS (HH AND HL GRADES)

(EN 10084-1998)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece												
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
20MnCr5 20MnCrS5	**+HH**	max	49	49	48	46	43	42	41	39	37	35	34	33	32
		min	44	42	40	37	34	33	31	30	28	26	25	24	23
	+HL	max	46	46	44	42	39	37	36	34	32	30	29	28	27
		min	41	39	36	33	30	28	26	25	23	21	…	…	…
18CrMo4 18CrMoS4	**+HH**	max	47	46	45	42	39	37	35	34	31	29	28	27	26
		min	42	40	38	34	31	28	26	25	22	20	…	…	…
	+HL	max	44	43	41	38	35	33	31	30	27	25	24	23	22
		min	39	37	34	30	27	24	22	21	…	…	…	…	…
22CrMoS3-5	**+HH**	max	50	49	48	47	45	43	41	40	37	35	34	33	32
		min	45	44	41	38	36	33	31	30	28	26	25	24	23
	+HL	max	47	46	44	42	40	38	36	35	32	31	30	29	28
		min	42	41	37	33	31	28	26	25	23	22	21	20	…
20MoCr3 20MoCrS3	**+HH**	max	49	47	45	40	35	32	31	30	28	26	25	24	23
		min	44	41	38	32	26	24	23	22	20	…	…	…	…
	+HL	max	46	44	41	36	31	28	27	26	24	22	21	20	…
		min	41	38	34	28	22	20	…	…	…	…	…	…	…

HARDNESS LIMITS FOR STEEL TYPES WITH RESTRICTED HARDENABILITY SCATTERBANDS (HH AND HL GRADES)

(EN 10084-1998)

Steel Designation			Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece												
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
20MoCr4 20MoCrS4	**+HH**	**max**	49	47	44	41	38	35	33	31	28	26	25	24	24
		min	44	40	35	32	29	26	24	22	…	…	…	…	…
	+HL	**max**	46	44	40	36	33	31	29	27	24	22	21	20	20
		min	41	37	31	27	24	22	…	…	…	…	…	…	…
16NiCr4 16NiCrS4	**+HH**	**max**	47	46	44	42	40	38	36	34	32	30	29	28	28
		min	42	39	37	33	31	29	27	26	24	22	21	20	20
	+HL	**max**	44	43	40	38	36	34	32	30	28	26	25	24	24
		min	39	36	33	29	27	25	23	22	20	…	…	…	…
10NiCr5-4	**+HH**	**max**	41	39	37	34	32	30	…	…	…	…	…	…	…
		min	33	29	26	24	21	20	…	…	…	…	…	…	…
	+HL	**max**	38	35	32	30	27	25	…	…	…	…	…	…	…
		min	32	27	24	22	…	…	…	…	…	…	…	…	…
18NiCr5-4	**+HH**	**max**	49	48	46	44	42	39	37	36	34	32	31	31	30
		min	44	42	39	36	33	31	29	28	25	24	23	23	22
	+HL	**max**	46	45	42	40	38	35	33	32	30	28	27	27	26
		min	41	39	35	32	29	27	25	24	21	20	…	…	…

HARDNESS LIMITS FOR STEEL TYPES WITH RESTRICTED HARDENABILITY SCATTERBANDS (HH AND HL GRADES)

(EN 10084-1998)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece													
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
17CrNi6-6	**+HH**	max	47	47	46	45	43	42	41	39	37	35	34	34	33
		min	42	41	39	38	36	34	32	30	28	26	25	25	24
	+HL	max	44	44	43	42	39	38	37	35	33	31	30	29	29
		min	39	38	36	35	32	30	28	26	24	22	21	20	20
15NiCr13	**+HH**	max	48	48	48	47	45	44	42	41	38	35	34	34	33
		min	43	43	43	42	40	39	36	34	29	26	26	25	25
	+HL	max	46	46	46	45	43	41	38	37	33	31	30	30	29
		min	41	41	41	40	38	36	33	30	24	22	22	21	21
20NiCrMo2-2 **20NiCrMoS2-2**	**+HH**	max	49	48	45	42	36	33	31	30	27	25	24	24	23
		min	44	41	36	31	27	24	22	21	...	...	...	...	...
	+HL	max	46	44	40	36	31	29	27	26	23	21	20	20	...
		min	47	37	31	25	22	20	...	...	...	...	...	...	...
17NiCrMo6-4 **17NiCrMoS6-4**	**+HH**	max	48	48	47	46	45	44	42	41	38	36	35	34	33
		min	43	43	40	38	35	33	32	31	29	27	26	25	24
	+HL	max	45	45	44	42	40	39	37	36	33	32	31	30	29
		min	40	40	37	34	30	28	27	26	24	23	22	21	...

HARDNESS LIMITS FOR STEEL TYPES WITH RESTRICTED HARDENABILITY SCATTERBANDS (HH AND HL GRADES)

(EN 10084-1998)

Steel Designation		Hardness (HRC) at a Distance (mm) from Quenched End of Test Piece													
Name	**Symbol**	**Limit**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**20**	**25**	**30**	**35**	**40**
20NiCrMoS6-4	**+HH**	max	49	49	48	48	47	47	46	44	41	39	38	37	36
		min	44	43	42	40	38	36	34	32	29	27	26	25	24
	+HL	max	46	46	45	44	42	41	40	38	35	33	32	31	30
		min	41	40	39	36	33	30	28	26	23	21	...	...	...
18CrNiMo7-6	**+HH**	max	48	48	48	48	47	47	46	46	44	43	42	41	41
		min	43	43	42	41	40	40	39	38	36	35	34	33	33
	+HL	max	45	45	45	45	44	43	42	42	40	39	38	37	37
		min	40	40	39	38	37	36	35	34	32	31	30	29	29
14NiCrMo13-4	**+HH**	max	47	47	46	46	46	46	46	45	43	42	40	39	38
		min	42	42	40	39	39	39	39	37	35	34	32	31	30
	+HL	max	44	44	43	43	43	43	42	41	39	38	36	35	34
		min	39	39	37	36	36	36	35	33	31	30	28	27	26

NOTES

CARBON STEEL FORGINGS FOR PIPING APPLICATIONS

(ASTM A 105/A 105M – 09)

Property	Value
Tensile Strength, min, ksi [MPa]	70 [485]
Yield Strength, min, ksi [MPa][A]	36 [250]
Elongation in 2 in. [50mm], min, %[B]	22
Reduction of Area, min, %	30
Hardness, HBN, max[C]	187

[A] Determined by either the 0.2% offset method or 0.5% extension-under-load method.

[B] When standard round 2 in. or 50mm gage length or smaller proportionally sized specimen with the gage length equal to 4D is used.

[C] The hardness range shall be 137-187 HBN.

CARBON AND LOW-ALLOY STEEL FORGINGS REQUIRING NOTCH TOUGHNESS TESTING FOR PIPING COMPONENTS

(ASTM A 350/A 350M – 07)

Grade	Tensile Strength, ksi [MPa]	Yield Strength, min, ksi [MPa]	Elongation, min, %	Reduction of Area, min, %
LF1	60-85 [415-485]	30 [205]	25	38
LF5 Class 1	60-85 [415-485]	30 [205]	25	38
LF2 Class 1 & 2	70-95 [485-655]	36 [250]	22	30
LF3 Class 1 & 2	70-95 [485-655]	37.5 [260]	22	30
LF5 Class 2	70-95 [485-655]	37.5 [260]	22	30
LF6 Class 1	66-91 [455-630]	52 [360]	22	30
LF6 Class 2 & 3	75-100 [515-690]	60 [415]	20	28
LF9	63-88 [435-605]	46 [315]	25	28
LF787 Class 2	65-85 [450-585]	55 [380]	20	28
LF787 Class 3	75-95 [515-655]	65 [450]	20	28

HOT ROLLED OR COLD FINISHED QUENCHED AND TEMPERED BARS

(ASTM A 434 – 06)

Class	Diameter, in. [mm]	Yield Strength, min, ksi [MPa][A]	Tensile Strength, min, ksi [MPa]	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %	Representative Grade[B]
BB[C]	1-1/2 [38.1] and under	90 [620]	110 [760]	20	50	3100, 4100, 8600, 8700
	Over 1-1/2 to 2-1/2 [38.1 to 63.5], incl	80 [550]	105 [720]	20	50	
	Over 2-1/2 to 4 [63.5 to 114], incl	75 [520]	100 [690]	20	50	
	Over 4 to 7 [114 to 178], incl	75 [520]	95 [660]	20	50	
	Over 7 to 9-1/2 [178 to 241.3], incl	65 [450]	90 [260]	18	40	
BC[C]	1-1/2 [38.1] and under	110 [760]	130 [900]	16	50	3100, 4100, 6100, 8600, 8700
	Over 1-1/2 to 2-1/2 [38.1 to 63.5], incl	105 [720]	125 [860]	16	50	
	Over 2-1/2 to 4 [63.5 to 114], incl	95 [660]	115 [790]	16	45	
	Over 4 to 7 [114 to 178], incl	85 [590]	110 [760]	16	45	3100, 4100, 4300, 9800
	Over 7 to 9-1/2 [178 to 241.3], incl	80 [550]	105 [720]	15	40	
BD[C]	1-1/2 [38.1] and under	130 [900]	155 [1070]	14	35	4100, 4300, 9800
	Over 1-1/2 to 2-1/2 [38.1 to 63.5], incl	120 [830]	150 [1030]	14	35	
	Over 2-1/2 to 4 [63.5 to 114], incl	110 [760]	140 [960]	14	35	
	Over 4 to 7 [114 to 178], incl	105 [720]	135 [930]	14	35	
	Over 7 to 9-1/2 [178 to 241.3], incl	100 [690]	130 [900]	14	35	

[A] Determined by the 0.2% offset method.

[B] Refers to standard AISI or SAE grade. Carbon content of all steels in this column may vary up to 0.55% max, as agreed upon by the manufacturer and the purchaser.

[C] Class BB, BC, BD hot-wrought; Class BB, BC cold-finished (Mechanical properties of hot-wrought bars ordered for cold finishing shall be governed by the cold-finished size).

ALLOY STEELS FOR HIGH/LOW TEMPERATURE FLANGES

(ASTM A 182/A 182M – 09a)

Identification Symbol	Tensile Strength, min, ksi [MPa]	Yield Strength, min, ksi [MPa][A]	Elongation in 2 in. [50 mm] or 4D, min, %	Reduction of Area, min, %	Brinnell Hardness Number
F1	70 [485]	40 [275]	20	30	143-192
F2	70 [485]	40 [275]	20	30	143-192
F5	70 [485]	40 [275]	20	35	143-217
F5a	90 [620]	65 [450]	22	50	187-248
F9	85 [585]	55 [380]	20	40	179-217
F10	80 [550]	30 [205]	30	50	...
F91	85 [585]	60 [415]	20	40	248 max
F92	90 [620]	64 [440]	20	45	269 max
F122	90 [620]	58 [400]	20	40	250 max
F911	90 [620]	64 [440]	18	40	187-248
F11 Class 1	60 [415]	30 [205]	20	45	121-174
F11 Class 2	70 [485]	40 [275]	20	30	143-207
F11 Class 3	75 [515]	45 [310]	20	30	156-207
F12 Class 1	60 [415]	32 [220]	20	45	121-174
F12 Class 2	70 [485]	40 [275]	20	30	143-207
F21	75 [515]	45 [310]	20	30	156-207
F3V and F3VCb	85-110 [585-760]	60 [415]	18	45	174-237

ALLOY STEELS FOR HIGH/LOW TEMPERATURE FLANGES

(ASTM A 182/A 182M – 09a)

Identification Symbol	Tensile Strength, min, ksi [MPa]	Yield Strength, min, ksi [MPa][A]	Elongation in 2 in. [50 mm] or 4D, min, %	Reduction of Area, min, %	Brinnell Hardness Number
F22 Class 1	60 [415]	30 [205]	20	35	170 max
F22 Class 3	75 [515]	45 [310]	20	30	156-207
F22 V	85-110 [585-760]	60 [415]	18	45	174-237
F23	74 [510]	58 [400]	20	30	220 max
F24	85 [585]	60 [415]	20	40	248 max
FR	63 [435]	46 [315]	25	38	197 max
F36 Class 1	90 [620]	64 [440]	15	...	252 max
F36 Class 2	95.5 [660]	66.5 [460]	15	...	252 max

[A] Determined by the 0.2% offset method.

ALLOY STEEL FOR BOLTING APPLICATIONS

(ASTM A193/A193M – 09)

Grade	Diameter (in)	Minimum Tempering Temperature (°F)	Tensile Strength, min (ksi)	Yield Strength, min (ksi)	Elongation, min (%)	Reduction of Area, min (%)	Hardness, max
B5	up to 4, incl	1100	100	80	16	50	...
B6	up to 4, incl	1100	110	85	15	50	...
B6X	up to 4, incl	1100	90	70	16	50	26 HRC
B7	2.5 and under	1100	125	105	16	50	321 HB or 35 HRC
	over 2.5 to 4		115	95	16	50	
	over 4 to 7		100	75	18	50	
B7M[A]	4 and under	1150	100	80	18	50	235 HB or 99 HRB
	over 4 to 7		100	75	18	50	
B16	2.5 and under	1200	125	105	18	50	321 HB or 35 HRC
	over 2.5 to 4		110	95	17	45	
	over 4 to 8		100	85	16	45	

[A] To meet the tensile requirements, the Brinell hardness shall be over 200 HB (93 HRB).

HSLA COLUMBIUM-VANADIUM STRUCTURAL STEEL

(ASTM A 572/A 572M – 07)

Grade	Yield Point, min		Tensile Strength, min		Minimum Elongation, %	
	ksi	[MPa]	ksi	[MPa]	in 8 in. [200mm]	in 2 in. [50mm]
42 [290]	42	290	60	415	20	24
50 [345]	50	345	65	450	18	21
55 [380]	55	380	70	485	17	20
60 [415]	60	415	75	520	16	18
65 [450]	65	450	80	550	15	17

HSLA STRUCTURAL STEEL WITH ATMOSPHERIC CORROSION RESISTANCE

(ASTM A 588/A 588M – 05)

Property	Plates and Bars			Structural Shapes
	Thicknesses 4” and less	Thicknesses Over 4” to 5”, incl	Thicknesses Over 5” to 8”, incl	All
Tensile Strength, min, ksi [MPa]	70 [485]	67 [460]	63 [435]	70 [485]
Yield Point, min, ksi [MPa]	50 [345]	46 [315]	42 [290]	50 [345]
Elongation in 8” [200mm], min, %	18	...	...	18
Elongation in 2” [50mm], min, %	21	21	21	21

REINFORCING BAR (REBAR) REQUIRMENTS

(ASTM A615/A615M – 09a)

Bar Designation No.	Nominal Weight, lb/ft [kg/m]	Nominal Dimensions[A]			Deformation Requirements, in. [mm]		
		Diameter, in. [mm]	Cross-Sectional Area, in^2 [mm^2]	Perimeter, in. [mm]	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
3 [10]	0.376 [0.560]	0.375 [9.5]	0.11 [71]	1.178 [29.9]	0.262 [6.7]	0.015 [0.38]	0.143 [3.6]
4 [13]	0.668 [0.994]	0.500 [12.7]	0.20 [129]	1.571 [39.9]	0.350 [8.9]	0.020 [0.51]	0.191 [4.9]
5 [16]	1.043 [1.552]	0.625 [15.9]	0.31 [199]	1.963 [49.9]	0.437 [11.1]	0.028 [0.71]	0.239 [6.1]
6 [19]	1.502 [2.235]	0.750 [19.1]	0.44 [284]	2.356 [59.8]	0.525 [13.3]	0.038 [0.97]	0.286 [7.3]
7 [22]	2.044 [3.042]	0.875 [22.2]	0.60 [387]	2.749 [69.8]	0.612 [15.5]	0.044 [1.12]	0.334 [8.5]
8 [25]	2.670 [3.973]	1.000 [25.4]	0.79 [510]	3.142 [79.8]	0.700 [17.8]	0.050 [1.27]	0.383 [9.7]
9 [29]	3.400 [5.060]	1.128 [28.7]	1.00 [645]	3.544 [90.0]	0.790 [20.1]	0.056 [1.42]	0.431 [10.9]
10 [32]	4.303 [6.404]	1.270 [32.3]	1.27 [819]	3.990 [101.3]	0.889 [22.6]	0.064 [1.63]	0.487 [12.4]
11 [36]	5.313 [7.907]	1.410 [35.8]	1.56 [1006]	4.430 [112.5]	0.987 [25.1]	0.071 [1.80]	0.540 [13.7]
14 [43]	7.65 [11.38]	1.693 [43.0]	2.25 [1452]	5.32 [135.1]	1.185 [30.1]	0.085 [2.16]	0.648 [16.5]
18 [57]	13.60 [20.24]	2.257 [57.3]	4.00 [2581]	7.09 [180.1]	1.58 [40.1]	0.102 [2.59]	0.864 [21.9]

[A] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight (mass) per foot (meter) as the deformed bar.

REINFORCING BAR (REBAR) REQUIRMENTS

(ASTM A615/A615M – 09a)

MECHANICAL PROPERTY REQUIREMENTS

Tensile strength, min, ksi [MPa]	Grade 40[A]	Grade 60	Grade 75	Grade 80
	60 [420]	90 [620]	100 [690]	150 [725]
Yield strength, min, ksi [MPa]	40 [280]	60 [420]	75 [520]	80 [550]
Bar Designation Number	Elongation in 8 in [200 mm], min, %			
3 [10]	11	9	7	7
4,5 [13,16]	12	9	7	7
6 [19]	12	9	7	7
7,8 [22,25]	...	8	7	7
9,10,11 [29,32,36]	...	7	6	6
14,18 [43,57]	...	7	6	6

[A] Grade 40 bars are furnished only in sizes 3 through 6 [10 through 19].

BEND TEST REQUIREMENTS

Bar Designation No.	Pin Diameter for Bend Tests[A]			
	Grade 40	Grade 60	Grade 75	Grade 80
3,4,5 [10,13,16]	3 1/2 *d*[B]	3 1/2 *d*	5*d*	5*d*
6 [19]	5*d*	5*d*	5*d*	5*d*
7,8 [22,25]	...	5*d*	5*d*	5*d*
9,10,11 [29,32,36]	...	7*d*	7*d*	7*d*
14,18 [43,57] (90°)	...	9*d*	9*d*	9*d*

[A] Test bends are 180° unless noted otherwise.

[B] *d* = nominal diameter of specimen.

ESTIMATED MECHANICAL PROPERTIES AND MACHINABILITY RATINGS OF STEEL BARS

(SAE J1397 MAY92)

Scope: The following information is intended to provide a guide to mechanical and machinability characteristics of some SAE steel grades. The ratings and properties shown are provided as general information and not as requirements for specifications unless each instance is approved by the source of supply. The data is based on resources which may no longer be totally accurate.

Mechanical properties and machinability ratings for carbon steel grades 10xx, 11xx, 12xx, and 15xx are listed Tables 1, 2, and 3. These properties can generally be expected from bars ranging in size from 3/4 to 1-1/4 inch (20 to 30 mm) based on the standard round tensile test specimen with 2 inch (50 mm) gage length. Sizes under 3/4 inch (20 mm) will show a strength which is slightly higher than those shown in the tables, while the mass effect of larger sections has a direct influence on mechanical properties and results in slightly lower values as the size increases.

TABLE 1: NONRESULFURIZED CARBON STEEL BARS, MANGANESE 1.00% MAXIMUM

Steel Grade	Type of Processing[A]	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in. [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1006	Hot Rolled	43	300	24	170	30	55	86	50
	Cold Drawn	48	330	41	280	20	45	95	
1008	Hot Rolled	44	303	24.5	170	30	55	86	55
	Cold Drawn	49	340	41.5	290	20	45	95	
1010	Hot Rolled	47	320	26	180	28	50	95	55
	Cold Drawn	53	370	44	300	20	40	105	
1012	Hot Rolled	48	330	26.5	180	28	50	95	55
	Cold Drawn	54	370	45	310	19	40	105	

TABLE 1: NONRESULFURIZED CARBON STEEL BARS, MANGANESE 1.00% MAXIMUM

Steel Grade	Type of Processing[A]	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in. [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1015	Hot Rolled	50	340	27.5	190	28	50	101	60
	Cold Drawn	56	390	47	320	18	40	111	
1016	Hot Rolled	55	380	30	210	25	50	111	70
	Cold Drawn	61	420	51	350	18	40	121	
1017	Hot Rolled	53	370	29	200	26	50	105	65
	Cold Drawn	59	410	49	340	18	40	116	
1018	Hot Rolled	58	400	32	220	25	50	116	70
	Cold Drawn	64	440	54	370	15	40	126	
1019	Hot Rolled	59	410	32.5	220	25	50	116	70
	Cold Drawn	66	460	55	380	15	40	131	
1020	Hot Rolled	55	380	30	210	25	50	111	65
	Cold Drawn	61	420	51	350	15	40	121	
1021	Hot Rolled	61	420	33	230	24	48	116	70
	Cold Drawn	68	470	57	390	15	40	131	
1022	Hot Rolled	62	430	34	230	23	47	121	70
	Cold Drawn	69	480	58	400	15	40	137	
1023	Hot Rolled	56	370	31	210	25	50	111	65
	Cold Drawn	62	430	52.5	360	15	40	121	
1025	Hot Rolled	58	400	32	220	25	50	116	65
	Cold Drawn	64	440	54	370	15	40	126	
1026	Hot Rolled	64	440	35	240	24	49	126	75
	Cold Drawn	71	490	60	410	15	40	143	

TABLE 1: NONRESULFURIZED CARBON STEEL BARS, MANGANESE 1.00% MAXIMUM

Steel Grade	Type of Processing[A]	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in. [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1030	Hot Rolled	68	470	37.5	260	20	42	137	70
	Cold Drawn	76	520	64	440	12	35	149	
1035	Hot Rolled	72	500	39.5	270	18	40	143	65
	Cold Drawn	80	550	67	460	12	35	163	
1037	Hot Rolled	74	510	40.5	280	18	40	143	65
	Cold Drawn	82	570	69	480	12	35	167	
1038	Hot Rolled	75	520	41	280	18	40	149	65
	Cold Drawn	83	570	70	480	12	35	163	
1039	Hot Rolled	79	540	43.5	300	16	40	156	60
	Cold Drawn	88	610	74	510	12	35	179	
1040	Hot Rolled	76	520	42	290	18	40	149	60
	Cold Drawn	85	590	71	490	12	35	170	
1042	Hot Rolled	80	550	44	300	16	40	163	
	Cold Drawn	89	610	75	520	12	35	179	60
	NCD	85	590	73	500	12	45	179	70
1043	Hot Rolled	82	570	45	310	16	40	163	
	Cold Drawn	91	630	77	530	12	35	179	60
	NCD	87	600	75	520	12	45	179	70
1044	Hot Rolled	80	550	44	300	16	40	163	
1045	Hot Rolled	82	570	45	310	16	40	163	
	Cold Drawn	91	630	77	530	12	35	179	55
	ACD	85	590	73	500	12	45	170	65

TABLE 1: NONRESULFURIZED CARBON STEEL BARS, MANGANESE 1.00% MAXIMUM

Steel Grade	Type of Processing[A]	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in. [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1046	Hot Rolled	85	590	47	320	15	40	170	
	Cold Drawn	94	650	79	540	12	35	187	55
	ACD	90	620	75	520	12	45	179	65
1049	Hot Rolled	87	600	48	330	15	35	179	
	Cold Drawn	97	670	81.5	560	10	30	197	45
	ACD	92	630	77	530	10	40	187	55
1050	Hot Rolled	90	620	49.5	340	15	35	179	
	Cold Drawn	100	690	84	580	10	30	197	45
	ACD	95	660	80	550	10	40	189	55
1055	Hot Rolled	94	650	51.5	360	12	30	192	
	ACD	96	660	81	560	10	40	197	55
1060	Hot Rolled	98	680	54	370	12	30	201	
	SACD	90	420	70	480	10	45	183	60
1064	Hot Rolled	97	670	53.5	370	12	30	201	
	SACD	89	610	69	480	10	45	183	60
1065	Hot Rolled	100	690	55	380	12	30	207	
	SACD	92	630	71	490	10	45	187	60
1070	Hot Rolled	102	700	56	390	12	30	212	
	SACD	93	640	72	500	10	45	192	55
1074	Hot Rolled	105	720	58	400	12	30	217	
	SACD	94.5	650	73	500	10	40	192	55

TABLE 1: NONRESULFURIZED CARBON STEEL BARS, MANGANESE 1.00% MAXIMUM

Steel Grade	Type of Processing[A]	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in. [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1078	Hot Rolled	100	690	55	380	12	30	207	
	SACD	94	650	72.5	500	10	40	192	55
1080	Hot Rolled	112	770	61.5	420	10	25	229	
	SACD	98	680	75	520	10	40	192	45
1084	Hot Rolled	119	820	65.5	450	10	25	241	
	SACD	100	690	77	530	10	40	192	45
1085	Hot Rolled	121	830	66.5	460	10	25	248	
	SACD	100.5	690	78	540	10	40	192	45
1086	Hot Rolled	112	770	61.5	420	10	25	229	
	SACD	97	670	74	510	10	40	192	45
1090	Hot Rolled	122	840	67	460	10	25	248	
	SACD	101	700	78	540	10	40	197	45
1095	Hot Rolled	120	830	66	460	10	25	248	
	SACD	99	680	76	520	10	40	197	45

[A] NCD represents normalized cold drawn, ACD represents annealed cold drawn, and SACD represents spheroidized annealed cold drawn.

[B] For the average machinability rating, grade 1212 is equal to 100%.

TABLE 2: RESULFURIZED CARBON STEEL BARS

Steel Grade[A]	Type of Processing	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1117	Hot Rolled	62	430	34	230	23	47	121	
	Cold Drawn	69	480	58	400	15	40	137	90
1132	Hot Rolled	83	570	45.5	310	16	40	167	
	Cold Drawn	92	630	77	530	12	35	183	75
1137	Hot Rolled	88	610	48	330	15	35	179	
	Cold Drawn	98	680	82	570	10	30	197	70
1141	Hot Rolled	94	650	51.5	360	15	35	187	
	Cold Drawn	105.1	720	88	610	10	30	212	70
1144	Hot Rolled	97	670	53	370	15	35	197	
	Cold Drawn	108	740	90	620	10	30	217	80
1146	Hot Rolled	85	590	47	320	15	40	170	
	Cold Drawn	94	650	80	550	12	35	187	70
1151	Hot Rolled	92	630	50.5	340	15	35	187	
	Cold Drawn	102	700	86	590	10	30	207	65
1211	Hot Rolled	55	380	33	230	25	45	121	
	Cold Drawn	75	520	58	400	10	35	163	95
1212	Hot Rolled	56	390	33.5	230	25	45	121	
	Cold Drawn	78	540	60	410	10	35	167	100
1213	Hot Rolled	56	390	34	230	25	45	121	
	Cold Drawn	78	540	60	410	10	35	163	135

[A] All 1100 and 1200 series steels are rated on the basis of 0.10% maximum Si or coarse grain melting practice.

[B] For the average machinability rating, grade 1212 is equal to 100%.

TABLE 3: NONRESULFURIZED CARBON STEEL BARS, MANGANESE MAXIMUM OVER 1.00%

Steel Grade	Type of Processing[A]	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	Elongation in 2 in [50mm] %	Reduction in Area %	Brinnel Hardness	Average Machinability Rating (Cold Drawn)[B]
1524	Hot Rolled	74	510	41	280	20	42	149	
	Cold Drawn	82	570	69	480	12	35	163	60
1527	Hot Rolled	75	520	41	280	18	40	149	
	Cold Drawn	83	570	70	480	12	35	163	65
1536	Hot Rolled	83	570	45.5	310	16	40	163	
	Cold Drawn	92	630	77.5	530	12	35	187	55
1541	Hot Rolled	92	630	51	350	15	40	187	
	Cold Drawn	102.5	710	87	600	10	30	207	45
	ACD[1]	94	650	80	550	10	45	184	60
1548	Hot Rolled	96	660	53	370	14	33	197	
	Cold Drawn	106.5	730	89.5	620	10	28	217	45
	ACD	93.5	640	78.5	540	10	35	192	50
1552	Hot Rolled	108	740	59.5	410	12	30	217	
	ACD	98	680	83	570	10	40	193	50

[A] ACD represents annealed cold drawn

[B] For the average machinability rating, grade 1212 is equal to 100%.

Alloy Steel: Hardness and machinability ratings for cold drawn alloy steel bars are listed in Table 4 with the appropriate microstructure. The microstructure listed for alloy steels in Table 4 is identified as follows:

- Type A: Predominantly lamellar pearlite and ferrite.
- Type B: Predominantly spheroidized.
- Type C: This is a hot rolled structure which depends upon grade, size, and rolling conditions of the producing mill. The structure may be coarse or fine pearlite or bainite. The pearlite at low magnification may be blocky or acicular.
- Type D: This is a structure resulting from a subcritical anneal or temper anneal. It is usually a granular or spheroidized carbide condition confined to the hot rolled grain pattern, which may be blocky or acicular.

TABLE 4: MACHINABIILTY OF ALLOY STEEL

Steel Grade	Machinability Rating	Condition	Range of Typical Hardness (HB)	Microstructure Type
1330	55	Annealed and Cold Drawn	179/235	A
1335	55	Annealed and Cold Drawn	179/235	A
1340	50	Annealed and Cold Drawn	183/241	A
1345	45	Annealed and Cold Drawn	183/241	A
4023	70	Cold Drawn	156/207	C
4024	75	Cold Drawn	156/207	C
4027	70	Annealed and Cold Drawn	167/212	A
4028	75	Annealed and Cold Drawn	167/212	A
4032	70	Annealed and Cold Drawn	174/217	A
4037	70	Annealed and Cold Drawn	174/217	A
4042	65	Annealed and Cold Drawn	179/229	A
4047	65	Annealed and Cold Drawn	179/229	A
4118	60	Cold Drawn	170/207	C
4130	70	Annealed and Cold Drawn	187/229	A

TABLE 4: MACHINABIILTY OF ALLOY STEEL

Steel Grade	Machinability Rating	Condition	Range of Typical Hardness (HB)	Microstructure Type
4135	70	Annealed and Cold Drawn	187/229	A
4137	70	Annealed and Cold Drawn	187/229	A
4140	65	Annealed and Cold Drawn	187/229	A
4142	65	Annealed and Cold Drawn	187/229	A
4145	60	Annealed and Cold Drawn	187/229	A
4147	60	Annealed and Cold Drawn	187/235	A
4150	55	Annealed and Cold Drawn	187/241	A,B
4161	50	Spheroidized and Cold Drawn	187/241	B,A
4320	60	Annealed and Cold Drawn	187/229	D,B,A
4340	50	Annealed and Cold Drawn	187/241	B,A
E4340	50	Annealed and Cold Drawn	187/241	B,A
4422	65	Cold Drawn	170/212	C
4427	65	Annealed and Cold Drawn	170/212	A
4615	65	Cold Drawn	174/223	C
4617	65	Cold Drawn	174/223	C
4620	65	Cold Drawn	182/229	C
4626	70	Cold Drawn	170/212	C
4718	60	Cold Drawn	187/229	C
4720	65	Cold Drawn	187/229	C
4815	50	Annealed and Cold Drawn	187/229	D,B
4817	50	Annealed and Cold Drawn	187/229	D,B
4820	50	Annealed and Cold Drawn	187/229	D,B
50B40	65	Annealed and Cold Drawn	174/223	A

TABLE 4: MACHINABIILTY OF ALLOY STEEL

Steel Grade	Machinability Rating	Condition	Range of Typical Hardness (HB)	Microstructure Type
50B44	65	Annealed and Cold Drawn	174/223	A
5046	60	Annealed and Cold Drawn	174/223	A
50B46	60	Annealed and Cold Drawn	174/223	A
50B50	55	Annealed and Cold Drawn	183/235	A
5060	55	Spheroidized Annealed and Cold Drawn	170/212	B
50B60	55	Spheroidized Annealed and Cold Drawn	170/212	B
5115	65	Cold Drawn	163/201	C
5120	70	Cold Drawn	163/201	C
5130	70	Annealed and Cold Drawn	174/212	A
5132	70	Annealed and Cold Drawn	174/212	A
5135	70	Annealed and Cold Drawn	179/217	A
5140	65	Annealed and Cold Drawn	179/217	A
5147	65	Annealed and Cold Drawn	179/229	A
5150	60	Annealed and Cold Drawn	183/235	A,B
5155	55	Annealed and Cold Drawn	183/235	A,B
5160	55	Spheroidized Annealed and Cold Drawn	179/217	B
51B60	55	Spheroidized Annealed and Cold Drawn	179/217	B
50100	40	Spheroidized Annealed and Cold Drawn	183/241	B
51100	40	Spheroidized Annealed and Cold Drawn	183/241	B
52100	40	Spheroidized Annealed and Cold Drawn	183/241	B
6118	60	Cold Drawn	179/217	C
6150	55	Annealed and Cold Drawn	183/241	B,A
8115	65	Cold Drawn	163/202	C
81B45	65	Annealed and Cold Drawn	179/223	A

TABLE 4: MACHINABIILTY OF ALLOY STEEL

Steel Grade	Machinability Rating	Condition	Range of Typical Hardness (HB)	Microstructure Type
8615	70	Cold Drawn	179/235	C
8617	70	Cold Drawn	179/235	C
8620	65	Cold Drawn	179/235	C
8622	65	Cold Drawn	179/235	C
8625	60	Annealed and Cold Drawn	179/223	A
8627	60	Annealed and Cold Drawn	179/223	A
8630	70	Annealed and Cold Drawn	179/229	A
8637	65	Annealed and Cold Drawn	179/229	A
8640	65	Annealed and Cold Drawn	184/229	A
8642	65	Annealed and Cold Drawn	184/229	A
8645	65	Annealed and Cold Drawn	184/235	A
86B45	65	Annealed and Cold Drawn	184/235	A
8650	60	Annealed and Cold Drawn	187/248	A,B
8655	55	Annealed and Cold Drawn	187/248	A,B
8660	55	Spheroidized Annealed and Cold Drawn	179/217	B
8720	65	Cold Drawn	179/235	C
8740	65	Annealed and Cold Drawn	184/235	A
8822	55	Cold Drawn	179/223	B
9254	45	Spheroidized Annealed and Cold Drawn	187/241	B
9260	40	Spheroidized Annealed and Cold Drawn	184/235	B
9310	50	Annealed and Cold Drawn	184/229	D
94B15	70	Cold Drawn	163/202	C
94B17	70	Cold Drawn	163/202	C
94B30	70	Annealed and Cold Drawn	170/223	A

AVERAGE MECHANICAL PROPERTIES VS CARBON CONTENT

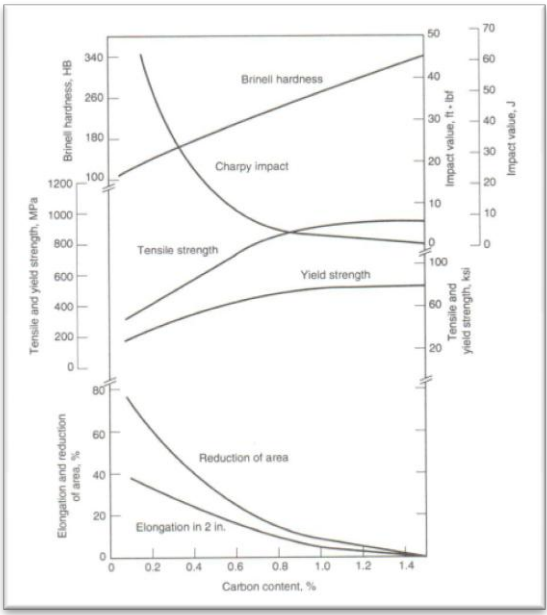


Figure 1: Variations in average mechanical properties of as-rolled 1 inch (25 mm) diameter bars of plain carbon steels, as a function of carbon content. (Carbon and Alloy Steels. ASM International, 1996, pg 12)

TOLERANCES FOR LEVEL ONE COLD FINSIHED BARS

COLD DRAWN OR TURNED AND POLISHED (ASTM A108-07)

Size (in.)[A]	Maximum of Carbon Range 0.28% or less	Maximum of Carbon Range over 0.28% to 0.55% incl.	Maximum of Carbon Range to 0.55% incl., Stress Relieved or Annealed after Cold Finishing	Maximum of Carbon Range over 0.55% or All Grades Quenched and Tempered or Normalized and Tempered before Cold Finishing
All tolerances are in inches and are minus[B]				
Rounds – Cold Drawn[C] to 6 in. or Turned and Polished				
To 1-1/2 [38.1], incl	0.003 [0.076]	0.004 [0.102]	0.005 [0.127]	0.006 [0.152]
Over 1-1/2 to 2-1/2 [38.1 to 63.5], incl	0.004 [0.102]	0.005 [0.127]	0.006 [0.152]	0.007 [0.178]
Over 2-1/2 to 4 [63.5 to 101.6], incl	0.005 [0.127]	0.006 [0.152]	0.007 [0.178]	0.008 [0.203]
Over 4 to 6 [101.6 to 152.4], incl	0.006 [0.152]	0.007 [0.178]	0.008 [0.203]	0.009 [0.229]
Over 6 to 8 [152.4 to 203.2], incl	0.007 [0.178]	0.008 [0.203]	0.009 [0.229]	0.010 [0.254]
Over 8 to 9 [203.2 to 228.6], incl	0.008 [0.203]	0.009 [0.229]	0.010 [0.254]	0.011 [0.279]
Squares				
To 3/4 [19.1], incl	0.003 [0.076]	0.005 [0.127]	0.006 [0.152]	0.008 [0.203]
Over 3/4 to 1-1/2 [19.1 to 38.1], incl	0.004 [0.102]	0.006 [0.152]	0.007 [0.178]	0.009 [0.229]
Over 1-1/2 to 2-1/2 [38.1 to 63.5], incl	0.005 [0.127]	0.007 [0.178]	0.008 [0.203]	0.010 [0.254]
Over 2-1/2 to 4 [63.5 to 101.6], incl	0.007 [0.178]	0.009 [0.229]	0.010 [0.254]	0.012 [0.305]
Over 4 to 5 [101.6 to 127.0], incl	0.011 [0.279]	...	...	...

[A] Standard manufacturing practice is shear cut for cold drawn bars (size limits vary by producer) which can cause end distortion resulting in those portions of the bar being outside The applicable size tolerance. When this end condition is undesirable, a saw cut end to remove end distortion should be considered.

[B] While size tolerances are usually specified as minus, tolerances may be ordered all plus, or distributed as plus and minus, with the sum being equivalent to the tolerances listed.

[C] Maximum allowable deviation in roundness around the circumference of the same cross section of a round cold drawn bar is 1/2 the size tolerance range.

RECOMMENDED COLD SHEARING LIMITATIONS FOR HOT-ROLLED ALLOY AND CARBON STEEL BARS AND BILLETS

(STANDARD AND FORMERLY STANDARD AISI AND SAE GRADES)

Maximum Dimension of Square Section (in)*

Grade Series Designation	When Maximum of Specified Percent Carbon Range Is:							
	Thru 0.20	Over 0.20 Thru 0.25	Over 0.25 Thru 0.33	Over 0.33 Thru 0.44	Over 0.44 Thru 0.49	Over 0.49 Thru 0.55	Over 0.55 Thru 0.76	Over 0.76 Thru 1.05
10XX	4-1/2	4-1/2	4	3	2-1/2	2	1-1/2	1
11XX thru 1.00 max Mn	4-1/2	4-1/2	4	3	2-1/2	2		
11XX over 1.00 max Mn	4-1/4	4	3-1/2	2-1/2	2			
12XX	4-1/2							
15XX	4-1/4	4	3-1/2	2-1/2	2	1-1/2	1	
13XX	4	3-1/2	2-1/2	2**				
40XX	4	4	4	3	2-1/2	2**	***	
41XX	4	4	3-1/2	2-1/2	***	***	***	
43XX	4	4	1-1/2**					
46XX	4	4	3-1/2	2**				
47XX	4							
48XX	4	3						
50XX	4	2	***					
50BXX	2	2**	***	***				
51XX	4	4	4	3	2	***		
51BXX	***							

* Refer to Table on Page 158 and 159 for Equivalent Round sizes, based on cross sectional area.

** Sizes 1 inch square and smaller should be cold shearing quality or thermally treated before cold shearing.

*** All sizes in this carbon range should be cold shearing quality or thermally treated before cold shearing.

RECOMMENDED COLD SHEARING LIMITATIONS FOR HOT-ROLLED ALLOY AND CARBON STEEL BARS AND BILLETS

(STANDARD AND FORMERLY STANDARD AISI AND SAE GRADES)

Maximum Dimension of Square Section (in)*

Grade Series Designation	When Maximum of Specified Percent Carbon Range Is:							
	Thru 0.20	Over 0.20 Thru 0.25	Over 0.25 Thru 0.33	Over 0.33 Thru 0.44	Over 0.44 Thru 0.49	Over 0.49 Thru 0.55	Over 0.55 Thru 0.76	Over 0.76 Thru 1.05
61XX	4	4	3	2-1/2	2**	***	***	
81XX	4	2-1/2						
81BXX	2-1/2							
86XX	4	4	3	2-1/2	2**	***	***	
86BXX	3	2**						
87XX	4	4	2-1/2	2**	***			
88XX	3-1/2							
92XX	***	***						
93XX	***							
94XX	2-1/2	***	***					
94BXX	4	4	2-1/2					
97XX	***	***						
98XX	***	***	***					

* Refer to Table on Page 158 and 159 for Equivalent Round sizes, based on cross sectional area.

** Sizes 1 inch square and smaller should be cold shearing quality or thermally treated before cold shearing.

*** All sizes in this carbon range should be cold shearing quality or thermally treated before cold shearing.

RECOMMENDED COLD SHEARING LIMITATIONS FOR COLD SHEARING QUALITY HOT ROLLED ALLOY AND CARBON STEEL BARS AND BILLETS

(STANDARD AND FORMERLY STANDARD AISI AND SAE GRADES)

Maximum Dimension of Square Section (in.)*

Grade Series Designation	When Maximum of Specified Percent Carbon Range Is:							
	Thru 0.20	Over 0.20 Thru 0.25	Over 0.25 Thru 0.33	Over 0.33 Thru 0.44	Over 0.44 Thru 0.49	Over 0.49 Thru 0.55	Over 0.55 Thru 0.76	Over 0.76 Thru 1.05
10XX	6-1/2	6-1/2	6	5	4-1/2	4	3-1/2	
11XX thru 1.00 max Mn	6-1/2	6-1/2	6	5	4-1/2	4		
11XX over 1.00 max Mn	6-1/4	6	5-1/2	4-1/2	4			
12XX	6-1/2							
15XX	6-1/4	6	5-1/2	4-1/2	4	3	2-1/4	
13XX	5	4-3/4	4-1/2	4				
40XX	5	5	4-3/4	4-1/2	4-1/2	4-1/2	**	
41XX	5	5	4-3/4	4-1/4	4	3	**	
43XX	4-3/4	4-3/4	**					
46XX	5	5	4-3/4	4-1/4				
47XX	5							
48XX	5	4-3/4						
50XX	5	4-1/4	**					
50BXX	4-1/2	4-1/4	3-1/2	**				
51XX	5	5	4-3/4	4-1/2	4	3-1/4		
51BXX	4	3-1/4	**					

* Refer to Table on page 158 and 159 for Equivalent Round size, based on cross sectional area.

** All sizes in this carbon range should be cold shearing quality or thermally treated before cold shearing.

RECOMMENDED COLD SHEARING LIMITATIONS FOR COLD SHEARING QUALITY HOT ROLLED ALLOY AND CARBON STEEL BARS AND BILLETS

(STANDARD AND FORMERLY STANDARD AISI AND SAE GRADES)

Maximum Dimension of Square Section (in.)*

Grade Series Designation	When Maximum of Specified Percent Carbon Range Is:							
	Thru 0.20	Over 0.20 Thru 0.25	Over 0.25 Thru 0.33	Over 0.33 Thru 0.44	Over 0.44 Thru 0.49	Over 0.49 Thru 0.55	Over 0.55 Thru 0.76	Over 0.76 Thru 1.05
61XX	5	5	4-3/4	4-1/4	4	3	**	
81XX	5							
81BXX	4							
86XX	5	5	4-3/4	4-1/2	4	3-1/4	**	
86BXX	4-3/4	4						
87XX	5	5	4-1/2	4	3-1/4			
88XX	4-3/4							
92XX	1	**						
93XX	3							
94XX	4-1/2	4	3-1/4					
94BXX	5	4-3/4	4-1/2					
97XX	3-1/4	**						
98XX	3-3/4	3	**					

* Refer to Table on page 158 and 159 for Equivalent Round size, based on cross sectional area.

** All sizes in this carbon range should be cold shearing quality or thermally treated before cold shearing.

CARBURIZING RATES OF CARBON AND ALLOY STEELS

For 0.10% Carbon (approx.) Alloy Carburizing Steels

Carburizing Time, (Hours)	Effective Case Depth @ 0.40% Carbon			
	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″	.052″	.065″	.078″
20	.048″	.059″	.073″	.088″
24	.052″	.065″	.080″	.096″
30	.059″	.073″	.089″	.108″

For 0.20% Carbon (approx.) Alloy Carburizing Steels

Carburizing Time, (Hours)	Effective Case Depth @ 0.40% Carbon			
	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	.033″	.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″	.068″	.084″	.099″
24	.062″	.075″	.092″	.109″
30	.070″	.085″	.103″	.122″

RECOMMENDED MAXIMUM HOT WORKING TEMPERATURES

Steel Grade	Maximum Temperature (°F)
1008	2250
1010	2250
1015	2250
1040	2200
1050	2200
1117	2250
1141	2200
1144	2200
4023	2250
4037	2200
4047	2200
4130	2200
4140	2200
4150	2200
4320	2200
4340	2200
4620	2300
4820	2250
4120	2250
5140	2200
4160	2150
52100	2050
6150	2200
8620	2250
8630	2200
8640	2200
8650	2200

CRITICAL TRANSFORMATION TEMPERATURES

(Approximate)

Grade	On Heating 50F/hr		On Cooling 50F/hr		On Quenching
	Ac1 (°F)	Ac3 (°F)	Ar3 (°F)	Ar1 (°F)	Ms (°F)
1010	1335	1610	1560	1260	904
1015	1335	1580	1525	1260	871
1020	1335	1555	1500	1260	838
1025	1340	1545	1440	1265	805
1030	1340	1495	1450	1250	752
1035	1340	1475	1425	1255	720
1040	1340	1460	1395	1240	690
1045	1340	1435	1385	1260	655
1050	1340	1415	1365	1260	610
1055	1340	1390	1350	1260	590
1060	1340	1375	1340	1265	555
1065	1340	1350	1325	1270	501
1070	1340	1350	1310	1275	490
1080	1345	1355	1290	1280	415
1090	1345	1370	1290	1270	365
1095	1350	1415	1340	1290	351
1117	1350	1550	1450	1245	809
1118	1345	1520	1495	1245	782
1137	1315	1420	1360	1220	654
1141	1310	1400	1340	1210	628
1335	1330	1440	1340	1160	640
1340	1320	1430	1330	1150	610
4026	1350	1540	1440	1240	775
4027	1340	1485	1400	1240	755
4037	1340	1495	1390	1210	690
4047	1340	1440	1330	1200	615
4130	1395	1490	1390	1280	685
4140	1350	1480	1370	1255	595
4145	1340	1470	1380	1250	569
4150	1370	1410	1345	1240	530
4320	1335	1490	1365	1170	720
4340	1335	1425	1310	1210	545
4820	1270	1440	1245	1110	695

CRITICAL TRANSFORMATION TEMPERATURES

(Approximate)

Grade	On Heating 50F/hr		On Cooling 50F/hr		On Quenching
	Ac1 (°F)	Ac3 (°F)	Ar3 (°F)	Ar1 (°F)	Ms (°F)
5120	1410	1540	1470	1290	760
5130	1370	1490	1370	1280	680
5140	1360	1450	1340	1280	620
5150	1330	1420	1330	1290	555
5160	1310	1410	1320	1250	590
52100	1340	1415	1320	1270	485
6150	1380	1450	1370	1280	545
8620	1350	1525	1415	1220	745
8630	1355	1460	1370	1220	680
8640	1350	1435	1340	1230	610
8645	1350	1430	1310	1230	575
8720	1350	1530	1420	1220	740
9260	1370	1500	1380	1315	550
Standard Boron Steels					
50B46	1130	1440	1340	1210	620
51B60	1335	1429	1345	1250	490

PERMISSIBLE VARIATIONS IN HOT-ROLLED BAR CROSS SECTION
(ASTM A29/A29M-05)

Specified Size (in)	Variation from Specified Size (in)[A]		Out-of-Round or Out-of-Square Section (in)[B]
	Over	Under	
Thru 5/16	0.005	0.005	0.008
Over 5/16 thru 7/16, incl.	0.006	0.006	0.009
Over 7/16 thru 5/8, incl.	0.007	0.007	0.010
Over 5/8 thru 7/8, incl.	0.008	0.008	0.012
Over 7/8 thru 1, incl.	0.009	0.009	0.013
Over 1 thru 1-1/8, incl.	0.010	0.010	0.015
Over 1-1/8 thru 1-1/4, incl.	0.011	0.011	0.016
Over 1-1/4 thru 1-3/8, incl.	0.012	0.012	0.018
Over 1-3/8 thru 1-1/2, incl.	0.014	0.014	0.021
Over 1-1/2 thru 2, incl.	1/64	1/64	0.023
Over 2 thru 2-1/2, incl.	1/32	0	0.023
Over 2-1/2 thru 3-1/2, incl.	3/64	0	0.035
Over 3-1/2 thru 4-1/2, incl.	1/16	0	0.046
Over 4-1/2 thru 5-1/2, incl.	5/64	0	0.058
Over 5-1/2 thru 6-1/2, incl.	1/8	0	0.070
Over 6-1/2 to 8-1/4, incl.	5/32	0	0.085
Over 8-1/4 to 9-1/2, incl.	3/16	0	0.100
Over 9-1/2 to 10, incl.	1/4	0	0.120

[A] Steel bars are regularly cut to length by shearing or hot sawing, which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is objectionable, a machine cut end should be considered.

[B] Out-of-round is the difference between the maximum and minimum diameters of the bar, measured at the same cross section. Out-of-Square is the difference in the two dimensions at the same cross section of a square bar between opposite faces.

NOMINAL CORNER RADII OF RCS BARS
(AISI Steel Products Manual AUG94)

Specified Size*		Nominal Corner Radii	
inch	**mm**	**inch**	**mm**
From 3/8 to 1/2 incl.	9.52 to 12.70	1/16	1.59
Over 1/2 to 13/16 incl.	12.70 to 20.64	3/32	2.38
Over 13/16 to 1-15/32 incl.	20.64 to 37.31	1/8	3.18
Over 1-15/32 to 1-15/16 incl.	37.31 to 49.21	1/4	6.35
Over 1-15/16 to 2-7/16 incl.	49.21 to 61.91	5/16	7.94
Over 2-7/16 to 2-7/8 incl.	61.91 to 73.02	3/8	9.52
Over 2-7/8 to 3-3/8 incl.	73.02 to 85.72	7/16	11.1
Over 3-3/8 to 3-7/8 incl.	85.72 to 98.42	1/2	12.7
Over 3-7/8 to 4-1/2 incl.	98.42 to 114.3	5/8	15.9
Over 4-1/2 to 5-1/2 incl.	114.3 to 139.7	3/4	19.1

*Size is defined as the distance between opposite sides. Round-Cornered Squares are rolled to dimensions, not to weights per linear foot (meter).

PERMISSIBLE VARIATIONS IN LENGTH FOR HOT-ROLLED ROUNDS AND SQUARES

(ASTM A29/A29M-05)

Specified Size of Rounds/Squares (in)	Permissible Variations Over Specified Length (in)[A]				
	5 to 10 ft, excl	10 to 20 ft, excl	20 to 30 ft, excl	30 to 40 ft excl	40 to 60 ft, excl
Mill Shearing					
To 1, incl	0.50	0.75	1.25	1.75	2.25
Over 1 to 2, incl	0.625	1.00	1.50	2.00	2.50
Over 2 to 5, incl	1.00	1.50	1.75	2.25	2.75
Over 5 to 10, incl	2	2.50	2.75	3	3.25
Hot Sawing					
2 to 3.5, incl	[B]	1.50	1.75	2.25	2.75
Over 3.5 to 5, incl	[B]	2.00	2.25	2.625	3.00
Over 5 to 10, incl	[B]	2.50	2.75	3	3.25

[A] No permissible variations under.

[B] Smaller sizes and shorter lengths are not hot sawed.

PERMISSIBLE VARIATIONS IN STRAIGHTNESS FOR HOT-ROLLED BARS

(ASTM A29/A29M-05)

Standard Tolerance	0.25 inch in any 5 feet and (0.25 inch x length in feet)/5
Special Tolerance	0.125 inch in any 5 feet and (0.125 inch x length in feet)/5

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

EQUIVALENT CROSS SECTIONS BY BAR SIZE AND SHAPE

Square Dimension (in.)	Equivalent** Round Dimension (in.)	Cross Sectional Area (in.^{2})
9	10 2/16	81.00
8-3/4	9 14/16	76.56
8-1/2	9 9/16	72.25
8-1/4	9 5/16	68.06
8	9	64.00
7-3/4	8 12/16	60.06
7-1/2	8 7/16	56.25
7-1/4	8 3/16	52.56
7	7 14/16	49.00
6-3/4	7 10/16	45.56
6-1/2	7 5/16	42.25
6-1/4	7 1/16	39.06
6	6 12/16	36.00
5-7/8	6 10/16	34.52
5-3/4	6 8/16	33.06
5-5/8	6 6/16	31.64
5-1/2	6 3/16	30.25
5-3/8	6 1/16	28.89
5-1/4	5 15/16	27.56
5-1/8	5 13/16	26.27
5	5 10/16	25.00
4-7/8	5 8/16	23.77
4-3/4	5 6/16	22.56
4-5/8	5 3/16	21.39
4-1/2	5 1/16	20.25
4-3/8	4 15/16	19.14
4-1/4	4 13/16	18.06
4-1/8	4 10/16	17.02
4	4 8/16	16.00
3 15/16	4 7/16	15.50
3 7/8	4 6/16	15.02
3 13/16	4 5/16	14.54
3 3/4	4 4/16	14.06
3 11/16	4 3/16	13.60
3 5/8	4 1/16	13.14
3 9/16	4	12.69
3 1/2	3 15/16	12.25
3 7/16	3 14/16	11.82
3 3/8	3 13/16	11.39
3 5/16	3 12/16	10.97
3 1/4	3 11/16	10.56
3 3/16	3 10/16	10.16
3 1/8	3 8/16	9.77
3 1/16	3 7/16	9.38
3	3 6/16	9.00

EQUIVALENT CROSS SECTIONS BY BAR SIZE AND SHAPE

Square Dimension (in.)	Equivalent** Round Dimension (in.)	Cross Sectional Area (in.^{2})
2 15/16	3 5/16	8.63
2 7/8	3 4/16	8.27
2 13/16	3 3/16	7.91
2 3/4	3 2/16	7.56
2 11/16	3 1/16	7.22
2 5/8	2 15/16	6.89
2 9/16	2 14/16	6.57
2 1/2	2 13/16	6.25
2 7/16	2 12/16	5.94
2 3/8	2 11/16	5.64
2 5/16	2 10/16	5.35
2 1/4	2 9/16	5.06
2 3/16	2 8/16	4.79
2 1/8	2 6/16	4.52
2 1/16	2 5/16	4.25
2	2 4/16	4.00
1 15/16	2 3/16	3.75
1 7/8	2 2/16	3.52
1 13/16	2 1/16	3.29
1 3/4	2	3.06
1 11/16	1 14/16	2.85
1 5/8	1 13/16	2.64
1 9/16	1 12/16	2.44
1 1/2	1 11/16	2.25
1 7/16	1 10/16	2.07
1 3/8	1 9/16	1.89
1 5/16	1 8/16	1.72
1 1/4	1 7/16	1.56
1 3/16	1 5/16	1.41
1 1/8	1 4/16	1.27
1 1/16	1 3/16	1.13
1	1 2/16	1.00

HOT ROLLED BAR WEIGHTS

Nominal Thickness or Diameter (in.)	Bar Weight (lb/ft)	
	Rounds	Round Cornered Squares
1/32	0.0026	0.0033
1/16	0.0104	0.0133
3/32	0.0234	0.0298
1/8	0.0417	0.0531
5/32	0.0651	0.0829
3/16	0.0938	0.1194
7/32	0.1276	0.1625
1/4	0.1667	0.2123
9/32	0.2110	0.2686
5/16	0.2605	0.3316
11/32	0.3152	0.4013
3/8	0.3751	0.4776
13/32	0.4402	0.5605
7/16	0.5105	0.6500
15/32	0.5861	0.7462
1/2	0.6668	0.8490
17/32	0.7528	0.9584
9/16	0.8439	1.075
19/32	0.9403	1.197
5/8	1.042	1.327
21/32	1.149	1.463
11/16	1.261	1.605
23/32	1.378	1.754
3/4	1.500	1.910
25/32	1.628	2.073
13/16	1.761	2.242
27/32	1.899	2.418
7/8	2.042	2.600
29/32	2.191	2.789
15/16	2.344	2.985
31/32	2.503	3.187
1	2.667	3.396
1 1/16	3.011	3.834
1 1/8	3.376	4.298
1 3/16	3.761	4.789
1 1/4	4.168	5.306
1 5/16	4.595	5.850
1 3/8	5.043	6.421
1 7/16	5.512	7.018
1 1/2	6.001	7.641
1 9/16	6.512	8.291
1 5/8	7.043	8.968
1 11/16	7.595	9.671
1 3/4	8.168	10.40
1 13/16	8.762	11.16
1 7/8	9.377	11.94
1 15/16	10.01	12.75
2	10.67	13.58

*Based upon the density of steel; 0.283 lbs/in^3.

HOT ROLLED BAR WEIGHTS

Nominal Thickness or Diameter (in.)	Bar Weight (lb/ft)	
	Rounds	Round Cornered Squares
2 1/16	11.35	14.45
2 1/8	12.04	15.34
2 3/16	12.76	16.25
2 1/4	13.50	17.19
2 5/16	14.26	18.16
2 3/8	15.04	19.16
2 7/16	15.85	20.18
2 1/2	16.67	21.23
2 9/16	17.51	22.30
2 5/8	18.38	23.40
2 11/16	19.26	24.53
2 3/4	20.17	25.68
2 13/16	21.10	26.86
2 7/8	22.05	28.07
2 15/16	23.02	29.30
3	24.00	30.56
3 1/16	25.02	31.85
3 1/8	26.05	33.16
3 3/16	27.10	34.50
3 1/4	28.17	35.87
3 5/16	29.27	37.26
3 3/8	30.38	38.68
3 7/16	31.52	40.13
3 1/2	32.67	41.60
3 9/16	33.85	43.10
3 5/8	35.05	44.63
3 11/16	36.27	46.18
3 3/4	37.51	47.76
3 13/16	38.77	49.36
3 7/8	40.05	50.99
3 15/16	41.35	52.65
4	42.68	54.34
4 1/8	45.38	57.79
4 1/4	48.18	61.34
4 3/8	51.05	65.00
4 1/2	54.01	68.77
4 5/8	57.05	72.64
4 3/4	60.18	76.62
4 7/8	63.39	80.71
5	66.68	84.90
5 1/8	70.06	89.20
5 1/4	73.52	93.60
5 3/8	77.06	98.11
5 1/2	80.68	102.7
5 5/8	84.39	107.5
5 3/4	88.18	112.3
5 7/8	92.06	117.2
6	96.02	122.3

*Based upon the density of steel; 0.283 lbs/in^3.

HOT ROLLED BAR WEIGHTS

Nominal Thickness or Diameter (in.)	Bar Weight (lb/ft)	
	Rounds	Round Cornered Squares
6 1/4	104.2	132.7
6 1/2	112.7	143.5
6 3/4	121.5	154.7
7	130.7	166.4
7 1/4	140.2	178.5
7 1/2	150.0	191.0
7 3/4	160.2	204.0
8	170.7	217.3
8 1/4	181.5	231.1
8 1/2	192.7	245.4
8 3/4	204.2	260.0
9	216.0	275.1

*Based upon the density of steel; 0.283 lbs/in^3.

HOT ROLLED BAR REDUCTION RATIOS AT STEEL DYNAMICS

Reduction ratio compares the cross-sectional area of the as-cast bloom or billet with the cross-sectional area of the hot rolled product.

		Reduction Ratio (from 10.3 x 14.1 blooms)	
Hot Rolled Size (in)		Hot Rolled Shape	
Fractional	Decimal	Round	RCS
9	9.000	2.2	1.8
8 3/4	8.7500	2.4	1.9
8 1/2	8.5000	2.5	2.0
8 1/4	8.2500	2.7	2.1
8	8.0000	2.8	2.3
7 3/4	7.7500	3.0	2.4
7 1/2	7.5000	3.2	2.6
7 1/4	7.2500	3.4	2.7
7	7.0000	3.7	2.9
6 3/4	6.7500	4.0	3.2
6 1/2	6.5000	4.3	3.4
6 1/4	6.2500	4.6	3.7
6	6.0000	5.1	4.0
5 7/8	5.8750	5.2	4.2
5 3/4	5.7500	5.5	4.4
5 5/8	5.6250	5.7	4.6
5 1/2	5.5000	6.0	4.8
5 3/8	5.3750	6.3	5.0
5 1/4	5.2500	6.6	5.3
5 1/8	5.1250	6.9	5.5

HOT ROLLED BAR REDUCTION RATIOS AT STEEL DYNAMICS

		Reduction Ratio (from 10.3 x 14.1 blooms)	
Hot Rolled Size (in)		**Hot Rolled Shape**	
Fractional	**Decimal**	**Round**	**RCS**
5	5.0000	7.3	5.8
4 7/8	4.8750	7.6	6.1
4 3/4	4.7500	8.0	6.4
4 5/8	4.6250	8.5	6.8
4 1/2	4.5000	9.0	7.1
4 3/8	4.3750	9.5	7.6
4 1/4	4.2500	10.1	8.1
4 1/8	4.1250	10.7	8.5
4	4.0000	11.4	9.1
3 15/16	3.9375	11.9	9.2
3 7/8	3.8750	12.1	9.7
3 13/16	3.8125	12.5	10.0
3 3/4	3.7500	12.9	10.3
3 11/16	3.6875	13.3	10.7
3 5/8	3.6250	13.8	11.0
3 9/16	3.5625	14.3	11.4
3 1/2	3.5000	14.9	11.9
3 7/16	3.4375	15.4	12.3
3 3/8	3.3750	16.0	12.8
3 5/16	3.3125	16.6	13.2
3 1/4	3.2500	17.2	13.7
3 3/16	3.1875	17.9	14.3

HOT ROLLED BAR REDUCTION RATIOS AT STEEL DYNAMICS

		Reduction Ratio (from 10.3 x 14.1 blooms)	
Hot Rolled Size (in)		**Hot Rolled Shape**	
Fractional	**Decimal**	**Round**	**RCS**
3 1/8	3.1250	18.6	14.9
3 1/16	3.0625	19.4	15.5
3	3.0000	20.2	16.2
2 15/16	2.9375	21.1	16.8
2 7/8	2.8750	22.0	17.3
2 13/16	2.8125	23.0	18.4
2 3/4	2.7500	24.0	18.8
2 11/16	2.6875	25.1	20.1
2 5/8	2.6250	26.3	21.1
2 9/16	2.5625	27.6	22.1
2 1/2	2.50000	29.2	23.2
2 7/16	2.43750	30.7	24.4
2 3/8	2.37500	32.3	25.7
2 5/16	2.31250	34.1	27.2
2 1/4	2.25000	36.0	28.7
2 3/16	2.18750	38.1	30.4
2 1/8	2.12500	40.3	32.2

HOT ROLLED BAR REDUCTION RATIOS AT STEEL DYNAMICS

		Reduction Ratio (from 10.3 x 14.1 blooms)	
Hot Rolled Size (in)		Hot Rolled Shape	
Fractional	Decimal	Round	RCS
2 1/16	2.06250	42.8	34.1
2	2.00000	46.2	36.3
1 15/16	1.93750	49.2	38.7
1 7/8	1.87500	52.5	41.3
1 13/16	1.81250	56.2	44.2
1 3/4	1.75000	60.3	47.4
1 11/16	1.68750	64.8	51.0
1 5/8	1.62500	69.9	55.0
1 9/16	1.56250	75.6	59.5
1 1/2	1.50000	82.1	64.5

GRAIN SIZE

As Rolled Grain Size

As rolled grain size is sometimes referred to as ferritic grain size, ferrite pearlite grain size, or room temperature gain size. As rolled grain size refers to the ASTM E 112 grain size number, which is given to the size of the ferrite and pearlite grains in the microstructure of the steel as measured after cooling from hot rolling. As rolled grain size is controlled by the associated rolling temperatures and cooling rates following hot rolling.

Austenitic Grain Size (McQuaid-Ehn Grain Size)

Austenitic grain size refers to the size of the grains which were present in the steel when it was in the austenite phase. The austenite phase occurs at elevated temperatures, generally greater than 1500°F. Austenite grain size requirements are often specified for applications involving carburizing or heat treatment. For the most part, fine grain steels are less sensitive to variations in heat treatments, while coarse grained steels are deeper hardening and are more readily machinable.

Classification as a fine or coarse grain steel is determined by the steelmaking procedure. If the procedure involves the addition of elements such as Al, V, Nb, Ti, or a combination of these elements, the steel is fine grained. Steels without the addition of these fine graining elements are referred to as coarse grained steels, and the McQuaid-Ehn grain size limits are not applicable. For the most part, steels with high C, high S, and/or high Mn tend to inherently resist grain coarsening.

When a steel is classified as fine grain steel, it refers to the fact that the steel has the ability to retain a fine austenitic grain size when heated into the austenite range. A steel which is classified as fine grain steel can still exhibit coarse grains at elevated temperatures depending on the thermal cycle to which the steel was exposed. Steels with an austenitic grain size number of 1 to 5 inclusive are referred to as coarse grained, while steels with an austenitic grain size number greater than 5 are referred to as fine grained (as measured by ASTM E112). When Al is used as a the grain refining element, the fine austenitic grain size requirement is met if, on heat analysis, the total Al content is not less than 0.020%.

A steel producer will certify a heat of steel as fine or coarse grain based on the steelmaking practice employed. If required, a grain size test can be performed to certify the steel as fine or coarse grain. This certification only refers to the ability of the steel to maintain a fine or coarse structure in the austenitic temperature range, and does NOT guarantee that the steel will remain fine grain regardless of the thermal conditions to which the steel is subjected to.

EFFECTS OF ALLOYING ELEMENTS ON THE PROPERTIES OF STEEL

Element	Percentage	Positive Attributes	Negative Attributes
Carbon		Strength Hardness Hardenability	Ductility Weldability
Manganese	0.30/1.15	Surface Quality (favoring MnS to FeS inclusions)	Machinability and Weldability
	1.20/1.65	Strength Surface Quality	
	Over 1.65	Hardenability	
Phosphorus	0.040 max	No special benefits	Ductility and toughness
	0.04/0.12	Machinability (desirable chip formation)	Ductility, toughness, and impact resistance
Sulfur	Under approx. 0.006	Surface Quality (due to ABSENCE of sulfur)	Machinability (poor chip formation)
	0.01/0.05	No special benefits	Chemical Impurity
	0.06/0.40	Machinability	Transverse properties, Impact Resistance, Weldability, Cold Formability
Silicon	0.10/0.40	Deoxidizer	Machinability
	Over 1.00	Strength of Ferrite Sag Resistance (Spring Steel)	Machinability Decarburization
Nickel	0.01/0.25	Strength (microalloy)	Machinability
	0.30/0.80	Hardenability Low Temperature Toughness	
	Approx. 1.00/4.00	Hardenability	

EFFECTS OF ALLOYING ELEMENTS ON THE PROPERTIES OF STEEL

Element	Percentage	Positive Attributes	Negative Attributes
Chromium	0.01/0.25	Strength (microalloy)	Machinability
	0.30/0.80	Hardenability	
	Approx. 1.00/2.00	Abrasion Resistance (carbide formation) High Temperature Strength Hardenability	
Molybdenum	0.08/0.60	Hardenability Creep Strength High Temperature Strength	Machinability Weldability
Copper	0.20 max	Strength (microalloy)	Surface Quality
	0.20/0.50	Corrosion Resistance	Surface Quality Forgeability
	Over 1.00	Yield Strength (alloy)	Ductility, Impact Resistance, and Forgeability
Nitrogen	0.020 max	Strength and Yield Strength (microalloy)	Cold Formability Ductility
Aluminum		Deoxidizer Grain Refiner	Machinability
	0.95/1.30	Ability to Nitride	

NOTES

GLOSSARY OF METALLURGICAL TERMS

STEEL TERMINOLOGY

Strand Casting (Continuous Casting)

A direct solidification process used to cast molten steel into blooms or billets, thereby bypassing the ingot solidification and reheat stages of steel production. In strand casting, a steel "melt" is tapped into a ladle in the conventional manner. The liquid steel is them teemed (poured) into a tundish, which acts as s reservoir to provide for a controlled casting rate. The molten steel flows from the tundish into the casting machine, where rapid surface solidification beings in the open-ended, water-cooled copper molds. The partially solidified bloom or billet is continuously extracted from the open bottom of the mold. Solidification is completed by further cooling the emerging continuous cast steel. Several strands may be cast side-by-side or in parallel, depending upon the heat tonnage and section size. Variations in chemical composition are minimized due to the rapid solidification rate of the strand cast product.

Bloom

A bloom is a rectangular product whose width is no more than twice its thickness, and whose area is usually at least 36 square inches. A bloom also may be furnished as either a semi finished hot rolled product, or an as-cast section.

Billet

A billet is either an as-cast section that has not yet been hot worked, or a solid semi finished round or square that has been hot worked, usually smaller than a bloom section. Billet can also be used as a general term for wrought starting stock for forgings, extrusions, or for re-rolling into other products.

Machinability

the relative ease with which a steel may be cut by machine tools. There is no single standard measurement of machinability. It is often expressed by one or more of the following terms: cutting speed; productivity; tool life; tool wear; part growth; chip formation; surface finish. The main machining operations are turning, parting, milling and drilling. The inherent machinability of a steel in related to its chemical composition and microstructure.

Pickling

an operation by which surface oxide (high temperature 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.

ROLES OF ALLOYING ELEMENTS IN STEEL

Aluminum (Al)
Is used to deoxidize steel and control grain size. Grain size is controlled by enabling aluminum to combine with nitrogen and oxygen to form a fine dispersion of particles which restrict austenite grain growth. Aluminum is also an extremely effective nitride former in nitriding steels. When such steels containing 0.95 to 1.30% aluminum are heated in a medium containing nitrogen, they develop a thin case containing aluminum nitride. This stable compound imparts a high surface hardness and exceptional wear resistance. The amount of aluminum present in nitriding steels is considerably more than needed to produce a fine austenitic grain size in other steels.

Boron (B)
In amounts ranging from 0.0005 and 0.0030% by weight produce significant increases in the hardenability of steels during quenching. Since it does not affect the ferrite strength of steel, ductility is not sacrificed, and does not impair formability or machinability in the annealed state. Boron also intensifies the hardenability effects of other alloys, and in some instances, may decrease costs by making possible a reduction of total alloy content. Boron is very effective in low-carbon alloy steels, but its effect is reduced as the carbon increases. Boron appears to be most detrimental to impact resistance in steels with low transition temperatures; thus, if nickel steel is to be used for low temperature applications, boron should not be added. Conversely, boron steels should contain nickel to offset the detrimental effect of boron on low temperature transition.

Calcium (Ca)
When used in certain steels, controls the shape, size, and distribution of oxide and/or sulfide inclusions. It may also be added in small amounts to enhance the continuous castability of steels. Benefits may include improved ductility, impact strength, and machinability.

Carbon (C)
Is the most important alloying element in steel. Carbon is essential to the formation of cementite (iron carbide), pearlite, spheroidite, bainite, and martensite. Compared to steels with similar microstructures the following properties are increased as the carbon content increases to approximately 0.60%: ultimate tensile strength, yield strength, hardness, maximum quenched hardness, hardenability, and ductile-to-brittle transition temperature. The toughness and ductility or pearlite steels are decreased with increasing carbon content.

Chromium (Cr)
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. Of the common alloying elements, chromium is surpassed only by manganese and molybdenum in its affect on hardenability.

Chromium forms the most stable carbide of any of the more common alloying elements, thereby imparting exceptional wear resistance to high-carbon chromium steels. This effect is primarily due to the high hardness of the chromium carbides.

Columbium (Cb)
Influences the properties of steel by (1) imparting fine grain size and preventing grain coarsening as high as 1875°F, (2) by slightly reducing hardenability, (3) by retarding softening during tempering, and (4) by enabling steel to resist creep and rupture at elevated temperatures.

An advantage of using columbium for grain refinement is that its low deoxidizing power does not introduce undesirable oxide inclusions into the steel. Columbium decreases the hardenability of steel by carbon impoverishment, grain refinement, and the nucleating effect of the carbides.

Copper (Cu)
May be specified in some carbon steels primarily to improve resistance to atmospheric corrosion. Copper tends to be detrimental to surface quality. In the small amount found in carbon steels, copper has no significant effect on mechanical properties. Copper is not removed by any of the conventional steelmaking processes.

Lead / Bismuth (Pb / Bi)
Both lead and bismuth improve machinability. Lead and bismuth do not dissolve in steel, but exist as globules. Environmental concerns are resulting in a decreased usage of lead, and an increased usage of bismuth in the steel industry.

Manganese (Mn)
Normally present in all commercial steels. Manganese contributes to steel's strength and hardness in much the same manner, but to a lesser extent, than carbon. Another important characteristic of manganese is its ability to decrease the critical cooling rate during hardening, thereby increasing the steels hardenability. This effect is greater than that of any of the other commonly used alloying elements.

Manganese (continued)
Manganese is also important because it deoxidizes the molten steel, and shows fewer tendencies to segregate during solidification than do most other alloying elements. Its presence in steel is highly beneficial to surface quality because it tends to combine with sulfur, thereby minimizing the formation of iron sulfide (the leading cause of hot shortness, or susceptibility to cracking and tearing at hot rolling temperatures).

Manganese combines with sulfur to form manganese sulfide (MnS) stringers which increase machinability. Manganese contributes to the effectiveness of normalizing for strengthening purposes, by promoting the formation of fine pearlite.

Molybdenum (Mo)
Increases hardenability of steel and helps maintain a specified hardenability level. Molybdenum is unique in the degree to which it increases the high temperature tensile and creep strengths of steel. Molybdenum hardened steels require higher temperatures for softening purposes, and more the tempering temperature out of the "blue brittle" range – therefore reduce steel's susceptibility to temper brittleness.

Nickel (Ni)
Is one of the fundamental steel alloying elements. When Ni is present in appreciable amounts, it provides improved low-temperature toughness (particularly the heat treated condition), increases hardenability, results in less distortion in quenching, and improves corrosion resistance.

Nitrogen (N)
Increases strength, harness and machinability of steel, but decreases ductility and toughness. In aluminum killed steels, nitrogen combines with the aluminum to provide grain size control, thereby contributing to increased toughness and strength. Nitrogen can reduce the effect of boron on the hardenability of steels.

Phosphorus (P)
Is considered to be an impurity in steel, and generally is restricted to amounts less than 0.040% by weight to minimize its detrimental effect on ductility and toughness. Certain free machining steels (12XX series) contain higher levels of phosphorus to enhance machinability by promoting chip breakage, but at the sacrifice of ductility and impact toughness.

Silicon (Si)
Is one of the principle deoxidizers of molten steel, and normally is present in amounts up to 0.35%. It slightly increases the strength of ferrite without a serious loss of ductility. It is used in greater amounts in some steels, such as the silico-manganese steels, where its effects tend to complement those of manganese to produce unusually high strength combined with good ductility and shock resistance in the quenched and tempered condition. Elevated silicon levels improve fatigue life and sag resistance in automotive coil springs. In these larger quantities, however, silicon has an adverse effect on machinability, and increases the steel's susceptibility to decarburization and graphitization.

Sulfur (S)
Sulfur is detrimental to transverse strength and impact resistance. Existing primarily in the form of manganese sulfide stringers, sulfur is typically added to enhance machinability. Sulfur is very detrimental to surface quality, particularly in the lower carbon and low manganese steels.

Titanium (Ti)
Is added to boron steels because it preferentially combines with oxygen and nitrogen, thus increasing the effectiveness of boron. Titanium, as titanium nitride, also provides grain size control at elevated temperatures in microalloyed steels. In excessive levels, titanium may be detrimental to machinability and internal cleanliness.

Tellurium (Te)
Tellurium is added to steel to modify sulfide type inclusion size, morphology and distribution. The resulting sulfide type inclusions remain ellipsoidal in shape following hot working, thereby improving machinability and transverse properties.

Vanadium (V)
Vanadium inhibits grain growth during heat treating, while improving strength and toughness of quenched and tempered steels. Vanadium additions up to 0.08% increase hardenability, whereas larger amounts tend to reduce hardenability because of carbon impoverishment due to the carbide formation. Higher amounts of vanadium also are utilized in ferrite/pearlite microalloyed steels to increase hardness through vanadium carbonitride precipitation strengthening of the matrix.

HEAT TREATING TERMS

Transformation Temperature
the temperature at which a change in solid phase occurs. The heat treatment of steel deals with those ranges of temperature which austenite forms upon heating and transforms to ferrite (or to ferrite plus cementite) during cooling. The two ranges are distinct (sometimes overlapping), but never coinciding. The limiting temperatures of the ranges depend on the composition of the steel and the rate of change in temperature, particularly during cooling.

The following symbols for critical temperatures are used for the heat treatment of steel:

Ac_1: The temperature at which austenite begins to form during heating.
Ac_3: The temperature at which transformation of ferrite to austenite is completed during heating.
Ar_3: The temperature at which austenite begins to transform to ferrite (or to ferrite plus cementite) during cooling.
Ar_1: The temperature at which transformation of austenite to ferrite (or to ferrite plus cementite) is complete during cooling.
Ms: The temperature at which the transformation of austenite to marten site starts during cooling.
Mf: The temperature at which transformation of austenite to marten site finished during cooling.

Annealing
in general, the annealing process is the threefold completion of a heating cycle, a holding period, and a controlled cooling cycle. Annealing may be used to achieve the following results: to soften or alter the grain structure of steel; to enhance formability, machinability or mechanical properties; or to relieve residual stresses. The desired final results dictate which heat treating temperatures and cooling rates are used. Thus, specific annealing cycles have become known by names characteristic of the particular processes or end results. The most frequently used of these processes are discussed below.

1. **Subcritical Annealing** (Also known as Process Annealing or Stress Relief Annealing) consists of heating steel to a temperature approaching the lower critical (Ac1) temperature. This represents the simplest form of annealing. Its function is to reduce residual stress and hardness, and make minor changes in microstructure. It is used frequently to facilitate cold shear-ability. It may also be used between cold forming operations to reduce the cold worked hardness and recrystallize the grain structure.

2. **Full Annealing** (Also known as Lamellar Pearlite – or so-called "LP" – Annealing) consists of heating steel above its upper critical (Ac3) temperature, and holding at that temperature for an extended period of time, then followed by a controlled rate of cooling to below the critical range. This treatment is used to produce a definite pearlitic microstructure, usually to satisfy one or more of these requirements: enhanced machinability; removal of residual stresses; reduced hardness level; cold formability; and improved ductility, toughness or other mechanical properties. Grain size is also refined.

3. **Spheroidize** Annealing is a special type of annealing that requires an extremely long time at temperature. This treatment is used to produce globular or spherical carbides in the microstructure. Spheroidize annealing is more effective in reducing hardness and improving ductility than is full annealing. A spheroidized microstructure is desirable for machinability and surface finish of high-carbon steels and when the material is to be severely cold deformed, e.g. severe cold upsetting, extruding, bending, or drawing.

4. **Isothermal Annealing** is another special type of annealing that involves cooling steel from austenite (and holding it for a specified extended time at a constant subcritical temperature) to allow transformation to either lamellar pearlitic or spheroidized structure with the desired harness level. A continuous furnace is generally used for this type of annealing, and may be atmosphere controlled to minimize decarburization and excessive scaling. In recent years, isothermal annealing directly after hot rolling has become increasingly popular by taking advantage of the fuel and time savings afforded by transforming steel which is already in the austenite state.

Normalizing

a thermal treatment which uniformly heats steel to a temperature at least 100°F above it upper critical range, followed by cooling in still air at room temperature. The treatment produces a recrystallization and refinement of the grain structure, and gives better uniformity of hardness and microstructure to the product.

Quenching & Tempering

a thermal treatment consisting of uniformly heating steel to a predetermined austenizing temperature and cooling rapidly in air or a liquid medium (usually water or oil) to produce a desired microstructure, usually martensite. As-quenched martensite is characteristically very hard and brittle. If allowed to remain in this highly stressed condition, cracks will tend to form in all but low carbon steels. It has been recognized that the optimum combinations of strength and toughness are developed in steel when a microstructure of martensite has been tempered. To prevent cracking, martensite should be tempered immediately after quenching, and at a temperature to produce the harness desired for service.

Hardenability (Response to Heat Treatment)
the physical property of steel which determines the depth of martensitic hardness that can be induced by quenching from temperatures over 1330°F. The chemical composition and austenitic grain size of the steel completely determine it hardenability, with almost all of the elements making varying degrees of contribution.

Hardenability should not be confused with hardness per se or with maximum hardness. Whereas the as-quenched surface hardness of steel is primarily dependent upon carbon content and cooling rate, *the depth* to which a certain hardness level is maintained with a given quenching condition is a measure of hardenability.

Jominy End Quench Hardenability Test
a laboratory heat treating procedure for determining the hardenability of steel by reproducing a range of specific quenching rates on a single test specimen. The test is performed by heating a standardized test specimen above the upper critical temperature, then quickly hanging the hot specimen in a fixture so that a column of cold water impinges on the bottom end of the specimen. The test specimen is progressively quenched to room temperature, and the decreasing hardness is measured from its maximum value (near the quenched end of the specimen) at regularly spaced intervals away from the quenched end. The harness measurements are plotted as a function of distance away from the quenched end. This plot is known as the steel's hardenability band. The range of cooling rates on a standard Jominy test specimen has been correlated to bar diameter size for both oil and water quenchants.

DI (Ideal Diameter)
The DI is an alternate method for predicting hardenability. DI represents the maximum theoretical bar diameter that will harden at the center with at least 50% martensite, when subjected to an "ideal" quench (e.g. Grossman quench severity in which H=infinity).

MECHANICAL PROPERTY TERMS

The following four mechanical properties are determined from a single uniaxial test specimen pulled in tension to the point of fracture:

Ultimate Tensile Strength (also abbreviated as "Tensile Strength")
Ultimate tensile strength is expressed as the ratio of the maximum applied load to the original cross sectional area. The maximum load is achieved at the onset of localized "necking" of the test specimen. Thereafter, the required tensile load is continuously reduced until the specimen is elongated to fracture.

The tensile strength of hot rolled steel is dependent first on the strength of pure iron. The overall strength of steel is increased in proportion to incremental additions of the various alloying elements. Besides chemical content, tensile strength of steel may be influenced its microstructure. For a given composition, the following microstructures exhibit increasing tensile strength: pearlite, bainite, martensite.

Yield Strength
the amount of stress which produces a defined amount of permanent deformation (e.g. 0.2% in 2" gage length) from otherwise elastic behavior. The term "yielding" refers to a stress state at which the rate of steel deformation is no longer proportional to the rate of applied loading. Once the applied load is released, the yielded steel no longer returns to it initially unstressed dimensions.

Elongation (also known as "EL")
Ductility is also measured in a tensile test by pre-stamping two gage marks (usually spaced 2" to 8" apart) along the tensile specimen, prior to running the test. Subsidized tensile specimens may evaluate elongation from 1" or 1.4" gage marks. Elongation is the increase in length over the initial standard gage length, and is usually expressed as a percentage of the original gage length.

Reduction of Area (also known as "R. of A." or "RA")
Another measurement of ductility represents the amount of "necking" (decrease in cross sectional area) which has taken place during a tensile test. Reduction of area is measured after the tensile test specimen has pulled to the point of fracture, and is usually expressed as a percentage of the original cross sectional area.

Ductility
A description of the ability of steel to withstand plastic deformation (e.g. change shape) without rupture. This is a vital property for users in the cold forming, heading or cold drawn bar markets. Ductility may be thought of as the opposite of brittleness. In hot rolled bars, ductility generally decreases with increased chemical content, tensile strength, and/or coarser grain size. Ductility is commonly measured by "elongation" and "reduction of area" in a standard tensile test.

Hardness
a measure of a metal's ability to resist plastic deformation, usually by indentation. Hardness is an indirect measure of the relative ultimate tensile strength of steel. The two most common hardness tests in general use are the Brinell hardness test and the family of Rockwel hardness tests.

In the Brinell test, a 10mm diameter steel ball is pressed into the steel sample under a 3000kg load. The Brinell Hardness Number (BNH) correlates inversely with the area of the spherical impression – the diameter of the indentation in measured, and the corresponding BNH is read off a chart. Automated Brinell test equipment measures the spherical impression and calculates direct readouts of BNH.

The Rockwell test presses either a cone-shaped diamond indentor or a 1/16" diameter steel ball into the steel sample under a 10 kg minor load. A major load of 60, 100 or 150 kg is then applied and released. The number on the Rockwell scale inversely correlates the difference of indentor depths penetrated by the minor and major loads.

Impact Toughness
a measure of a metal's ability to resist fracture under high-velocity loading from the force of a single blow. The Charpy V-Notch test is the most common method for testing impact toughness. A standard test specimen with a machined V-Notch is placed into a fixture, and struck from behind the notch by a swinging pendulum of standard weight (mass). Other types of impact tests modify the geometries of the notches, e.g. U-Notch or Izod tests.

Impact toughness varies according to composition, microstructure, grain size, and service temperature of the steel. The impact toughness of steel is known to abruptly change from ductile to brittle failure, when the temperature falls below a certain critical value. For this reason, whole series of impact tests are often carried out over a range of expected service temperatures.

Brittle test specimens hardly slow down the pendulum, and therefore exhibit very low impact resistance. A "tough" (or ductile) test sample absorbs much more energy by decreasing the pendulum's velocity, and therefore exhibits greater impact toughness.

MICROSTRUCTURAL TERMS

Microstructure
Microstructure refers to the quantity, size, shape and distribution of various phases in the steel. It depends totally on the chemistry, hardenability, heat treatment, and cooling rates employed. Ferrite, the purest form of iron in steel, is the softest and lowest strength constituent with highest ductility. Martensite, a supersaturated solution of carbon in iron, is the hardest and most brittle microstructure. The controlled diffusion of carbon, which is managed by regulating the tempering time and temperature, softens the quenched martensitic microstructure and improves ductility. Slow cooling from high temperatures causes the carbon to precipitate out as iron carbide (or cementite) which is a hard phase. A mixture of ferrite and lamellar (or plate-like) cementite is called pearlite. If the pearlitic microstructure is heated to approximately 1300°F, and held there for some time, a spheroidized carbide structure emerges which consists of iron carbide plates that have coalesced into spherical shapes. Microstructural bainite can be described as "feathery" carbide. The Microstructural appearance of martensite in an etched specimen does not reveal structure of grain boundaries.

Austenite is a term applied to the solid solution of carbon in gamma (or face-centered cubic) iron and is present in carbon steels when they are heated above the Ac3 transformation temperature. "Restrained austenite" is austenite the remains in the microstructure after a part has been quenched from its austenizing temperature. It is a softer Microstructural constituent. Tempered martensite has a needle-like appearance with no grain boundary detail.

Grain Size
A steel's grain size usually is expressed as the average diameter, or as a numeric value representing the quantity of grains per unit area or volume. Two types of grain size are commonly expressed: 1) "austenitic" (high temperature) grain size, as determined by the McQuaid-Ehn test; and 2) various forms of room-temperature grain size which are called as-rolled, or ferritic/pearlitic grain size. Evaluation of grain size is performed with a metallurgical microscope in accordance with ASTM E-112. ASTM grain size is often reported as a number: ASTM #1 through #5 are generally called "coarse grain"; ASTM #5 and higher numbers are generally classified as "fine grain".

Inclusions
Nonmetallic inclusions are particles of various oxides and silicates which form during steel melting and refining. These inclusions consist of oxidized material, sulfides, aluminates, silicates or nitrides in various combinations and mixtures. ASTM E-45 specifies various methods for classifying and reporting various types of inclusions. Inclusions are inherent to normal steelmaking practice. They are chiefly derived from the oxidizing reactions of the refining processes and the deoxidizing materials added to the molten steel in the furnace. In the case of free-machining steels, sulfur, phosphorus and/or lead/bismuth are deliberately added to form inclusions. Some inclusions will elongate in the hot rolling direction, while others will remain as relatively point type features. The resulting inclusions' shapes are influenced by the hot mill rolling temperature and the inclusions' melting points.

Segregation (Also known as Chemical Segregation or Alloy Segregation)
A centerline condition in which the local chemical composition of the steel departs from the average composition. The chemical segregation (expressed in weight percent) along the centerline of a hot rolled bar is either "positive" (greater) or "negative (smaller) compared to the bar's average chemical composition. Segregation is a natural phenomenon associated with the solidification of steel.

In general, the metal that solidifies rapidly, and close to the mold wall forms a "chill zone" which has approximately the same chemical composition as the liquid metal entering the mold. As the solidification rate decreases, the mechanism of solidification is such that crystals of purer metal tend to solidify first; the first crystals to form contain less carbon, manganese, phosphorus, sulfur and other elements – than from the liquid steel from which they were formed. The remaining liquid steel in enriched by these elements as they are continually rejected during the solidification process. Thus, the last material to solidify contains the largest amount of the rejected elements. In descending order, the following common elements in steel tend to segregate: sulfur, phosphorus, carbon, silicon, and manganese.

Decarburization
Depletion of the nominal carbon content at the surface of a bar. The combination of time and temperature in the reheat furnace enables oxygen in the atmosphere to react with carbon at the surface of the steel. Surface carbon and furnace oxygen combine to form carbon monoxide, leaving the steel surface partially or totally depleted of carbon.

STEEL DEFECT TERMS

Seam
Longitudinal surface crevices the contain scales and decarburization, usually oriented perpendicular to the bar's surface. Seams can vary in length from a few inches to several feet, and generally are randomly found along the length and around the circumference of a bar. Medium to large sized seams can be detected with the naked eye, especially after the hot rolled bar surface has been descaled. Magnetic and eddy current testing offer greater assurance of detecting seams. The recommended stock removal to rid bars of seams is 0.001" per size for each 1/16" of bar diameter (non-resulfurized steel grades), or 0.0015" per side for each 1/16" of bar diameter (resulfurized steel grades).

Lap
Longitudinal crevices that contain scale and decarburization, usually oriented at least 30 degrees off radial, created by the folding over (but not welding) of steel during hot working. The most frequent cause of laps is "overfill" during hot rolling, in which steel gets forced into the roll gap, folds over and gets rolled into the bar surface during subsequent roll passes. Shorter laps can be caused by the steel momentarily failing to fill out the pass as it goes through the mill. Laps are generally the result of poor workmanship, and are independent of the steel grade.

Sliver
Loose or torn segments of steel rolled onto the bar surface in a random distribution of small, rolled-out point defects.

Overfill
A protrusion on one or both sides of a hot rolled bar caused by the section being too large for the roll pass during hot working. If the defect is on one side only, it is usually referred to as being "off the hole", indicating a guiding or other alignment problem. If not corrected at the source, overfill frequently leads to laps in subsequent mill stands. Overfill can sometimes occur on the extreme front and back ends of rolled bars because the billet is not experiencing a steady rolling state. The front end is adjusted to the pass while the back end does not have sufficient tension, due to a lack of trailing material. Such material needs to be discarded.

Scratch
Longitudinal indentations usually running parallel to the rolling direction, caused by mechanical rubbing of the bar on protrusions as it is processed. Mechanical scratches vary from small, sharp defects to large, plowed-out gouges. The distinguishing feature of a scratch is the absence of scale and decarburization associated with it. Scratches may occur during hot rolling (called mill scratches) or after hot rolling (usually called handling damage).

Flakes (Also known as Hydrogen Flakes)
Short, discontinuous internal fissures in steel attributed to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working. In a fracture surface, flakes appear as bright silvery areas; viewed on edge along an etched micro specimen, flakes appear as short, discontinuous cracks. The term "snow flake" was originally applied to this condition, due to the glistening appearance of the fracture surfaces in failed sections. With time, the term was shortened to "flakes". Normal steel mill practices provide methods to control material cooling from rolling temperatures to prevent the formation of hydrogen flakes. The hydrogen content, bar diameter and the steel's volumetric expansion/contraction characteristics during the transformation of austenite are also strong factors in hydrogen flake formation for a given sheet.

Internal Unsoundness (Also known as Porosity or Center Looseness)
A solidification defect carried through to the finished hot rolled product. It is manifested as a longitudinal centerline feature in the bar which is associated with the thermal contraction of the original as-cast dendritic condition. Gross center looseness is considered to be the result of casting at temperatures much higher than the inherent freezing temperature of the steel, followed by insufficient hot working.

Center looseness is often called an "etching phenomenon", wherein different orientations of grains (dendritic patterns) are preferentially attacked by the etchant. This preferential acid attack reveals visible contrast in the micro specimen. On macro etched transverse sections, unsoundness appears either as an etched-out hole or remnants of dendritic structure.

Scale
A high-temperature, gray-colored iron oxide layer which forms on the surface of a hot rolled bar. Scale can be detrimental to the finished product, particularly if the scale is rolled into the surface (rolled-in scale), or if it adheres tightly to the steel. Up to three layers of high-temperature iron oxide scale can form on hot rolled steel products. The relative amounts of these three oxide layers depend upon the length of time the steel is exposed to atmospheric oxygen at a particular temperature range.

Roll Mark
Repeating patterns of "embossed" elevations or depressions. Elevations are caused by depressions or cavity flaws on the mill rolls. Depressions on the bars are caused by pieces of foreign matter which have impacted into the rolls.

Burnt Steel
A severe surface defect which occurs when intergranular oxidation weakens the grain boundaries to the point where they can no longer support mechanically induced rolling stresses. This condition may be caused by grain boundary melting, or extreme hot shortness, and is usually attributed to excessively high heating temperatures. If not detected within the first few rolling mill stands, burnt steel can deform further and appear to be surface scabs in the finished product.

HARDNESS CONVERSION TABLE

(Approximate equivalent hardness numbers for steel and approximate relationship between hardness number and Ultimate Tensile Strength for steel.)

Brinell Indentation Diameter (mm)	Brinell Hardness Number 3000kg load 10mm Tungsten Carbide Ball	Rockwell Hardness Number			Ultimate Tensile Strength (Approximate) times 1000 psi
		A-Scale 60kg Load Brale Penetrator	B-Scale 100kg Load 1/16 In. Diam. Ball	C-Scale 150kg Load Brale Penetrator	
2.25	745	84.1		65.3	
2.30	710	83.2		63.3	
2.35	682	82.2		61.7	
2.40	653	81.2		60.0	
2.45	627	80.5		58.7	
2.50	601	79.8		57.3	
2.55	578	79.1		56.0	
2.60	555	78.4		54.7	298
2.65	534	77.8		53.5	288
2.70	514	76.9		52.1	274
2.75	495	76.3		51.0	264
2.80	477	75.6		49.6	252
2.85	461	74.9		48.5	242
2.90	444	74.2		47.1	230
2.95	429	73.4		45.7	219
3.00	415	72.8		44.5	212
3.05	401	72.0		43.1	202
3.10	388	71.4		41.8	193
3.15	375	70.6		40.4	184
3.20	363	70.0		39.1	177
3.25	352	69.3	(110.0)	37.9	171
3.30	341	68.7	(109.0)	36.6	164
3.35	331	68.1	(108.5)	35.5	159
3.40	321	67.5	(108.0)	34.3	154
3.45	311	66.9	(107.5)	33.1	149
3.50	302	66.3	(107.0)	32.1	146
3.55	293	65.7	(106.0)	30.9	141
3.60	285	65.3	(105.5)	29.9	138
3.65	277	64.6	(104.5)	28.8	134
3.70	265	64.1	(104.0)	27.6	130
3.75	262	63.6	(103.0)	26.6	127
3.80	255	63.0	(102.0)	25.4	123

HARDNESS CONVERSION TABLE

(Approximate equivalent hardness numbers for steel and approximate relationship between hardness number and Ultimate Tensile Strength for steel.)

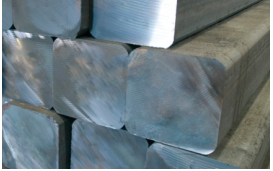
Brinell Indentation Diameter (mm)	Brinell Hardness Number 3000kg load 10mm Tungsten Carbide Ball	Rockwell Hardness Number			Ultimate Tensile Strength (Approximate) times 1000 psi
		A-Scale 60kg Load Brale Penetrator	B-Scale 100kg Load 1/16 In. Diam. Ball	C-Scale 150kg Load Brale Penetrator	
3.85	248	62.5	(101.0)	24.2	120
3.90	241	61.8	100.0	22.8	116
3.95	235	61.4	99.0	21.7	114
4.00	229	60.8	98.2	20.5	111
4.05	223		97.3	(18.8)	108
4.10	217		96.4	(17.5)	105
4.15	212		95.5	(16.0)	102
4.20	207		94.6	(15.2)	100
4.25	201		93.8	(13.8)	98
4.30	197		92.8	(12.7)	95
4.35	192		91.9	(11.5)	93
4.40	187		90.7	(10.0)	90
4.45	183		90.0		89
4.50	179		89.0		87
4.55	174		87.7		85
4.60	170		86.8		83
4.65	167		86.0		81
4.70	163		85.0		79
4.80	156		82.9		76
4.90	149		80.8		73
5.00	143		78.7		71
5.10	137		76.4		67
5.20	131		74.0		65
5.30	126		72.0		63
5.40	121		69.8		60
5.50	116		67.6		58
5.60	111		65.7		56

Note 1: Values shown in parentheses are beyond the normal range of the test scale and are given only for comparison with values in other test scales.

Note 2: In the event of disagreement between hardness and tensile strength, the tensile strength shall govern.

COMMON CONVERSION FACTORS

To Convert To →	Multiplier	← To Convert To	
Length		**Length**	
Inch (in)	25.4	0.0394	Millimeter (mm)
Foot (ft)	30.48	0.0328	Centimeter (cm)
Yard (yd)	0.914	1.0936	Meter (m)
Mile (mi)	1.609	0.6214	Kilometer (km)
Area		**Area**	
Square Inch	645.2	0.00155	Square Millimeter
Square Inch	6.452	0.155	Square Centimeter
Square Foot	0.0929	10.76	Square Meter
Volume		**Volume**	
Cubic Inch	16.39	0.06102	Cubic Centimeter
Cubic Foot	0.02832	35.31	Cubic Meter
Force or Weight		**Force or Weight**	
Pound (lb)	0.453597	2.205	Kilogram
Ton	0.907	1.102	Metric Ton
Stress		**Stress**	
Pounds/square inch (psi)	0.0703	14.22	Kilograms/square cm
Pounds/square inch (psi)	0.006895	145	Megapascal (MPa)
Kilopounds/square inch (ksi)	6.895	0.145	Megapascal (MPa)
Mass Density		**Mass Density**	
Pounds/Cubic Foot	1.602	0.6242	Grams/cubic cm
Temperature		**Temperature**	
Fahrenheit (F)	0.555 x (F - 32)	(1.8 x C) + 32	Celsius (C)



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