CASTI

Metals Black Book™

North American Ferrous Data

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Dedication

CASTI Metals Black Book™ - North American Ferrous Data is dedicated to my mother, Mary Bringas, and her parents, my grandparents, Luigi and Regina Zorzit; whose dream they shared of having their son and grandson become an engineer, and my honour to have accomplished their dream.

Additionally this book is dedicated to the memory of my first metallurgy teacher, Mr. George Chirgwin, W.D. Lowe Technical School, Windsor, Ontario. Not only did Mr. Chirgwin encourage me to study metallurgy, but his unique way of teaching influenced me to also teach the wondrous science of metals.

John E. Bringas, P.Eng.
Edmonton, Alberta

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Chapter 1

INTRODUCTION TO THE METALLURGY OF FERROUS MATERIALS

Introduction

The expression *ferrous materials* is used to mean the metallic element iron and the entire range of iron-based metallic alloys. There are a great many different ferrous materials, but they can be divided into three basic categories, namely wrought iron, steel and cast iron.

Wrought iron, which is no longer commercially produced, is a relatively pure iron containing non-metallic slag inclusions. Modern wrought iron products are actually made of low carbon steel.

Steels are iron-based alloys whose most important component element next to iron itself is carbon. The carbon contents of steels are low, usually below 1%, but the presence and amount of carbon in the steel have a major effect on its behavior in service. By far the most common type of steel is plain carbon steel, i.e. steel containing only iron and carbon plus small amounts of manganese and, usually, silicon or aluminum. The manganese, silicon and aluminum are added to compensate for the presence of the impurities sulfur, oxygen and nitrogen. Another important type of steel, the alloy steels, contain in addition to the above-mentioned elements, significant quantities of such elements as chromium, nickel and molybdenum, which distinguishes them from plain carbon steels. A specialized range of alloy steels, known as stainless steels, contain a minimum of 11.5% chromium. Tool steels, the final type to be considered here, are specialized carbon or alloy steels which are capable of functioning under the demanding service conditions associated with the working and shaping of metallic and non-metallic materials into desired forms. Some steel is used in the form of steel castings, but most steel objects are mechanically worked into their final forms and are thus categorized as wrought products.

Cast irons contain much higher carbon and silicon levels than steels, typically 3-5% carbon and 1-3% silicon. These comprise another category of ferrous materials, which are intended to be cast from the liquid state to the final desired shape.

Ferrous alloys dominate the world of construction materials. Their widespread applications are the result of a broad range of desirable material properties combined with favorable economics. Iron is the least expensive of all the metals and the second most abundant in nature.

This chapter supplies an introduction to the metallurgical aspects of ferrous materials, especially steels. Subsequent chapters provide data on many aspects of various ferrous materials. More details relating to the metallurgy of particular products are discussed in introductions to the sections on Carbon and Alloy Steels, Cast Steels, Cast Irons, Tool Steels and Stainless Steels.

Historical Aspects

Iron is one of the seven metals of antiquity, and is associated with the Roman god Mars and the planet of the same name. The first iron to have been used by humanity was probably meteoritic iron; this is readily identifiable because the so-called 'iron' meteorites are in fact iron-nickel alloys containing an average of about 8% nickel. Objects made from meteoritic iron are found among the archaeological artifacts left by many ancient cultures worldwide. Meteoritic iron, the metal from the sky, was used for utilitarian, decorative and ornamental purposes, and in some cases for objects with ceremonial functions.

However, most of the iron found in the archaeological record has been smelted from ores of iron, and the existence of this early material has led to the designation "Iron Age" for a particular stage of the evolution of societies, which began during the second millennium B.C. The first instances of iron smelting are not known, but it is possible that the earliest smelted iron was an inadvertent by-product of copper smelting operations. Here it was sometimes necessary to add iron oxide to the smelting furnace charge as a flux in order to lower the melting temperature of the silicate slag. Overly reducing conditions in the copper smelting furnace could have led to the subsequent reduction of metallic iron from the slag. Certainly smelted iron was in use by about 2000 B.C. and was relatively widespread by 1000 B.C. The original form in which smelted iron was used was wrought iron, a heterogeneous mixture of iron with silicate slag. Wrought iron was produced in bloomery furnaces by the solid state reduction of iron ore to metal, well below the melting temperature of iron. The product of this smelting operation was a bloom,

a mixture of slag and metallic iron which was hot hammered to remove as much slag as possible. With improvements in bellows and furnace technology, smelting temperatures increased until they were adequate to permit the production of liquid iron, in blast furnaces. This iron, which contained a high carbon content, could then be cast directly to useful shapes, as cast iron. Alternatively it could be converted to wrought iron by subjecting it to decarburization, initially by treating it in fining furnaces and later by the puddling process. Cast iron came into use in the western world some time in the 11th-13th centuries A.D., although it had been used since about 500 B.C. in China, where higher temperature furnaces were available much earlier than in the west.

The intentional addition of carbon to wrought iron to make steel was being carried out during the first millennium B.C. but once again the precise chronological and geographical origins are not yet known. A high production industrial version of the solid state carburization process, known as cementation, was widely used in the western world beginning early in the 17th century. For severe service applications this was supplemented in the mid-18th century by crucible steel, which was made by remelting cementation steel to produce a higher quality material. However, steel remained a relatively low volume, high cost product until the development of the mass production processes (the Bessemer process and the Siemens-Martin open hearth process) for producing steel from blast furnace iron in the mid-19th century. Prior to these developments wrought iron and cast iron, rather than steel, were the predominant ferrous materials in use for structural applications.

Iron and Steel Production

Iron is one of the most abundant elements in the earth's crust, where it is a major constituent of many minerals including oxides, sulfides, silicates and carbonates. Commercially viable ores are predominantly of the oxide or carbonate type, and metallic iron is reduced from such ores with relative ease. Most of the iron produced goes directly for conversion into steel, with minor amounts being modified for use as cast iron. Typical primary production operations involve the blast furnace reduction of iron ore to produce liquid pig iron, a metallic iron containing some 4% carbon. Liquid pig iron is subsequently treated in steelmaking furnaces where carbon and impurities are removed by preferential oxidation. The basic oxygen furnace is the technology most widely used for this purpose at present. Some steel is also produced by remelting scrap or combinations of scrap and ore (e.g. pre-treated pellets) in electric arc furnaces.

All steel is produced in the liquid state, so that before further processing it must be allowed to solidify. In commercial operations this solidification

is carried out using two different practices. The molten steel may be teemed into tall rectangular molds to solidify as ingots, which are subsequently reheated and worked, usually by hot rolling, into semifinished products known as blooms, billets or slabs depending on their dimensions. More commonly, blooms, billets or slabs may be produced directly from liquid iron by continuous casting. In this process the liquid steel is poured into the top of an open-bottomed water-cooled mold while a strand of solid steel is withdrawn continuously from the bottom of the mold. Semifinished steel is converted into finished wrought products such as bars, sheets, strips, plates, structural shapes, wire, rails and tubular products using such operations as hot and cold rolling, drawing, forging and extruding. Many finished products require specific forms of heat treatment which, in combination with the forming operations, produce the specific combinations of properties desired for particular engineering applications.

Deoxidation and Desulfurization

Liquid steel coming from the steelmaking furnace contains high levels of dissolved oxygen which must be removed before the steel is cast, either in a continuous caster or as ingots. Typical deoxidants employed for this purpose are aluminum and silicon (in the form of ferrosilicon). The removal of oxygen from the steel is referred to as killing, thus the expressions "silicon-killed" and "aluminum-killed" steel. Fully killed steel is relatively homogeneous in its chemical composition and properties, and this practice is common in alloy steels and steels which are intended to be forged or carburized. Semi-killed steel has less deoxidant added than is the case for killed steel, and is typically used for low to medium carbon steels for structural applications. However some steels are not killed, and the oxygen remains in the steel where it reacts with carbon forming porosity (blowholes) of carbon oxide gases. These rimmed steels solidify with marked variations in chemical composition within the ingot. They have an outer rim of relatively pure iron, low in carbon, phosphorus and sulfur. These elements occur at higher than average levels in the center of the ingot, especially near the top. The higher purity outer rim makes these steels more suitable for the production of low carbon steel sheet with good surface quality. Capped steels are intermediate between rimmed and semi-killed steels, and are suitable for sheet, strip, wire and bars with carbon levels above 0.15%.

The sulfur in steel originates as impurities in coal, the material which, after it is converted to coke, is used as the fuel and reductant in the iron blast furnace. Conventionally, the addition of manganese compensates for the sulfur in steel, the sulfur being tied up as manganese sulfides, rather than iron sulfides which would be molten at hot rolling

Heat Treating of Steel - The Effects of Carbon Content and Cooling Rate

The heat treating of steel normally begins with heating into the austentite temperature range and allowing the pre-existing microstructure to transform fully to austenite as required by the phase diagram. This austenitizing process may be carried out in any one of a number of atmospheres including air, inert gas, vacuum or molten salt. The hot austenitic steel is then cooled at some rate ranging from rapid (e.g. thousands of degrees per second by quenching in chilled brine) to slow (e.g. as little as a few degrees per hour by furnace cooling in a hot furnace which is allowed to cool with the steel inside). It is important to remember that the cooling rate is normally not uniform throughout the cross-section of the steel object, particularly at rapid cooling rates. The inside of a thick section can only cool by conducting its heat to the surface, where it is removed into the cooling medium; this is always a relatively slow process. The consequence is that if a thick section of steel is quenched, its surface undergoes a much higher cooling rate than its center, and therefore the surface and the center can have different microstructures and properties. Furthermore there will be residual stresses in the material associated with this situation. These effects can be beneficial or detrimental to the application of the material. However in the following discussion such complications will be avoided by considering only the cooling of a thin section, where it can be assumed that the cooling rate is constant throughout the cross-section.

During cooling the austenite becomes unstable, as predicted by the phase diagram, and decomposes or transforms to form a different microstructure, the characteristics of which depend on the austenitization conditions, the carbon content and the cooling rate. There are also effects due to the presence of other alloying elements as discussed below.

A description will first be given of the effects of slow cooling of hypoeutectoid (e.g. 0.4%C) steel from the temperature range where austenite is stable. Note that a finite austenitization time is required to dissolve all pre-existing carbides and to take all carbon into solid solution; this time depends on the thickness of the steel part and is frequently specified as one hour per inch of thickness. The higher the austenitizing temperature above the A_3 temperature (which for this 0.4%C steel is about 820°C or 1504°F), and the longer the time at the austenitizing temperature, the larger the austenite grain size will become. This austenite grain growth has detrimental effects on mechanical properties, so austenitization is generally carried out no more than 60°C (110°F) above the A_3 temperature.

form at cooling rates faster than the maximum at which pearlite can form. Furthermore the details of bainite formation depend strongly on the temperature at which the austenite transforms. At transformation temperatures in the upper part of the bainite formation range, upper bainite is formed. This is a rather feathery-appearing microstructural constituent, in contrast to lower bainite which forms at lower temperatures and is finer and more lenticular (lens-shaped). The distinction between upper and lower bainite is significant, and they can differ appreciably in mechanical properties. For the most part, a steel with a bainitic microstructure is harder, stronger and tougher at low temperatures than steels with ferrite-pearlite or fully pearlitic microstructures and equivalent carbon content. Unfortunately it can be extremely difficult to distinguish a steel microstructure as upper or lower bainite using the optical microscope, or to distinguish upper bainite from fine pearlite or lower bainite from martensite, a phase which will be discussed at length below. Examination using the electron microscope is needed to fully characterize bainites.

Martensite Formation

If austenite can be cooled to a sufficiently low temperature, for example by cooling very rapidly, its diffusion-controlled transformation to ferrite, pearlite or even bainite will not be possible. Instead, the austenite becomes so unstable that it is able to change its crystal structure by a diffusionless shearing transformation which moves blocks of atoms by small distances simultaneously. The transformation product is then *martensite*, a metastable phase which, like bainite, does not appear on the phase diagram since it does not exist under equilibrium conditions. The martensite structure is basically the result of the steel's attempt to transform from austenite (fcc) to ferrite (bcc), a process which is prevented by the presence in the austenite of a large amount of carbon, an amount far above the very low solubility limit of carbon in ferrite. This large supersaturation of carbon prevents a true bcc structure from forming so that the martensite is therefore a compromise structure. It can be thought of as a bcc structure which is highly distorted to accommodate the presence of the excessive amounts of carbon which are trapped at interstitial sites within the martensite structure. As a result, martensite possesses a crystal structure which is body-centered but not cubic; it is rather a body-centered tetragonal (bct) structure as shown in Fig. 1.9.

martensite. Thus the M_s and M_f temperatures decrease with increasing carbon content of the steels. Alloying elements (other than Co) also lower the M_s and M_f temperatures. The M_f temperatures of medium and high carbon steels can be below room temperature, with the consequence that if such a steel is austenitized and quenched to room temperature, its microstructure can consist of a mixture of martensite along with some retained austenite. This retained austenite can affect mechanical properties by lowering the strength and increasing the toughness, but is generally considered to be undesirable since it can cause problems by transforming to (brittle) martensite during subsequent stages of heat treatment or service.

Tempered Martensite

Although martensite is a very hard, strong, wear resistant material it lacks ductility and toughness, so much so that in all but low carbon steels brittle failure of martensite is so easily initiated that its strength cannot normally even be measured. Thus a steel through-hardened (transformed to martensite throughout its thickness) is not a satisfactory engineering material for most applications. However, a surface layer of martensite on a tougher ferrite-pearlite base can provide useful properties as discussed below. Furthermore, and even more usefully, martensite can be heat treated by tempering to obtain a tempered martensite microstructure with properties which are appropriate for industrial purposes. This tempering heat treatment allows a limited amount of carbon diffusion in the distorted bct martensite structure, so as to allow some degree of structural change (e.g. limited carbide formation). This reduces the distortion of the martensite and its internal stresses, with a consequent increase in ductility and toughness at some expense to hardness, strength and wear resistance. The extent of tempering and hence the mechanical properties can be controlled by varying the tempering time and temperature.

As predicted by the iron-iron carbide phase diagram, the stable structure for a carbon steel at ambient temperature is a mixture of ferrite and cementite. Thus during tempering martensite, a non-equilibrium (metastable) phase, tends to decompose in the direction of ferrite and cementite. At normal ambient temperatures, the mobility of carbon in martensite is too low for such changes to occur, and examples of martensite are known which date from more than 3000 years ago. Thus for engineering purposes, martensite can be considered stable. However if carbon is given the chance to diffuse, by tempering even at relatively low temperatures (e.g. hours at as little as 150°C or 300°F) then the amount of carbon diffusion can be sufficient to permit important changes in the martensite. At low tempering temperatures and/or short tempering

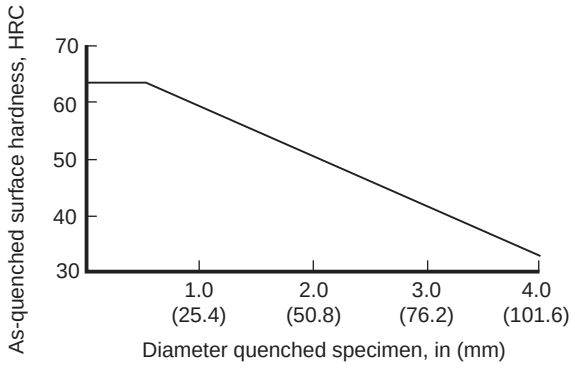


Figure 1.14 Section size effect on surface hardness of 0.54%C steel, water quenched from 830°C (1525°F).

Low carbon steels are characterized by low hardenability, with critical cooling rates only exceeded in thin sections. In higher carbon steels, the hardenability is greater, but the very high hardness and brittleness of high carbon martensite is normally undesirable. In alloy steels, however, the situation is such that a high hardenability can be combined with a good combination of strength and toughness. This is because in alloy steels the interactions between the atoms of alloying element (e.g. Cr, Mo) and carbon atoms slow the rate of carbon diffusion and thus increase the time required for the formation of diffusion-controlled austenite transformation products such as ferrite and pearlite. In other words, alloying elements increase the hardenability, permitting the attainment of a martensite microstructure, which is suitable for tempering, at lower cooling rates. This high hardenability is one of the major reasons for the use of alloy steels. In fact highly alloyed steels can form martensite at rates slow enough to be equivalent to cooling in oil or even in air, hence the designations oil-hardening and air-hardening steels. The use of slower cooling rates to produce martensite is beneficial since it permits martensite formation at a greater depth beneath the surface. Furthermore, slower cooling reduces the magnitude of the residual stresses which are present in the steel after quenching. These residual stresses are caused by a combination of thermal contraction and the volume expansion (2-4%) which accompanies the transformation of austenite to martensite. When these volume changes occur at different times at the surface and at the center of a piece of steel, high levels of residual stresses can result, with consequent distortion and the potential for quench cracking of the steel.

Because the cooling rate will vary with depth, there will also be a hardness gradient from the surface to the center of a quenched bar, the details of which depend on the bar diameter, cooling rate and

hardenability. A standard test, the Jominy end-quench test (ASTM A 255, SAE J406), based on this effect is used to quantitatively evaluate hardenability. Furthermore, the effect can be used in a deliberate way by quenching a steel of limited hardenability to obtain a surface layer (case) of hard brittle martensite on a tough ferrite-pearlite bulk (core) microstructure, as discussed in more detail below.

IT, TTT and CCT Diagrams

Two types of diagram are used to display the hardenability characteristics of steels graphically. These are the *isothermal transformation* (IT) or *time-temperature-transformation* (TTT) *diagram*, and the *continuous cooling transformation* (CCT) *diagram*. The detailed appearance of these diagrams depends on the steel's composition (carbon and alloy content) and its austenite grain size (i.e. austenitization conditions), and thus every steel will have its own diagram for a given set of austenitization conditions. Both types of diagram are designed to predict in detail the transformation characteristics of a particular steel after austenitization, by showing which transformation product microstructures (and in some cases the as-transformed hardnesses) are obtained by various cooling conditions for that steel. The diagrams can also be used in the reverse sense for predicting the cooling conditions necessary to obtain a given microstructure and hardness.

IT diagrams are plots of temperature versus (log) time. They are determined by evaluating the microstructures of austenite which has been quenched from the austenitizing temperature into baths which are at fixed temperatures (hence the name isothermal) below the eutectoid temperature, and held for various amounts of time to allow the austenite to transform. They therefore give a graphical illustration of the time necessary for austenite to transform to its various transformation products at different temperatures.

For example the times necessary for the beginning and the end of the formation of pearlite and bainite can thus be determined as can the M_s and M_f temperatures. These IT curves for plain carbon steels have a very characteristic shape, as shown in Fig. 1.15 which is an IT diagram for 0.8%C steel with an austenite grain size of ASTM No. 6 (the ASTM grain size measurement system is discussed in a section near the end of this chapter). Here the two heavy lines represent the beginning and completion of the transformation of austenite to pearlite and bainite, with an intermediate line showing an estimate of the time necessary for 50% of the austenite to have transformed. Above the nose of the curve the austenite transforms to pearlite while below the nose only bainite forms. The M_s temperature is shown along with the temperature at which

The ASTM grain size number corresponds to a certain number of grains per unit area of the image at the specified magnification, as shown in Table 1.1.

Table 1.1 ASTM No, Grains/in^2, grains/mm^2

ASTM No.	Grains/in^2 at 100X	grains/mm^2 at 1X
0	0.5	8
1	1	16
2	2	31
3	4	62
4	8	124
5	16	248
6	32	496
7	64	992
8	128	1980
9	256	3970
10	512	7940
11	1024	15,870
12	2048	31,700

The relationships between the grain size number and the number of grains per unit area are given by the expressions:

$$N=2^{(n-1)}$$

where N= number of grains per square inch at 100X magnification, and n = ASTM grain size number, or, for SI units, and

$$N = 2^{(n+3)}$$

where N = number of grains per square millimeter (at 1X magnification), and n = ASTM grain size number (BS4490:1969).

In the Planimetric (Jeffries') Procedure a known area is inscribed in the observed field, and the grains within this area (minimum 50) are counted (including half the number of grains which intersect the perimeter of the field) and multiplied by Jeffries' multiplier. The product is the number of grains per square millimeter.

The Intercept Method has two procedures, the lineal (Heyn) procedure and the circular procedure. Both involve placing a grid pattern on the field of observation, and counting the number of grains at each grid intercept within a selected area.

In recent years, software and procedures have been developed to permit the automatic determination of grain size directly from images obtained in microscopes. A number of these computerized image analysis systems and procedures are available, generally from microscope manufacturers or suppliers.

The grain size is one of the most important of the microstructural parameters, as it has a strong effect on the strength and fracture resistance of materials. At high temperatures where creep is a problem, coarser grained materials have advantages. However at normal temperatures a finer-grained microstructure provides improved strength and fracture resistance (toughness) properties compared to a coarser-grained microstructure. For example the yield strength varies as the inverse square root of the average grain diameter. *Grain refinement* is the one process which improves both the yield strength and toughness simultaneously; other strengthening mechanisms, such as cold-working, tend to degrade toughness. Hence many proprietary line pipe steel specifications contain requirements on ferrite grain size to minimize the risk of brittle fracture.

The influence of grain size on fatigue resistance is profound, but not simple. Fine grained materials show greater resistance to fatigue crack initiation, but less resistance to fatigue crack propagation. Fine grained material often exhibits superior formability, particularly in cold bending. Even in high temperature service, fine grained materials often exhibit superior thermal fatigue resistance. Thus, for many elevated temperature service applications an intermediate grain size (e.g. ASTM grain size no. 3 to 8) will provide the best combination of formability, creep and thermal fatigue resistance.

Another good example of the importance of grain size concerns the heat treating of steel. During austenitization above the A_3 or A_{cm} temperatures, the previous microstructure of the steel disappears, pre-existing carbides gradually dissolve, and a new microstructure consisting of equiaxed austenite grains replaces the old one. At higher austenitizing temperatures and/or longer austenitizing times the austenite becomes more homogeneous and opportunity is provided in high carbon steels for more of the pre-existing carbides to dissolve. However, in addition to these effects, growth of the newly formed austenite grains also takes place. For hypoeutectoid steels which have been deoxidized with silicon the austenite grain size increases continuously and progressively as the austenitizing temperature is raised above the A_3 temperature, a behavior considered to be normal. *Coarser grained austenite* tends to transform to coarser grained products after cooling, with correspondingly poorer strength and toughness. For this reason austenitizing temperatures are

Chapter 2

WROUGHT CARBON & ALLOY STEEL METALLURGY

Carbon steels, the most important group of engineering materials in use today, are defined as steels for which there is no minimum specified content of the elements which are normally considered to be alloying elements, including Cr, Co, Mo, Nb (Cb), Ni, Ti, V, W and Zr. Carbon steels must also contain less than 1.65%Mn, less than 0.60%Si and less than 0.60%Cu. Alloy steels contain manganese, silicon and copper in excess of these limits and furthermore have specified ranges or minimums for one or more other alloying elements. *Low alloy steels* are those alloy steels with total alloying element contents, including carbon, of less than about 5%. Low alloy constructional steels are dealt with in this chapter, and the higher alloy stainless steels and tool steels in later chapters. Another type of steel, the *High Strength Low Alloy* (HSLA) steels, can be considered to be intermediate between carbon steels and alloy steels. The HSLA steels are designed to have higher mechanical properties than carbon steels but without the need for the quench and temper heat treatments which are associated with alloy steels.

Carbon and alloy steels are classified in a wide variety of ways. Most common is designation by chemical composition, as in the SAE system (specified by SAE J402), and the UNS system (specified by ASTM E 527 and SAE J1086). Alternatively, steels can be classified on the basis of mechanical properties such as strength, as in ASTM standards, or on the basis of quality descriptors such as forging quality or structural quality. Other bases for classification include the manufacturing method (e.g. basic oxygen furnace or electric furnace), the finishing method (hot rolling, cold rolling, etc.), the product form (bar, sheet, etc.), the deoxidation practice (rimmed, capped, semi-killed, killed), the microstructure (ferritic, pearlitic, martensitic), the heat treatment (annealed, normalized, quenched and tempered). More details describing the various North American metal designation systems are given in Chapter 7.

Chapter 3

CAST STEEL METALLURGY

Steel castings are produced by allowing molten steel to solidify in molds which are appropriately formed so that the solidified steel has a desired shape. Molds suitable for steel castings can be made from metal, ceramic, graphite, or any of a wide variety of types of sand, the choice of mold material being determined by the size, intricacy, surface finish and dimensional accuracy of the casting as well as cost. Castings are made in approximately the same steel compositions that are available as wrought products, and the properties can be expected to be similar, although the mechanical properties of castings are generally less directional. Castings are however susceptible to internal defects and surface imperfections, which can have a potentially serious effect on service performance.

In general, castings are made using fully-killed steel, most often aluminum-killed. Steel castings normally have sulfur and phosphorus limits of 0.06% and 0.05% respectively, slightly higher than those of wrought steels, and they also contain 0.30 to 0.65% silicon and 0.50 to 1.0% manganese. Steel castings are heat treated in much the same manner as are wrought products.

Castings are available in low, medium and high carbon steel as well as in low alloy steel. Low carbon cast steels typically contain between 0.16 and 0.19%C, and are typically either annealed or normalized after casting to refine the structure and relieve residual stresses. Some are quenched and tempered, and some are carburized for wear resistance. Free machining grades contain 0.08 to 0.30% sulfur. Applications include automotive and railway castings as well as furnace components and castings for electrical and magnetic equipment.

Medium carbon grades (0.20 to 0.50%C) are the most commonly produced cast steels. These are heat treated, typically by normalizing and tempering, to produce the desired mechanical properties, but this heat treatment also serves to relieve internal stresses and to refine the microstructure. Alternatively, quench and temper treatments can be used for maximum mechanical properties.

Chapter 4

CAST IRON METALLURGY

Cast irons are ferrous alloys which contain carbon contents in the 2-5% range, well above the normal carbon contents of steels. The other critical alloying element in cast irons is silicon, which is present at concentrations between 1 and 3%. Further alloying elements can be added as required to control specific properties such as resistance to abrasion, wear and corrosion. Like steels, perhaps to an even greater extent, the microstructures and properties of cast irons are determined not only by composition but also by the specific processing conditions which include the solidification process, the solidification rate, the cooling rate in the solid state, and the subsequent heat treating schedules.

The main applications of cast irons arise from a combination of their relatively low cost and wide ranges of properties. Their relatively low melting temperatures compared to steel permit lower cost casting processes and their compositions are such that sound and intricate castings can be obtained. Six basic types of cast iron are produced, namely gray cast iron (gray iron), white cast iron (white iron), ductile (nodular) cast iron, malleable cast iron, compacted graphite cast iron and high alloy cast iron. These cannot be clearly distinguished solely on the basis of chemical composition, since the thermal processing is at least as important as the composition in determining the type of cast iron produced. This is illustrated in Fig. 4.1, which shows the ranges of silicon and iron content for the first four types.

One feature of cast irons which is not encountered to a significant extent in steels is the presence of graphite in the microstructure. In carbon steels the carbon is mainly in the form of cementite (iron carbide) with only a small amount in solution in the ferrite. However, in cast irons (other than white iron) some or all of the carbon is in elemental form as graphite, the balance being mainly as iron carbide. The presence of particular alloying elements in iron stabilizes graphite at the expense of iron carbide, the most important of these graphite stabilizers being silicon and carbon (other less common ones include nickel, aluminum, copper, titanium and zirconium). Thus the higher the silicon and carbon

Chapter 5

TOOL STEEL METALLURGY

Tool steels are ferrous alloys which are intended for use in the working and shaping of metallic and non-metallic materials. They are heat-treatable alloys, ranging from simple carbon steels of high carbon content to complex alloy steels. Applications include drills, dies for extrusion, casting, forming, thread rolling and deep drawing, shear blades, punches, and cutting tools such as chisels, lathe tools and milling cutters. These are demanding applications, and consequently tool steels are high quality materials produced in relatively small quantities with good quality control in compliance with strict specifications. They are supplied in the annealed condition, the purchaser being responsible for forming the steel to the desired shape, then heat treating it by austenitizing, quenching and tempering to obtain the desired properties. Depending on the application, the required properties after heat treatment include strength (hardness), resistance to deformation, to wear and to high temperatures, dimensional stability and edge retention.

Although tool steels were traditionally bar materials ("long products"), much flat bar is now produced as plate ("flat product") and is sawed to size by the distributor.

Tool steels are also employed for structural applications in severe service conditions and in machinery components including high temperature springs, fasteners, valves and bearings.

Austenitization is carried out at a temperature between 770 and 1300°C (1420-2370°F) depending on the alloy. In some cases this involves complete dissolution of pre-existing carbides so that during the subsequent tempering an entirely new dispersion of carbide particles can form. Other cases require only partial carbide dissolution so that the ultimate heat treated microstructure includes both a coarse dispersion of primary carbides and a fine dispersion of secondary carbides, precipitated during tempering, to provide wear resistance and strength respectively. In some cases, such as the high speed steels, carbides can account for up

Chapter 6

STAINLESS STEEL METALLURGY

Development of stainless steels began about 1910 in England and Germany. Since that time these alloys have become an integral part of the world materials scene, playing a vital role in many industries while accounting for only a few percent of total steel production. The early stainless steels were simple alloys of iron and chromium, with chromium contributing the corrosion resistance, oxidation resistance and pleasing appearance which are responsible for the applications of these alloys. When exposed to oxidizing environments, chromium in amounts greater than about 11.5% is responsible for the formation of an invisible adherent passive film on the surface of iron which protects it from further reaction with the environment. This layer, which can be considered to be a chromium-rich oxide, is self-healing if ruptured in oxidizing environments and as long as it is present the alloy can be considered "stainless". The protective layer allows many of these alloys to be useful in high temperature gaseous oxidizing environments as well as in lower temperature and ambient liquid media. In environments which destroy this passive layer, globally or locally, the stainless steel corrodes as if it were carbon steel, and the extra cost of the material has been wasted.

Stainless steels are available in the complete range of product forms. Wrought alloys are produced as plate, sheet, strip, foil, bar, wire, expanded metal mesh, piping and tubing. Cast products are also available, with applicable foundry practices similar to those for carbon and alloy steels. It is important to note the split between long product (bar and billet) producers and flat product (plate, sheet and strip) producers. There are no full-line (long plus flat product) stainless steel producers in the U.S. and there is relatively little co-ordination between the two product lines. Those alloys which are produced across the board often show significant compositional differences. However, many alloys, especially the ferritic stainless steels, are produced only in one of these forms. For example, free-machining alloys are produced as bar and occasionally as plate product but never as sheet or strip. High chromium stabilized ferritic alloys are widely produced as sheet and strip but rarely (type 446 being the significant exception) as bar or plate due to the influence of section size on the ductile-brittle transition.

Chapter 7

NORTH AMERICAN METAL STANDARD DESIGNATION SYSTEMS

Introduction

In the world of standardization, metals pioneered the way at the turn of this century. In 1895, the French government assigned a commission to formulate standard methods of testing materials of construction. Later that year, the European member countries of the International Association for Testing Materials (IATM) held their first conference in Zurich and standardization of metals began.

Today, there are numerous national, continental, and international standards each with its own cryptic designation system to identify metals and their alloys. The evolution of the metals industry has left us with numerous designation systems, even within an individual standards organization, and these have become blurred and less meaningful as new generations of technical personnel are passed the torch to carry on the task of standardization.

By reviewing some examples of the more prominent metals designation systems, a direction is offered to assist those who use metal standards as a part of their work or study. This chapter is not all inclusive. The amount of information on this topic could easily make up a complete book.

American Metal Standard Organizations

There are many metals standards organizations in the United States, a few of the more prominent ones are listed as follows:

AA	The Aluminum Association
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
AMS	Aerospace Material Specifications (SAE)
ASME	ASME International
ASTM	ASTM International
AWS	American Welding Society
CSA	CSA International
SAE	SAE International

For each North American organization issuing metal specifications and standards, there is a designation system used to identify various metal and alloys. These designation systems grew according to the history of each group, and generally identify a metal by use of a coded number or alphanumeric designator. In some cases, numbers and letters were assigned in a sequential order by the respective listing organization, while in other cases they were given in a manner which directly identified chemical composition or mechanical properties. Some of the more popular North American designation systems for metals are presented below, with descriptive examples given.

American Society for Testing and Materials (ASTM)

Founded in 1898, the first complete book of ASTM Standards was published in 1915. Today there are over 70 ASTM books of standards contained in 15 sections, with over 11,000 standards. For the most part, the metals related standards are found in Section 1 - Iron and Steel Products (7 volumes), Section 2 - Nonferrous Metal Products (5 volumes), and Section 3 - Metals Test Methods and Analytical Procedures (6 volumes). ASTM standards must be revised or reissued every 5 years, although many are revised much sooner. Some standards (e.g. ASTM A 240) change several times a year and letter suffixes (a, b, c, etc.) are used to track mid-year revisions. Aproximately 40% of ASTM standards change every year, not including the new standards that were issued that year, which makes staying current with the latest standards a major challenge.

ASTM Specification System

Steel products are catagorized according to designation systems such as the ASTM/SAE Unified Numbering System described below, and also according to specification systems. These are statements of requirements, technical and commercial, that a product must meet, and therefore they can be used for purposes of procurement. One widely used system of specifications has been developed by the ASTM. The designation consists of a letter (A for ferrous materials) followed by an arbitrary serially-assigned number. These specifications often apply to specific products, for example ASTM A 548 is applicable to cold-heading quality carbon steel wire for tapping or sheet metal screws. Metric ASTM specifications have a suffix letter M. Some ASTM specifications (e.g. bars, wires and billets for forging) incorporate SAE designations for composition while others (e.g. plates and structural shapes) specify composition limits and ranges directly. Such requirements as strength levels, manufacturing and finishing methods and heat treatments are frequently incorporated into the ASTM product specifications.

Ferrous Metal Definition

Prior to 1993 the ASTM definition for ferrous metals was based on nominal chemical composition, where an iron content of 50% or greater determined the alloy to be ferrous. Consequently, these standards begin with the letter "A". If the iron content was less than 50%, then the next abundant element would determine the type of nonferrous alloy. Generally these standards begin with the letter "B". For example, should nickel be the next predominant element then the metal would be a nickel alloy.

Currently, ASTM has a definition similar to that in the EuroNorm Standard CEN EN10020 - Definition and Classification of Steel, which defines steel as:

> "A material which contains by weight more iron than any single element, having a carbon content generally less than 2% and containing other elements. A limited number of chromium steels may contain more than 2% of carbon, but 2% is the usual dividing line between steel and cast iron."

The CEN committee responsible for this standard has suggested changing the term "by weight" to "by mass" in order to stay consistent with the International System of Units.

The ASTM A 941-01 definition has already adopted the use of mass instead of weight and, recognizing that the issues relate more to specifications than metallurgy, defines steel as:

> "steel, n—a material that conforms to a specification that requires, by mass percent, more iron than any other element and a maximum carbon content of generally less than 2."

ASTM Steels

Examples of the ASTM ferrous metal designation system, describing its use of specification numbers and letters, are as follows.

ASTM A 516/A 516M-01 Grade 70 - Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service:

- the "A" describes a ferrous metal, but does not sub-classify it as cast iron, carbon steel, alloy steel or stainless steel.
- 516 is simply a sequential number without any direct relationship to the metal's properties.
- the "M" indicates that the standard A 516M is written in SI units (as a soft conversion) (the "M" comes from the word "Metric"), hence together A 516/A 516M utilizes both inch-pound and SI units.
- 01 indicates the year of adoption or revision. If a lower case letter follows, it indicates that there was more than one edition published in that year.
- Grade 70 indicates the minimum tensile strength in ksi, i.e. 70 ksi (70,000 psi) minimum.

Originally in the carbon and alloy steel industries, but not the stainless industry, the terms "grade", "type" and "class" had specific meaning. "Grade" was used to describe chemical composition, "type" was used to define deoxidation practice, and "class" was used to indicate other characteristics such as strength level or surface finish. However, within ASTM standards these terms were adapted for use to identify a particular metal within a metal standard and are used without any strict definition, but essentially mean the same thing. Some rules-of-thumb do exist, with a few examples as follows.

Unified Numbering System (UNS) For Metals And Alloys

SAE and ASTM began discussion of a Unified Numbering System (UNS) for metals and alloys in 1967. The intent of the program was three-fold:

1. Simplify the many differing designation systems, independently established over the previous 60 years.
2. Give trade names a generic number, especially helpful when several companies produced the same alloy under different trade names.
3. Make a new system computer friendly by developing a consistent designation.

In 1969 the U.S. Army sponsored a study by SAE and ASTM into the development of a Unified Numbering System. The first published edition of the UNS for Metals and Alloys was in 1975, co-published by SAE and ASTM, and has since been updated about every 3 years. The UNS is available as a hard copy book and in a software version. The computer software program is known as UNSearch. Details of the Unified Numbering System are specified in ASTM E 527: Practice for Numbering Metals and Alloys (UNS).

UNS Designations

The UNS is an alphanumeric designation system consisting of a letter followed by five numbers. This system only represents chemical composition for an individual metal or alloy and is not a metal standard or specification. For the most part, existing systems, such the SAE designations, were incorporated into the UNS so that some familiarity was given to the system where possible. For example, the UNS prefix letter for carbon and alloy steels is "G", and the first four digits are the SAE designation, e.g. G10400. The intermediate letters "B" and "L" of the SAE system are replaced by making the fifth digit of the UNS designation 1 and 4 respectively, while the prefix letter "E" for electric furnace steels is designated in UNS system by making the fifth digit "6". The AISI/SAE steels which have a hardenability requirement indicated by the suffix letter "H" are designated by the Hxxxxx series in the UNS system. Carbon and alloy steels not referred to in the SAE system are categorized under the prefix letter "K".

Where possible, the first letter in the system denotes the metal group, for instance "S" designates stainless steels. 0f the five digits of the UNS designation for stainless steels, the first three are from the AISI designation if there was one, e.g. S304xx. The final two digits are equivalent to the various modifications represented by suffix letters in the

Chapter

8

METALLURICAL TERMS DEFINITIONS & GLOSSARY

English/French Definitions

A

A_1 temperature. The eutectoid temperature of a steel.
température A_1. La température eutectoïde d'un acier.

A_2 temperature. Curie temperature, where bcc iron upon reaching this temperature, 1420°F (770°C), becomes nonmagnetic.
température A_2. La température de Curie, température à laquelle le fer bcc, lorsqu'atteignant cette température, 1420°F (770°C), devient non magnétique.

A_3 temperature. The temperature at which proeutectoid ferrite begins to separate from austenite under conditions of slow cooling.
température A_3. La température à laquelle la ferrite proeutectoïde commence à se séparer de l'austénite sous des conditions de refroidissement lent.

A_{cm} temperature. The temperature at which proeutectoid cementite begins to separate from austenite under conditions of slow cooling.
température A_{cm}. La température à laquelle la cémentite proeutectoïde commence à se séparer de l'austénite sous des conditions de refroidissement lent.

abrasion. The process of grinding or wearing away using abrasives.
abrasion. Le procédé consistant à moudre ou à user en utilisant des abrasifs.

abrasive. A substance capable of grinding away another material.

abrasif. Une substance capable de moudre un autre matériau.

age hardening. Hardening by aging, usually after rapid cooling or cold working.
durcissement par vieillissement. Durcissement par vieillissement, habituellement après refroidissement rapide ou après écrouissage.

aging. A change in properties that occurs at ambient or moderately elevated temperatures after hot working or a heat treating operation (quench aging in ferrous alloys), or after a cold working operation (strain aging). The change in properties is often, but not always, due to a phase change (precipitation), but does not involve a change in chemical composition.
vieillissement. Un changement de propriétés qui se produit à la température ambiante ou à des températures modérément élevées après formage à chaud ou après une opération de traitement thermique (vieillissement après trempe pour les alliages ferreux), ou après une opération d'écrouissage (vieillissement sous tension). Le changement de propriétés est souvent, mais pas toujours, dû à un changement de phase (précipitation), mais n'implique pas de changement de la composition chimique.

allotriomorph. A particle of a phase that has no regular external shape.
allotriomorphe. Une particule d'une phase qui n'a pas de forme externe régulière.

allotropy. The property whereby certain elements may exist in more than one crystal structure. See *polymorphism.*
allotropie. La propriété par laquelle certains éléments peuvent exister sous plus qu'une structure de cristal. Voir *polymorphisme*.

alloy. A substance having metallic properties and composed of two or more chemical elements of which at least one is a metal.
alliage. Une substance ayant des propriétés métalliques et composée de deux éléments chimiques ou plus dont au moins un est un métal.

alloy steel. Steel containing significant quantities of alloying elements (other than carbon and the commonly accepted amounts of manganese, silicon, sulfur and phosphorus) added to effect changes in mechanical or physical properties. Those containing less than 5% total metallic alloying elements tend to be termed low-alloy steels, and those containing more than 5% tend to be termed high-alloy steels.
acier allié. Acier contenant des quantités significatives d'éléments d'alliage (autre que le carbone et les quantités communément acceptées de manganèse, de silicium, de soufre, et de phosphore) ajoutés pour effectuer

GLOSSARY / LEXIQUE / LÉXICO / WÖRTERVERZEICHNIS			
ENGLISH	**FRENCH**	**SPANISH**	**GERMAN**
case hardening	trempe superficielle; durcissement superficiel	cementación en caja	Einsatzhärtung; Oberflächenhärten
cast iron	fonte de moulage	arrabio; hierro colado	Gußeisen
cast steel	acier moulé	acero moldeado; vaciado	Stahlguß
casting	moulage	pieza fundida; pieza de fundición; colada del acero líquido; fundición	Gußerzeugnisse
cementation	cémentation	cementación	Zementation
cementite	cémentite	cementita	Zementit
chafery	chaferie	rozamiento	chaferie
chemical polishing	polissage chimique	pulido químico	chemisches Polieren
cleavage	clivage	exfoliación o despegue	Spaltbruch; Spaltung
cleavage fracture	rupture par clivage	fractura transcristalina a través de planos de deslizamiento	Trennbruch; Sprödbruch
cleavage plane	plan de clivage	plano de despegue	Spaltfläche
columnar structure	structure basaltique	estructura columnar	Stengelgefüge
constituent	constituant	constituyente	Konstituent; Bestandteil
constitutional diagram	diagramme de constitution	diagrama de fases	Zustandsschaubild
continuous phase	phase continue	fase continua	kontinuierliches Phase
controlled rolling	laminage contrôlé	laminado controlado	Regelrollen
coring	noyautage; cernes	microsegregación o segregación intragranular	Kristallseigerung; Mikroseigerung
corrosion	corrosion	corrosión	Korrosion
creep	fluage	fluencia	Kriechen
critical cooling rate	vitesse de refroidissement critique	velocidad crítica de enfriamiento	kritische Abkühlungsgeschwindigkeit

Chapter

9

CAST IRONS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS, & MECHANICAL PROPERTIES

CAST IRONS (Continued)	
White Iron Castings	
A 518/A 518M	Corrosion-Resistant High-Silicon Iron Castings
A 532/A 532M	Abrasion-Resistant Cast Irons
A 667/A 667M	Centrifugally Cast Dual Metal (Gray and White Cast Iron) Cylinders
A 748/A 748M	Statically Cast Chilled White Iron-Gray Iron Dual Metal Rolls for Pressure Vessel Use
A 942	Centrifugally Cast White Iron/Gray Iron Dual Metal Abrasion-Resistant Roll Shells
Iron Pipe and Fittings	
A 74	Cast Iron Soil Pipe and Fittings
A 126	Gray Iron Castings for Valves, Flanges, and Pipe Fittings
A 338	Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine, and Other Heavy Duty Service at Temperatures Up to 650°F (345°C)
A 377	Ductile-Iron Pressure Pipe, Index of Specifications for
A 674	Polyethylene Encasement for Ductile Iron Pipe for Water or Other Liquids
A 716	Ductile Iron Culvert Pipe
A 746	Ductile Iron Gravity Sewer Pipe
A 861	High-Silicon Iron Pipe and Fittings
A 888	Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications
General	
A 644	Iron Castings, Terminology Relating to
A 834	Common Requirements for Iron Castings for General Industrial Use
A 842	Compacted Graphite Iron Castings
Methods of Testing Cast Iron	
A 247	Evaluating the Microstructure of Graphite in Iron Castings
A 327	Impact Testing of Cast Irons
A 327M	Impact Testing of Cast Irons [Metric]
A 367	Chill Testing of Cast Iron
A 438	Transverse Testing of Gray Cast Iron

Chapter 10

CASTINGS CARBON & ALLOY STEELS: AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

CHEMICAL COMPOSITION OF ALLOY STEEL CASTINGS FOR PRESSURE CONTAINING PARTS (Continued)

ASTM Spec.	UNS	C	Mn	Si	S	P	Cr	Ni	Mo	Other
A 487 Gr 14 Cl A	J15580	0.55	0.80-1.10	0.60	0.045	0.04	---	1.40-1.75	0.20-0.30	d
A 487 Gr 16 Cl A	J31200	0.12[f]	2.10[f]	0.50	0.02	0.02	---	1.00-1.40	---	c
A 757 Gr B2N, B2Q	J22501	0.25	0.50/0.80	0.60	0.025	0.025	---	2.0/3.0	---	0.03 V, 0.50 Cu, 0.40 Cr, 0.25 Mo[a]
A 757 Gr B3N, B3Q	J31500	0.15	0.50/0.80	0.60	0.025	0.025	---	3.0/4.0	---	0.03 V, 0.50 Cu, 0.40 Cr, 0.25 Mo[a]
A 757 Gr B4N, B4Q	J41501	0.15	0.50/0.80	0.60	0.025	0.025	---	4.0/5.0	---	0.03 V, 0.50 Cu, 0.40 Cr, 0.25 Mo[a]
A 757 Gr C1Q	J12582	0.25	1.20	0.60	0.025	0.025	---	1.5/2.0	0.15/0.30	0.03 V, 0.50 Cu, 0.40 Cr[a]
A 757 Gr D1N1, D1Q1, D1N2, D1Q2, D1N3, D1Q3	J22092	0.20	0.40/0.80	0.60	0.025	0.025	2.0/2.75	---	0.90/1.20	0.03 V, 0.50 Cu, 0.50 Ni, 0.10 W[a]
A 757 Gr E1Q	J42220	0.22	0.50/0.80	0.60	0.025	0.025	1.35/1.85	2.5/3.5	0.35/0.60	0.03 V, 0.50 Cu[e]
A 757 Gr E2N, E2Q	J42065	0.20	0.40/0.70	0.60	0.020	0.020	1.50/2.0	2.75/3.90	0.40/0.60	0.03 V, 0.50 Cu, 0.10 W[e]

a. Total residual elements not to exceed 1.00%; see ASTM specs. for details.
b. Total residual elements not to exceed 0.60%; see ASTM specs for details.
c. Total residual elements not to exceed 0.50%; see ASTM specs for details.
d. Total residual elements not to exceed 0.75%; see ASTM specs for details.
e. Total residual elements not to exceed 0.70%; see ASTM specs for details.
f. For each reduction of 0.01% C below the maximum carbon content, an increase of 0.04% Mn above the maximum allowable is permitted up to a maximum of 1.00% for ASTM A 356/A 356M Gr 2 and Gr 5, and 2.30% Mn for ASTM A 487 Gr 16 Cl A.
Single values are maximums, unless otherwise specified.

CHEMICAL COMPOSITION OF STEEL CASTING ALLOYS, SPECIALLY HEAT-TREATED FOR PRESSURE-CONTAINING PARTS, SUITABLE FOR HIGH-TEMPERATURE SERVICE

ASTM Spec.	UNS	C	Mn	Si	S	P	Cr	Mo	V	Application
A 389 Gr. C23	J12080	0.20	0.30-0.80	0.60	0.045	0.04	1.00-1.50	0.45-0.65	0.15-0.25	Pressure-containing parts
A 389 Gr. C24	J12092	0.20	0.30-0.80	0.60	0.045	0.04	0.80-1.25	0.90-1.20	0.15-0.25	Pressure-containing parts

Single values are maximums, unless otherwise specified.

CHEMICAL COMPOSITION OF ALLOY STEEL CASTINGS FOR PRESSURE CONTAINING PARTS FOR LOW TEMPERATURE SERVICE

ASTM Spec.	UNS	C	Mn	Si	S	P	Cr	Ni	Mo	Other
A 352 Gr LC1	J12522	0.25	0.50-0.80	0.60	0.045	0.04	---	---	0.45-0.65	---
A 352 Gr LC2	J22500	0.25	0.50-0.80	0.60	0.045	0.04	---	2.00-3.00	---	---
A 352 Gr LC2-1	J42215	0.22	0.55-0.75	0.50	0.045	0.04	1.35-1.85	2.50-3.50	0.30-0.60	---
A 352 Gr LC3	J31550	0.15	0.50-0.80	0.60	0.045	0.04	---	3.00-4.00	---	---
A 352 Gr LC4	J41500	0.15	0.50-0.80	0.60	0.045	0.04	---	4.00-5.00	---	0.30 Cu
A 352 Gr LC9	J31300	0.13	0.90	0.45	0.045	0.04	0.50	8.50-10.0	0.20	0.03 V

Single values are maximums, unless otherwise specified.

CHEMICAL COMPOSITION OF AUSTENITIC MANGANESE STEEL CASTINGS

ASTM Spec[a, c]	UNS	C	Mn	Si	P	Cr	Mo	Ni
A 128 Gr. A[b]	J91109	1.05-1.35	11.0 min.	1.00	0.07	---	---	---
A 128 Gr. B-1	J91119	0.9-1.05	11.5-14.0	1.00	0.07	---	---	---
A 128 Gr. B-2	J91129	1.05-1.2	11.5-14.0	1.00	0.07	---	---	---
A 128 Gr. B-3	J91139	1.12-1.28	11.5-14.0	1.00	0.07	---	---	---
A 128 Gr. B-4	J91149	1.2-1.35	11.5-14.0	1.00	0.07	---	---	---
A 128 Gr. C	J91309	1.05-1.35	11.5-14.0	1.00	0.07	1.5-2.5	---	---
A 128 Gr. D	J91459	0.7-1.3	11.5-14.0	1.00	0.07	---	---	3.0-4.0

Chapter 11

WROUGHT CARBON & ALLOY STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

STRUCTURAL STEELS	
ASTM Spec.	**Title**
A 6/A 6M	General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
A 36/A 36M	Carbon Structural Steel
A 131/A 131M	Structural Steel for Ships
A 242/A 242M	High-Strength Low-Alloy Structural Steel
A 252	Welded and Seamless Steel Pipe Piles
A 283/A 283M	Low and Intermediate Tensile Strength Carbon Steel Plates
A 328/A 328M	Steel Sheet Piling
A 514/A 514M	High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Welding
A 529/A 529M	High-Strength Carbon-Manganese Steel of Structural Quality
A 572/A 572M	High-Strength Low-Alloy Columbium-Vanadium Structural Steel
A 573/A 573M	Structural Carbon Steel Plates of Improved Toughness
A 588/A 588M	High-Strength Low-Alloy Structural Steel with 50 ksi [345 MPa] Minimum Yield Point to 4-in. [100-mm] Thick
A 633/A 633M	Normalized High-Strength Low-Alloy Structural Steel Plates
A 656/A 656M	Hot-Rolled, Structural Steel, High-Strength Low-Alloy Plate with Improved Formability
A 673/A 673M	Sampling Procedure for Impact Testing of Structural Steel
A 678/A 678M	Quenched-and-Tempered Carbon and High-Strength Low-Alloy Structural Steel Plates
A 690/A 690M	High-Strength Low-Alloy Steel H-Piles and Sheet Piling for Use in Marine Environments
A 709/A 709M	Carbon and High-Strength Low-Alloy Structural Steel Shapes, Plates, and Bars and Quenched-and-Tempered Alloy Structural Steel Plates for Bridges
A 710/A 710M	Age-Hardening Low-Carbon Nickel-Copper-Chromium-Molybdenum-Columbium Alloy Structural Steel Plates
A 769/A 769M	Carbon and High-Strength Electric Resistance Welded Steel Structural Shapes
A 786/A 786M	Hot-Rolled Carbon, Low-Alloy, High-Strength Low-Alloy, and Alloy Steel Floor Plates
A 808/A 808M	High-Strength Low-Alloy Carbon, Manganese, Columbium, Vanadium Steel of Structural Quality with Improved Notch Toughness
A 827/A 827M	Plates, Carbon Steel, for Forging and Similar Applications
A 829/A 829M	Alloy Structural Steel Plates
A 830/A 830M	Plates, Carbon Steel, Structural Quality, Furnished to Chemical Composition Requirements

ASTM A 36/A 36M – CHEMICAL REQUIREMENTS FOR CARBON STRUCTURAL STEEL[a] (Continued)

a. Single values are maximums, except for Cu which are minimum values. b. Mn content of 0.85-1.35% and Si content of 0.15-0.40% is required for shapes over 426 lb/ft (634 kg/m). c. For each reduction of 0.01% below the specified C maximum, an increase of 0.06% Mn above the specified maximum will be permitted up to the maximum of 1.35%. d. When copper steel is specified. incl. – inclusive.

ASTM A 830/A 830M – CHEMICAL COMPOSITION FOR CARBON STEEL PLATES[a, b]

UNS	SAE	C	Mn	P	S
G10060	1006	0.08 max.	0.45 max.	0.035	0.04
G10080	1008	0.10 max	0.50 max.	0.035	0.04
G10090	1009	0.15 max.	0.60 max.	0.035	0.04
G10100	1010	0.08-0.13	0.30-0.60	0.035	0.04
G10120	1012	0.10-0.15	0.30-0.60	0.035	0.04
G10150	1015	0.12-0.18	0.30-0.60	0.035	0.04
G10160	1016	0.12-0.18	0.60-0.90	0.035	0.04
G10170	1017	0.14-0.20	0.30-0.60	0.035	0.04
G10180	1018	0.14-0.20	0.60-0.90	0.035	0.04
G10190	1019	0.14-0.20	0.70-1.00	0.035	0.04
G10200	1020	0.17-0.23	0.30-0.60	0.035	0.04
G10210	1021	0.17-0.23	0.60-0.90	0.035	0.04
G10220	1022	0.17-0.23	0.70-1.00	0.035	0.04
G10230	1023	0.19-0.25	0.30-0.60	0.035	0.04
G10250	1025	0.22-0.28	0.30-0.60	0.035	0.04
G10260	1026	0.22-0.28	0.60-0.90	0.035	0.04
G10300	1030	0.27-0.34	0.60-0.90	0.035	0.04
G10330	1033	0.29-0.36	0.70-1.00	0.035	0.04
G10350	1035	0.31-0.38	0.60-0.90	0.035	0.04
G10370	1037	0.31-0.38	0.70-1.00	0.035	0.04

ASTM A 36/A 36M - MECHANICAL PROPERTIES FOR CARBON STRUCTURAL STEEL[a]

	Tensile Strength		Yield Point, min.		% El., min., in 8 in. (200 mm)	% El., min., in 2 in. (50 mm)
	ksi	MPa	ksi	MPa		
Plates, Shapes[b], Bars	58-80	400-550	36[c]	250[c]	---	---
Plates, Bars[d,e]	---	---	---	---	20	23
Shapes	---	---	---	---	20	21[b]

a. See Specimen Orientation under the Tension Tests section of Specification A 6/A6 M.

b. For wide flange shapes over 426 lb/ft (634 kg/m), the 80 ksi (550 MPa) maximum tensile strength does not apply and a minimum elongation in 2 in. (50 mm) of 19% applies.

c. Yield point 32 ksi (220 MPa) for plates over 8 in. (200 mm) in thickness.

d. Elongation not required to be determined for floor plate.

e. For plates wider than 24 in. (600 mm), the elongation requirement is reduced two percentage points. See elongation requirement adjustments under the Tension Tests section of Specification A 6/A6 M.

ASTM A 573/A 573M - MECHANICAL PROPERTIES FOR STRUCTURAL CARBON STEEL PLATES OF IMPROVED TOUGHNESS[a]

	Tensile Strength		Yield Point, min.		% El., min., in 8 in. (200 mm)[b,c]	% El., min., in 2 in. (50 mm)[b,c]
	ksi	MPa	ksi	MPa		
Grade 58 (400)	58-71	400-490	32	220	21	24
Grade 65 (450)	65-77	450-530	35	240	20	23
Grade 70 (485)	70-90	485-620	42	290	18	21

a. See Specimen Orientation in the Tension Tests section of Specification A 6/A 6M.

b. Elongation not required to be determined for floor plate.

c. For plates wider than 24 in. (600 mm), the elongation requirement is reduced two percentage points. See elongation requirement adjustments under the Tension Tests section of Specification A 6/A6 M.

ASTM A 678/A 678M - MECHANICAL PROPERTIES FOR QUENCHED-AND-TEMPERED CARBON AND HIGH-STRENGTH LOW-ALLOY STRUCTURAL STEEL PLATES[a]

	Tensile Strength, ksi (MPa)					Yield Strength, min., ksi (MPa)[b]					% El., min.[d,e], in 2 in. (50 mm)
Thickness in. (mm)	To ¾ (20), incl.	> ¾ to 1½ (20 to 40), incl.	> 1½ to 2 (40 to 50), incl.	> 2 to 2½ (50 to 65), incl.	> 2½ to 3 (65 to 75), incl.	To ¾ (20), incl.	> ¾ to 1½ (20 to 40), incl.	> 1½ to 2 (40 to 50), incl.	> 2 to 2½ (50 to 65), incl.	> 2½ to 3 (65 to 75), incl.	
Grade A	70-90 (485-620)	70-90 (485-620)	c	c	c	50 (345)	50 (345)	c	c	c	22
Grade B	80-100 (550-690)	80-100 (550-690)	80-100 (550-690)	80-100 (550-690)	c	60 (415)	60 (415)	60 (415)	60 (415)	c	22
Grade C	95-115 (655-790)	90-110 (620-760)	85-105 (585-720)	c	c	75 (515)	70 (485)	65 (450)	c	c	19
Grade D	90-110 (620-760)	90-110 (620-760)	90-110 (620-760)	90-110 (620-760)	90-110 (620-760)	75 (515)	75 (515)	75 (515)	75 (515)	75 (515)	18

a. See Specimen Orientation under the Tension Tests section of Specification A 6/A 6M. b. Measured at 0.2% offset or 0.5% extension under load. c. The size and grade is not described in this specification. d. For thickness of ¾ in. (20 mm) and under, measured on 1½ in. (40 mm) wide full thickness rectangular specimen as shown in Fig. 4 of Test Methods and Definitions A 370. The elongation is measured in a 2-in. (50-mm) gage length which includes the fracture and which shows the greatest elongation. e. For plates wider than 24 in. (600 mm), the elongation requirement is reduced two percentage points. See elongation requirement adjustments in the Tension Tests section of Specification A 6/A 6M.

ASTM A 871/A 871M - MECHANICAL PROPERTIES FOR HIGH-STRENGTH LOW-ALLOY STRUCTURAL STEEL PLATE WITH ATMOSPHERIC CORROSION RESISTANCE[a]

	Tensile Strength, min.		Yield Strength[b], min.		% El., min., in 8 in. (200 mm)[c]	% El., min., in 2 in. (50 mm)[c]	Impact (Charpy V-Notch) ft-lb (J) at °F (°C)
	ksi	MPa	ksi	MPa			
Grade 60	75	520	60	415	16	18	15 (20) at 0 (-18)[d] 15 (20) at -20 (-29)[e]
Grade 65	80	550	65	450	15	17	15 (20) at 0 (-18)[d] 15 (20) at -20 (-29)[e]

Chapter 12

FORGINGS CARBON, ALLOY & STAINLESS STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

CARBON, ALLOY AND STAINLESS STEEL FORGINGS	
ASTM Spec.	**Title**
Carbon and Alloy Steel Forgings	
A 105/A 105M	Carbon Steel Forgings for Piping Applications
A 181/A 181M	Carbon Steel Forgings, for General-Purpose Piping
A 182/A 182M	Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
A 266/A 266M	Carbon Steel Forgings for Pressure Vessel Components
A 288	Carbon and Alloy Steel Forgings for Magnetic Retaining Rings for Turbine Generators
A 289/A 289M	Alloy Steel Forgings for Nonmagnetic Retaining Rings for Generators
A 290	Carbon and Alloy Steel Forgings for Rings for Reduction Gears
A 291	Steel Forgings, Carbon and Alloy, for Pinions, Gears and Shafts for Reduction Gears
A 336/A 336M	Alloy Steel Forgings for Pressure and High-Temperature Parts
A 350/A 350M	Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components
A 372/A 372M	Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels
A 427	Wrought Alloy Steel Rolls for Cold and Hot Reduction
A 469	Vacuum-Treated Steel Forgings for Generator Rotors
A 470	Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts
A 471	Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels
A 508/A 508M	Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels
A 521	Steel, Closed-Impression Die Forgings for General Industrial Use
A 522/A 522M	Forged or Rolled 8 and 9% Nickel Alloy Steel Flanges, Fittings, Valves, and Parts for Low-Temperature Service
A 541/A 541M	Quenched and Tempered Carbon and Alloy Steel Forgings for Pressure Vessel Components
A 579	Superstrength Alloy Steel Forgings
A 592/A 592M	High-Strength Quenched and Tempered Low-Alloy Steel Forged Fittings and Parts for Pressure Vessels
A 646	Premium Quality Alloy Steel Blooms and Billets for Aircraft and Aerospace Forgings
A 649/A 649M	Forged Steel Rolls Used for Corrugating Paper Machinery
A 668/A 668M	Steel Forgings, Carbon and Alloy, for General Industrial Use
A 694/A 694M	Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service

CHEMICAL COMPOSITION OF CARBON STEEL FORGINGS							
ASTM Spec.	**UNS**	**C**	**Mn**	**Si**	**S**	**P**	**Other**
A 105	---	0.35	0.60-1.05	0.10-0.35	0.040	0.035	0.40 Cu, 0.40 Ni, 0.30 Cr, 0.12 Mo, 0.08 V, 0.02 Cb
A 181 Cl 60,70	K03502	0.35	1.10	0.10-0.35	0.05	0.05	---
A 266 Gr 1, 2	K03506	0.30	0.40-1.05	0.15-0.35	0.025	0.025	---
A 266 Gr 3	K05001	0.35	0.80-1.35	0.15-0.35	0.025	0.025	---
A 266 Gr 4	K03017	0.30	0.80-1.35	0.15-0.35	0.025	0.025	---
A 288 Cl 1	K05002	0.50	0.60-1.00	0.15-0.30	0.025	0.025	---
A 290 Cl A, B	K04000	0.35-0.50	0.60-0.90	0.35	0.040	0.040	0.30 Ni, 0.25 Cr, 0.10 Mo, 0.06 V, 0.35 Cu
A 290 Cl C, D	K04500	0.40-0.50	0.60-0.90	0.35	0.040	0.040	0.30 Ni, 0.25 Cr, 0.10 Mo, 0.06 V, 0.35 Cu
A 291 Cl 1	K05500	0.55	0.60-0.90	0.35	0.040	0.040	0.30 Ni, 0.25 Cr, 0.10 Mo, 0.06 V, 0.35 Cu
A 291 Cl 2	K05000	0.50	0.40-0.90	0.35	0.040	0.040	0.10 V, 0.35 Cu
A 350 Gr LF1	K03009	0.30	0.60-1.35	0.15-0.30	0.040	0.035	0.40 Ni, 0.30 Cr, 0.12 Mo, 0.40 Cu, 0.02 Cb, 0.05 V
A 350 Gr LF2	K03011	0.30	0.60-1.35	0.15-0.30	0.040	0.035	0.40 Ni, 0.30 Cr, 0.12 Mo, 0.40 Cu, 0.02 Cb, 0.05 V
A 372 Gr A	K03002	0.30	1.00	0.15-0.35	0.025	0.025	---
A 372 Gr B	K04001	0.35	1.35	0.15-0.35	0.025	0.025	---
A 372 Gr C	K04801	0.48	1.65	0.15-0.35	0.025	0.025	---
A 469 Cl 1	K14501	0.45	0.90	0.15-0.35	0.015	0.015	0.03-0.12 V
A 470 Cl 1	K14501	0.45	0.90	0.15-0.35	0.025	0.025	0.03 min V
A 508 Gr 1	K13502	0.35	0.40-1.05	0.15-0.40	0.025	0.025	0.40 Ni, 0.25 Cr, 0.10 Mo, 0.05 V
A 508 Gr 1A	K13502	0.30	0.70-1.35	0.15-0.40	0.025	0.025	0.40 Ni, 0.25 Cr, 0.10 Mo, 0.05 V
A 541 Gr 1	K03506	0.35	0.40-0.90	0.15-0.35	0.025	0.025	0.40 Ni, 0.25 Cr, 0.10 Mo, 0.05 V
A 541 Gr 1A	---	0.30	0.70-1.35	0.15-0.40	0.025	0.025	0.40 Ni, 0.25 Cr, 0.10 Mo, 0.05 V
A 649 Cl 2	K05001	0.55	0.50-0.90	0.15-0.35	0.025	0.025	---
A 649 Cl 4	---	0.35	0.60-1.05	0.15-0.35	0.025	0.025	---
A 694 [a, c]	K03014	0.26	1.40	0.15-0.35	0.025	0.025	---
A 707 Gr L1[a]	K02302	0.20	0.60-1.50	0.35	0.030	0.030	0.30 Cr, 0.40 Ni, 0.12 Mo, 0.05 V, 0.40 Cu, 0.02 Cb
A 707 Gr L2[a]	K03301	0.30	0.60-1.35	0.35	0.030	0.030	0.30 Cr, 0.40 Ni, 0.12 Mo, 0.05 V, 0.40 Cu, 0.02 Cb

CHEMICAL COMPOSITION OF CARBON STEEL FORGINGS (Continued)							
ASTM Spec.	**UNS**	**C**	**Mn**	**Si**	**S**	**P**	**Other**
A 727[a]	---	0.25	0.90-1.35	0.15-0.30	0.025	0.035	0.40 Ni, 0.30 Cr, 0.12 Mo, 0.40 Cu, 0.02 Cb, 0.05 V
A 765 Gr I [b]	K03046	0.30	0.60-1.05	0.15-0.35	0.020	0.020	0.50 Ni, 0.05 V, 0.05 Al, 0.40 Cr, 0.25 Mo, 0.35 Cu
A 765 Gr II [b]	K03047	0.30	0.60-1.35	0.15-0.35	0.020	0.020	0.50 Ni, 0.05 V, 0.05 Al, 0.40 Cr, 0.25 Mo, 0.35 Cu
A 765 Gr IV [b]	K02009	0.20	1.00-1.60	0.15-0.50	0.020	0.020	0.50 Ni, 0.06 V, 0.05 Al, 0.40 Cr, 0.25 Mo, 0.35 Cu

a. Heat analysis. b. Intentional additions of up to 0.40% Cr, 0.25% Mo and 0.50% Ni are permitted by the manufacturer. c. Chemistry listed is for all Grades of ASTM A 694. Single values are maximums, unless otherwise specified.

CHEMICAL COMPOSITION OF ALLOY STEEL FORGINGS										
ASTM Spec.	**UNS**	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Other**
A 182 Gr F1	K12822	0.28	0.60-0.90	0.15-0.35	0.045	0.045	---	--	0.44-0.65	---
A 182 Gr F2	K12122	0.05-0.21	0.30-0.80	0.10-0.60	0.040	0.040	0.50-0.81	---	0.44-0.65	---
A 182 Gr F5	K41545	0.15	0.30-0.60	0.50	0.030	0.030	4.0-6.0	0.50	0.44-0.65	---
A 182 Gr F5a	K42544	0.25	0.60	0.50	0.040	0.030	4.0-6.0	0.50	0.44-0.65	---
A 182 Gr F9	K90941	0.15	0.30-0.60	0.50-1.00	0.030	0.030	8.0-10.0	---	0.90-1.10	---
A 182 Gr F11 Cl 1	K11597	0.05-0.15	0.30-0.60	0.50-1.00	0.030	0.030	1.00-1.50	---	0.44-0.65	---
A 182 Gr F11 Cl 2, 3	K11572	0.10-0.20	0.30-0.80	0.50-1.00	0.040	0.040	1.00-1.50	---	0.44-0.65	---
A 182 Gr F12 Cl 1	K11562	0.05-0.15	0.30-0.60	0.50	0.045	0.045	0.80-1.25	---	0.44-0.65	---
A 182 Gr F12 Cl 2	K11564	0.10-0.20	0.30-0.80	0.10-0.60	0.040	0.040	0.80-1.25	---	0.44-0.65	---
A 182 Gr F21	K31545	0.05-0.15	0.30-0.60	0.50	0.040	0.040	2.7-3.3	---	0.80-1.06	---
A 182 Gr F3V	K31830	0.05-0.18	0.30-0.60	0.10	0.020	0.020	2.8-3.2	---	0.90-1.10	0.20-0.30 V, 0.015-0.035 Ti, 0.001-0.003 B
A 182 Gr F3VCb	---	0.10-0.15	0.30-0.60	0.10	0.020	0.010	2.7-3.3	0.25	0.90-1.10	0.20-0.30 V, 0.015 Ti, 0.015-0.070 Cb, 0.25 Cu, 0.0005-0.0150 Ca
A 182 Gr F22 Cl 1, 3	K21590	0.05-0.15	0.30-0.60	0.50	0.040	0.040	2.00-2.50	---	0.87-1.13	---

MECHANICAL PROPERTIES OF AUSTENITIC STAINLESS STEEL FORGINGS[a] (Continued)

Product Form	ASTM Specification	Grade	UNS No.	Heat Treat Condition[b]	Tensile Strength		Yield Strength		% El	% RA
					ksi	MPa	ksi	MPa		
Forging (continued)	A 965	F304L	S30403	---	65	450	25	170	30	45
		F309H	S30909	---	70	485	30	205	30	45
		F310H	S31009	---	70	485	30	205	30	45
		F316	S31600	---	70	485	30	205	30	45
		F316L	S31603	---	65	450	25	170	30	45
		F321	S32100	---	70	485	30	205	30	45
		F347	S34700	---	70	485	30	205	30	45
		F348	S34800	---	70	485	30	205	30	45
Forging	A 473	304	S30400	A	75	485	30	205	40	50
		304L	S30403	A	65	450	25	170	40	50
		308	S30800	A	75	515	30	205	40	50
		310	S31000	A	75	515	30	205	40	50
		316	S31600	A	75	515	30	205	40	50
		316L	S31603	A	65	450	25	170	40	50
		317	S31700	A	75	515	30	205	40	50
		321	S32100	A	75	515	30	205	40	50
		347	S34700	A	75	515	30	205	40	50
		348	S34800	A	75	515	30	205	40	50
Pipe Flanges, Forged Fittings, Valves & Parts	B 462	20Cb-3	N08020	Stabilized A	80	551	35	241	30.0	50.0
		20Mo-4	N08024	A	80	551	35	241	30.0	50.0
		20Mo-6	N08026	Solution A	80	551	35	241	30.0	50.0
		AL-6XN	N08367	Solution A	95	655	45	310	30.0	50.0
Forging	B 564	AL-6XN	N08367	---	95	655	45	310	30	---

a. Fe-Ni-Cr-Mo alloys and their variations have been included in this table of “austenitic stainless steels”. b. A - annealed, ST & Q – solution treated and quenched. Single values are minimums, unless otherwise specified.

Chapter 13

TUBULAR PRODUCTS CARBON, ALLOY & STAINLESS STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

CARBON, ALLOY AND STAINLESS STEEL PIPES	
Carbon and Alloy Steel Pipes	
ASTM Spec.	**Title**
A 53/A 53M	Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A 106	Seamless Carbon Steel Pipe for High-Temperature Service
A 134	Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over)
A 135	Electric-Resistance-Welded Steel Pipe
A 139	Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)
A 252	Welded and Seamless Steel Pipe Piles
A 333/A 333M	Seamless and Welded Steel Pipe for Low-Temperature Service
A 335/A 335M	Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service
A 369/A 369M	Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service
A 381	Metal-Arc-Welded Steel Pipe for Use with High-Pressure Transmission Systems
A 426	Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service
A 523	Plain End Seamless and Electric-Resistance-Welded Steel Pipe for High-Pressure Pipe-Type Cable Circuits
A 524	Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures
A 530/A 530M	General Requirements for Specialized Carbon and Alloy Steel Pipe
A 587	Electric-Resistance-Welded Low-Carbon Steel Pipe for the Chemical Industry
A 589	Seamless and Welded Carbon Steel Water-Well Pipe
A 660	Centrifugally Cast Carbon Steel Pipe for High-Temperature Service
A 671	Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures
A 672	Electric-Fusion-Welded Steel Pipe for High-Pressure Service at Moderate Temperatures
A 691	Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures
A 714	High-Strength Low-Alloy Welded and Seamless Steel Pipe
A 795	Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Use
A 984/A 984M	Steel Line Pipe, Black, Plain-End, Electric-Resistance-Welded
A 1005/A 1005M	Steel Line Pipe, Black, Plain-End, Longitudinal and Helical Seam, Double Submerged-Arc Welded
A 1006/A 10006M	Steel Line Pipe, Black, Plain-End, Laser Beam Welded

CHEMICAL COMPOSITION OF CARBON STEEL PIPES						
ASTM Specification	**Pipemaking Process**	**C**	**Mn**	**P**	**S**	**Si**
A 53 (Type F)[a]	Furnace-welded	0.30	1.20	0.05	0.045	---
A 53 (Type E) Gr A[a]	Electric-resistance-welded	0.25	0.95	0.05	0.045	---
A 53 (Type E) Gr B[a]	Electric-resistance-welded	0.30	1.20	0.05	0.045	---
A 53 (Type S) Gr A[a]	Seamless	0.25	0.95	0.05	0.045	---
A 53 (Type S) Gr B[a]	Seamless	0.30	1.20	0.05	0.045	---
A 106 Gr A[a]	Seamless	0.25[b]	0.27-0.93	0.035	0.035	0.10
A 106 Gr B[a]	Seamless	0.30[b]	0.29-1.06	0.035	0.035	0.10
A 106 Gr C[a]	Seamless	0.35[b]	0.29-1.06	0.035	0.035	0.10
A 135 Gr A	Electric resistance welded	0.25	0.95	0.035	0.035	---
A 135 Gr B	Electric resistance welded	0.30	1.20	0.035	0.035	---
A 139 Gr A	Arc welded	0.25	1.00	0.035	0.035	---
A 139 Gr B	Arc welded	0.26	1.00	0.035	0.035	---
A 139 Gr C	Arc welded	0.28	1.20	0.035	0.035	---
A 139 Gr D	Arc welded	0.30	1.30	0.035	0.035	---
A 139 Gr E	Arc welded	0.30	1.40	0.035	0.035	---
A 252	Welded or seamless	---	---	0.050	---	---
A 333 Gr 1	Welded or seamless	0.30[b]	0.40-1.06	0.025	0.025	---
A 333 Gr 6	Welded or seamless	0.30[b]	0.29-1.06	0.025	0.025	0.10 min
A 381	Submerged arc welded	0.26	1.40	0.025	0.025	---
A 523 Gr A	Seamless	0.22	0.90	0.035	0.050	---
A 523 Gr A	Electric resistance welded	0.21	0.90	0.035	0.050	---
A 523 Gr B	Seamless	0.27	1.15	0.035	0.050	---
A 523 Gr B	Electric resistance welded	0.26	1.15	0.035	0.050	---
A 524 Gr I, II	Seamless	0.21	0.90-1.35	0.035	0.035	0.10-0.40
A 587[c]	Electric resistance welded	0.15	0.27-0.63	0.035	0.035	---

CHEMICAL COMPOSITION OF ALLOY STEEL PIPE (Continued)

a. Although sulfur and phosphorous are not listed, they are specified; see standard for more details. b. Contains 0.04-0.30% Al. c. Contains 0.06% Al, 0.12% V, 0.05% Nb. d. Contains 0.02% V minimum. e. Contains 0.02-0.10% V. f. Carbon content for Grade L80 Type 1 and Grade C95 may be increased to 0.50% C and 0.55% C respectively, if the product is oil quenched.
S – Seamless; W – Welded; CC – Centrifugally Cast; N.L. – No limit.
Single values are maximums, unless otherwise specified.

CHEMICAL COMPOSITION OF ALLOY STEEL TUBES

ASTM Spec.[a]	C	Mn	P	S	Si	Cr	Mo	Others
A 209 Gr T1, A 250 Gr T1	0.10-0.20	0.30-0.80	0.025	0.025	0.10-0.50	---	0.44-0.65	---
A 209 Gr T1a, A 250 Gr T1a	0.15-0.25	0.30-0.80	0.025	0.025	0.10-0.50	---	0.44-0.65	---
A 209 Gr T1b, A 250 Gr T1b	0.14	0.30-0.80	0.025	0.025	0.10-0.50	---	0.44-0.65	---
A 213 Gr T2, A 250 Gr T2	0.10-0.20	0.30-0.61	0.025	0.025	0.10-0.30	0.50-0.81	0.44-0.65	---
A 213 Gr T5	0.15	0.30-0.60	0.025	0.025	0.50	4.00-6.00	0.45-0.65	---
A 213 Gr T5b	0.15	0.30-0.60	0.025	0.025	1.00-2.00	4.00-6.00	0.45-0.65	---
A 213 T5c[b]	0.12	0.30-0.60	0.025	0.025	0.50	4.00-6.00	0.45-0.65	---
A 213 Gr T9	0.15	0.30-0.60	0.025	0.025	0.25-1.00	8.00-10.00	0.90-1.10	---
A 213 Gr T11, A 250 Gr 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	---
A 213 Gr T12, A 250 Gr T12	0.05-0.15	0.30-0.61	0.025	0.025	0.50	0.80-1.25	0.44-0.65	---
A 213 Gr T17	0.15-0.25	0.30-0.61	0.025	0.025	0.15-0.35	0.80-1.25	---	0.15 V min
A 213 Gr T21	0.05-0.15	0.30-0.60	0.025	0.025	0.50	2.65-3.35	0.80-1.06	---
A 213 Gr T22, A 250 Gr T22	0.05-0.15	0.30-0.60	0.025	0.025	0.50	1.90-2.60	0.87-1.13	---
A 213, Gr T91	0.08-0.12	0.30-0.60	0.020	0.010	0.20-0.50	8.00-9.50	0.85-1.05	0.18-0.25V, 0.06-0.1 Cb, 0.030-0.070 N, 0.40 Ni, 0.04 Al,
A 334 Gr 3	0.19	0.31-0.64	0.025	0.025	0.18-0.37	---	---	3.18-3.82 Ni
A 334 Gr 7	0.19	0.90	0.025	0.025	0.13-0.32	---	---	2.03-2.57 Ni
A 334 Gr 8	0.13	0.90	0.025	0.025	0.13-0.32	---	---	8.40-9.60 Ni

CHEMICAL COMPOSITION OF ALLOY STEEL TUBES (Continued)

ASTM Spec.[a]	C	Mn	P	S	Si	Cr	Mo	Others
A 334 Gr 9	0.20	0.40-1.06	0.025	0.025	---	---		0.75-1.25 Cu, 1.60-2.24 Ni
A 423 Gr 1	0.15	0.55	0.06-0.16	0.060	0.10 min	0.24-1.31	---	0.20-0.60 Cu, 0.20-0.70 Ni
A 423 Gr 2	0.15	0.50-1.00	0.04	0.05	---	---	0.10 min	0.30-1.00 Cu, 0.40-1.10 Ni

a. Also published as ASME specifications as SA XXX. b. Grade 5Tc has a Ti content of not less than 4 times %C and not more than 0.70% C. Single values are maximums, unless otherwise specified.

MECHANICAL PROPERTIES OF CARBON STEEL PIPES

ASTM Spec.	Form	Tensile Strength		Yield Strength		% Elongation	Other Tests
		ksi	Mpa	ksi	Mpa		
A 53 Type F	FBW, W	48	330	30	205	see A 53	---
A 53 Types E, S Gr A	ERW, S	48	330	30	205	see A 53	---
A 53 Types E, S Gr B	ERW, S	60	415	35	240	see A 53	---
A 106 Gr A	S	48	330	30	205	35 L, 25 T	---
A 106 Gr B	S	60	415	35	240	30 L, 16.5 T	---
A 106 Gr C	S	70	485	40	275	30 L, 16.5 T	---
A 135 Gr A	ERW	48	331	30	207	35	---
A 135 Gr B	ERW	60	414	35	241	30	---
A 139 Gr A	AW	48	330	30	205	35	---
A 139 Gr B	AW	60	415	35	240	30	---
A 139 Gr C	AW	60	415	42	290	25	---
A 139 Gr D	AW	60	415	46	315	23	---
A 139 Gr E	AW	66	455	52	360	22	---
A 252 Gr 1	W, S	50	345	30	205	30	---

Chapter 14

BOILERS & PRESSURE VESSELS CARBON, ALLOY & STAINLESS STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS, MECHANICAL PROPERTIES, P NUMBERS & S NUMBERS

CARBON AND ALLOY STEEL PLATES FOR BOILERS AND PRESSURE VESSELS	
ASTM Spec.	**Title**
A 20/A 20M	General Requirements for Steel Plates for Pressure Vessels
A 202/A 202M	Pressure Vessel Plates, Alloy Steel, Chromium-Manganese-Silicon
A 203/A 203M	Pressure Vessel Plates, Alloy Steel, Nickel
A 204/A 204M	Pressure Vessel Plates, Alloy Steel, Molybdenum
A 225/A 225M	Pressure Vessel Plates, Alloy Steel, Manganese-Vanadium-Nickel
A 285/A 285M	Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength
A 299/A 299M	Pressure Vessel Plates, Carbon Steel, Manganese-Silicon
A 302/A 302M	Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel
A 353/A 353M	Pressure Vessel Plates, Alloy Steel, 9 Percent Nickel, Double-Normalized and Tempered
A 387/A 387M	Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum
A 455/A 455M	Pressure Vessel Plates, Carbon Steel, High Strength Manganese
A 515/A 515M	Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service
A 516/A 516M	Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service
A 517/A 517M	Pressure Vessel Plates, Alloy Steel, High-Strength, Quenched and Tempered
A 533/A 533M	Pressure Vessel Plates, Alloy Steel, Quenched and Tempered, Manganese-Molybdenum and Manganese-Molybdenum-Nickel
A 537/A 537M	Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel
A 542/A 542M	Pressure Vessel Plates, Alloy Steel, Quenched-and-Tempered, Chromium-Molybdenum, and Chromium-Molybdenum-Vanadium
A 543/A 543M	Pressure Vessel Plates, Alloy Steel, Quenched and Tempered Nickel-Chromium-Molybdenum
A 553/A 553M	Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 8 and 9 Percent Nickel
A 562/A 562M	Pressure Vessel Plates, Carbon Steel, Manganese-Titanium for Glass or Diffused Metallic Coatings
A 612/A 612M	Pressure Vessel Plates, Carbon Steel, High Strength, for Moderate and Lower Temperature Service
A 645/A 645M	Pressure Vessel Plates, Five Percent Nickel Alloy Steel, Specially Heat Treated
A 724/A 724M	Pressure Vessel Plates, Carbon-Manganese-Silicon Steel, Quenched and Tempered, for Welded Layered Pressure Vessels
A 734/A 734 M	Pressure Vessel Plates, Alloy Steel and High-Strength Low-Alloy Steel, Quenched-and-Tempered
A 735/A 735M	Pressure Vessel Plates, Low-Carbon Manganese-Molybdenum-Columbium Alloy Steel, for Moderate and Lower Temperature Service

CARBON AND ALLOY STEEL PLATES FOR BOILERS AND PRESSURE VESSELS (Continued)	
ASTM Spec.	**Title**
A 736/A 736M	Pressure Vessel Plates, Low-Carbon Age-Hardening Nickel-Copper-Chromium-Molybdenum-Columbium and Nickel-Copper-Manganese-Molybdenum-Columbium Alloy Steel
A 737/A 737M	Pressure Vessel Plates, High-Strength, Low-Alloy Steel
A 738/A 738M	Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel, for Moderate and Lower Temperature Service
A 770/A 770M	Steel Plates for Special Applications, Through-Thickness Tension Testing of
A 782/A 782M	Pressure-Vessel Plates, Quenched-and-Tempered, Manganese-Chromium-Molybdenum-Silicon Zirconium Alloy Steel
A 832/A 832M	Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum-Vanadium
A 841/A 841M	Steel Plates for Pressure Vessels, Produced by Thermo-Mechanical Control Process (TMCP)
A 844/A 844M	Steel Plates, 9 % Nickel Alloy, for Pressure Vessels, Produced by the Direct-Quenching Process

CHEMICAL COMPOSITIONS OF PRESSURE VESSEL STEELS[a]										
ASTM	**Grade/Type**	**C**	**Mn**	**P**	**S**	**Si**	**Ni**	**Cr**	**Mo**	**Other**
A 202/A 202M	Gr A	0.17	0.97-1.52	0.035	0.035	0.54-0.96	---	0.31-0.64	---	---
	Gr B	0.25	0.97-1.52	0.035	0.035	0.54-0.96	---	0.31-0.64	---	---
A 203/A 203M	Gr A (≤ 2 in.)	0.17	0.78	0.035	0.035	0.13-0.45	2.03-2.57	---	---	---
	Gr B (≤ 2 in.)	0.21	0.78	0.035	0.035	0.13-0.45	2.03-2.57	---	---	---
	Gr D (≤ 2 in.)	0.17	0.78	0.035	0.035	0.13-0.45	3.18-3.82	---	---	---
	Gr E (≤ 2 in.)	0.20	0.78	0.035	0.035	0.13-0.45	3.18-3.82	---	---	---
	Gr F (≤ 2 in.)	0.20	0.78	0.035	0.035	0.13-0.45	3.18-3.82	---	---	---
A 204/A 204M	Gr A (≤ 1 in.)	0.18	0.98	0.035	0.035	0.13-0.45	---	---	0.41-0.64	---
	Gr B (≤ 1 in.)	0.20	0.98	0.035	0.035	0.13-0.45	---	---	0.41-0.64	---
	Gr C (≤ 1 in.)	0.23	0.98	0.035	0.035	0.13-0.45	---	---	0.41-0.64	---
A 225/A 225M	Gr C	0.25	1.72	0.035	0.035	0.13-0.45	0.37-0.73	---	---	0.11-0.20 V
	Gr D	0.20	1.84	0.035	0.035	0.08-0.56	0.37-0.73	---	---	0.08-0.20 V
A 285/A 285M	Gr A	0.17	0.98	0.035	0.035	---	---	---	---	---

ASME FERROUS METALS - P NUMBERS & S NUMBERS

ASME Spec No.	Type or Grade	Nominal Composition	Product Form	Tensile Strength[a] ksi	Welding				UNS No.
					P No	Group No.	S No.	Group No.	
SA-36	---	C-Mn-Si	Plate, bar & shapes	58	1	1	---	---	K02600
SA-53	Type F	C	Furnace welded pipe	48	1	1	---	---	---
SA-53	Type S, Grade A	C	Seamless pipe	48	1	1	---	---	K02504
SA-53	Type E, Grade A	C	ERW pipe	48	1	1	---	---	K02504
SA-53	Type E, Grade B	C-Mn	ERW pipe	60	1	1	---	---	K03005
SA-53	Type S, Grade B	C-Mn	Seamless pipe	60	1	1	---	---	K03005
SA-105	---	C-Si	Flanges & fittings	70	1	2	---	---	K03504
SA-106	A	C-Si	Seamless pipe	48	1	1	---	---	K02501
SA-106	B	C-Si	Seamless pipe	60	1	1	---	---	K03006
SA-106	C	C-Si	Seamless pipe	70	1	2	---	---	K03501
A 108	1015 CW	C	Bar	60	---	---	1	1	G10150
A 108	1018 CW	C	Bar	60	---	---	1	1	G10180
A 108	1020 CW	C	Bar	60	---	---	1	1	G10200
SA 134	SA 283 Grade A	C	Welded pipe	45	1	1	---	---	---
SA 134	SA 283 Grade B	C	Welded pipe	50	1	1	---	---	---
SA 134	SA 283 Grade C	C	Welded pipe	55	1	1	---	---	K02401
SA 134	SA 283 Grade D	C	Welded pipe	60	1	1	---	---	K02702
SA 134	SA 285 Grade A	C	Welded pipe	45	1	1	---	---	K01700
SA 134	SA 285 Grade B	C	Welded pipe	50	1	1	---	---	K02200
SA 134	SA 285 Grade C	C	Welded pipe	55	1	1	---	---	K02801
SA-135	A	C	ERW pipe	48	1	1	---	---	---
SA-135	B	C	ERW pipe	60	1	1	---	---	---
A 139	A	C	Welded pipe	48	---	---	1	1	---
A 139	B	C	Welded pipe	60	---	---	1	1	K03003
A 139	C	C	Welded pipe	60	---	---	1	1	K03004

Chapter 15

FASTENERS CARBON, ALLOY & STAINLESS STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

CARBON AND ALLOY STEEL FASTENERS (Continued)	
ASTM Spec.	**Title**
Bolts (Continued)	
F 738M	Stainless Steel Metric Bolts, Screws, and Studs
F 788/F 788M	Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series
F 901	Aluminum Transmission Tower Bolts and Nuts
F 1554	Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength
Nuts	
A 563	Carbon and Alloy Steel Nuts
A 563M	Carbon and Alloy Steel Nuts (Metric)
F 467	Nonferrous Nuts for General Use
F 467M	Nonferrous Nuts for General Use (Metric)
F 594	Stainless Steel Nuts
F 812/F 812M	Surface Discontinuities of Nuts, Inch and Metric Series
F 836M	Style 1 Stainless Steel Metric Nuts
F 901	Aluminum Transmission Tower Bolts and Nuts
Rivets	
A 31	Steel Rivets and Bars for Rivets, Pressure Vessel
A 449	Quenched and Tempered Steel Bolts and Studs
A 502	Steel Structural Rivets (Discontinued 1999)
A 574	Alloy Steel Socket-Head Cap Screws
A 574M	Alloy Steel Socket-Head Cap Screws (Metric)
F 468	Nonferrous Bolts, Hex Cap Screws, and Studs for General Use
F 468M	Nonferrous Bolts, Hex Cap Screws, and Studs for General Use (Metric)
F 568M	Carbon and Alloy Steel Externally Threaded Metric Fasteners
F 593	Stainless Steel Bolts, Hex Cap Screws, and Studs
F 738M	Stainless Steel Metric Bolts, Screws, and Studs
F 788/F 788M	Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series
F 835	Alloy Steel Socket Button and Flat Countersunk Head Cap Screws

ASTM A 325 - CHEMICAL REQUIREMENTS FOR STRUCTURAL STEEL TYPE 3 BOLTS[a, b]

Type 3	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Ti
Class A	0.33-0.40	0.90-1.20	0.040	0.050	0.15-0.35	0.25-0.45	0.25-0.45	0.45-0.65	---	---	---
Class B	0.38-0.48	0.70-0.90	0.06-0.12	0.050	0.30-0.50	0.20-0.40	0.50-0.80	0.50-0.75	---	0.06	---
Class C	0.15-0.25	0.80-1.35	0.035	0.040	0.15-0.35	0.20-0.50	0.25-0.50	0.30-0.50	0.020 min	---	---
Class D	0.15-0.25	0.40-1.20	0.040	0.050	0.25-0.50	0.30-0.50	0.50-0.80	0.50-1.00	---	0.10	0.05
Class E	0.20-0.25	0.60-1.00	0.040	0.040	0.15-0.35	0.30-0.60	0.30-0.60	0.60-0.90	---	---	---
Class F	0.20-0.25	0.90-1.20	0.040	0.040	0.15-0.35	0.20-0.40	0.20-0.40	0.45-0.65	---	---	---

a. A, B, C, D, E, and F are classes of material used for Type 3 bolts. Selection of a class shall be at the option of the bolt manufacturer. b. Heat analysis only; for product analysis see ASTM A 325 Table 2. All single values are maximums unless otherwise stated.

ASTM A 354 - CHEMICAL REQUIREMENTS FOR FASTENERS[a]

	C			
All Grades	For sizes through 1½ in.	For sizes > 1½ in.	P	S
Product Analysis	0.28-0.55	0.33-0.55	0.040	0.045
Heat Analysis	0.30-0.53	0.35-0.53	0.035	0.040

a. Chemical requirements pertain to grades BC and BD. All single values are maximums.

ASTM A 449 - CHEMICAL REQUIREMENTS FOR TYPE 1 AND TYPE 2 BOLTS AND STUDS

Type 1	C	Mn	P	S	B
Product Analysis	0.25-0.58	0.57 min	0.048	0.058	---
Heat Analysis	0.28-0.55	0.60 min	0.040	0.050	---
Type 2					
Product Analysis	0.13-0.14	0.67 min	0.048	0.058	0.0005 min
Heat Analysis	0.15-0.38	0.70 min	0.040	0.050	0.0005 min

Single values are maximums, unless otherwise specified.

ASTM A 489 - CHEMICAL REQUIREMENTS FOR CARBON STEEL LIFTING EYES					
Types 1 & 2	**C**	**Mn**	**P**	**S**	**Si**
Product Analysis	0.51	1.06	0.048	0.058	0.12-0.38
Heat Analysis	0.48	1.00	0.040	0.050	0.15-0.35

Single values are maximums.

ASTM A 490 - CHEMICAL REQUIREMENTS FOR STRUCTURAL STEEL TYPE 1 BOLTS				
For sizes through 1⅜ in.	**C**	**P**	**S**	**Alloying Elements**
Product Analysis	0.28-0.50	0.045	0.045	a
Heat Analysis	0.30-0.48	0.040	0.040	a
For size 1½ in.				
Product Analysis	0.33-0.55	0.045	0.045	a
Heat Analysis	0.35-0.53	0.040	0.040	a

a. The steel shall contain sufficient alloying elements to qualify it as an alloy steel. See ASTM A 490 paragraph 6.1 for more details.
Single values are maximums.

ASTM A 490 - CHEMICAL REQUIREMENTS FOR STRUCTURAL STEEL TYPE 2 AND TYPE 3 BOLTS									
Type 2	**C**	**Mn**	**P**	**S**	**Cu**	**Cr**	**Ni**	**Mo**	**B**
Product Analysis	0.13-0.37	0.67	0.048 max	0.058 max	---	---	---	---	0.0005
Heat Analysis	0.15-0.34	0.70	0.040 max	0.050 max	---	---	---	---	0.0005
Type 3									
Product Analysis ≤ 0.75 in.	0.19-0.55	0.37	0.045 max	0.055 max	0.63 max	0.42	0.17	0.14	---
> 0.75 in.	0.28-0.55	0.37	0.045 max	0.055 max	0.63 max	0.42	0.17	0.14	---
Heat Analysis ≤ 0.75 in.	0.20-0.53	0.40	0.040 max	0.050 max	0.60 max	0.45	0.20	0.15	---
> 0.5 in	0.30-0.53	0.40	0.040 max	0.050 max	0.60 max	0.45	0.20	0.15	---

Single values are minimums unless otherwise specified.

MECHANICAL PROPERTIES OF CARBON STEEL BOLTING & OTHER FASTENERS

SAE J429 Grade	Products	Nominal Size Diameter in.	Full Size[a]		Machine Specimens[b]				Surface Hardness HR30N max	Core Hardness max	Grade Indentification Marking
			Proof Load psi	Tensile Strength ksi	Yield Strength ksi	Tensile Strength ksi	% El	% R.A.			
1	B, Sc, St	¼ through 1½	33	60	36	60	18	35	---	70-100 HRB	None
2	B, Sc, St	¼ through ¾	55	74	57	74	18	35	---	80-100 HRB	None
	B, Sc, St	> ¾ through 1½	33	60	36	60	18	35	---	70-100 HRB	None
4	St	¼ through 1½	65	115	100	115	10	35	---	22-32 HRC	None
5	B, Sc, St	¼ through 1	85	120	92	120	14	35	54	25-34 HRC	
	B, Sc, St	> 1 through 1½	74	105	81	105	14	35	50	19-30 HRC	
5.1	Se	No. 4 through ⅝	85	120	---	---	---	---	59.5	25-40 HRC	
5.2	B, Sc	¼ through 1	85	120	92	120	14	35	56	26-36 HRC	
8	B, Sc, St	¼ through 1½	120	150	130	150	12	35	58.6	33-39 HRC	
8.1	St	¼ through 1½	120	150	130	150	10	35	---	32-38 HRC	None
8.2	B, Sc	¼ through 1	120	150	130	150	10	35	58.6	33-39 HRC	

a. Full size bolts, screws, studs and screw & washer assemblies; for proof load requirements see SAE J429 Table 1.
b. Machine test specimens of bolts, screws and studs.
c. Other restrictions apply, see SAE J429 Table 1 footnotes for details.
B - Bolts; Sc - Screws; St - Studs; Se - Screw & Washer assembly. Single values are minimums, unless otherwise specified.

ASTM A 307 - TENSILE REQUIREMENTS FOR MACHINED SPECIMENS OF CARBON STEEL BOLTS AND STUDS[a]					
Grade	Tensile Strength		Yield Point		% Elongation
	ksi	MPa	ksi	MPa	
A	60	415	---	---	18
B	60-100	415-690	---	---	18
C	58-80	400-550	36	50	23

a. Full-size tensile testing of these bolts and studs may be required, see ASTM A 307 Table 2 for details.
Single values are minimums.

ASTM A 325 - HARDNESS REQUIREMENTS FOR STRUCTURAL STEEL BOLTS[b]			
Bolt Size, in.	Bolt Length, in.	Brinell (HB)	Rockwell C (HRC)
½ to 1, incl.	less than 3D[a]	253-319	25-34
	3D and over	319 max	34 max
1⅛ to 1½, incl.	less than 3D[a]	223-286	19-30
	3D and over	286 max	30 max

a. Bolts having a length less than 3 times the diameter are subject only to minimum/maximum hardness. Such lengths cannot be reasonably tensile tested. D = Nominal diameter or thread size.
b. All bolt types and classes.

ASTM A 354 - HARDNESS REQUIREMENTS FOR FULL-SIZE ALLOY STEEL BOLTS, STUDS AND FASTENERS			
Grade	Size, in.	Hardness	
		Brinell (HB)	Rockwell C (HRC)
BC	¼ to 2½	255-331	26-36
BC	> 2½	235-311	22-33
BD	¼ to 2½	311-363	33-39
BD	> 2½	293-363	31-39

Chapter 16

TOOL STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS, HEAT TREATMENT DATA, HARDNESS REQUIREMENTS, & SELECTED PROPERTIES

Tool Steels	
ASTM Spec.	**Title**
A 561	Macroetch Testing of Tool Steel Bars
A 597	Cast Tool Steel
A 600	Tool Steel High Speed
A 681	Tool Steels Alloy
A 686	Tool Steel, Carbon
SAE Spec.	**Title**
J 438b	Tool and Die Steels

CHEMICAL COMPOSITION OF TOOL STEELS[a]

Type	UNS	C	Mn	Cr	Mo	W	V	Co	Other
Molybdenun High-Speed Tool Steels									
M1	T11301	0.78-0.88	0.15-0.40	3.50-4.00	8.20-9.20	1.40-2.10	1.00-1.35	---	---
M2 (reg. C)	T11302	0.78-0.88	0.15-0.40	3.75-4.50	4.50-5.50	5.50-6.75	1.75-2.20	---	---
M2 (high C)	T11302	0.95-1.05	0.15-0.40	3.75-4.50	4.50-5.50	5.50-6.75	1.75-2.20	---	---
M3 Cl 1	T11313	1.00-1.10	0.15-0.40	3.75-4.50	4.75-6.50	5.00-6.75	2.25-2.75	---	---
M3 Cl 2	T11323	1.15-1.25	0.15-0.40	3.75-4.50	4.75-6.50	5.00-6.75	2.75-3.25	---	---
M4	T11304	1.25-1.40	0.15-0.40	3.75-4.75	4.25-5.50	5.25-6.50	3.75-4.50	---	---
M6	T11306	0.75-0.85	0.15-0.40	3.75-4.50	4.50-5.50	3.75-4.75	1.30-1.70	11.00-13.00	---
M7	T11307	0.97-1.05	0.15-0.40	3.50-4.00	8.20-9.20	1.40-2.10	1.75-2.25	---	---
M10 (reg. C)	T11310	0.84-0.94	0.10-0.40	3.75-4.50	7.75-8.50	---	1.80-2.20	---	---
M10 (high C)	T11310	0.95-1.05	0.10-0.40	3.75-4.50	7.75-8.50	---	1.80-2.20	---	---
M30	T11330	0.75-0.85	0.15-0.40	3.50-4.25	7.75-9.00	1.30-2.30	1.00-1.40	4.50-5.50	---
M33	T11333	0.85-0.92	0.15-0.40	3.50-4.00	9.00-10.00	1.30-2.10	1.00-1.35	7.75-8.75	---
M34	T11334	0.85-0.92	0.15-0.40	3.50-4.00	7.75-9.20	1.40-2.10	1.90-2.30	7.75-8.75	---
M36	T11336	0.80-0.90	0.15-0.40	3.75-4.50	4.50-5.50	5.50-6.50	1.75-2.25	7.75-8.75	---
M41	T11341	1.05-1.15	0.20-0.60	3.75-4.50	3.25-4.25	6.25-7.00	1.75-2.25	4.75-5.75	---

TYPICAL NORMALIZING AND ANNEALING TEMPERATURES FOR TOOL STEELS

Type	Normalizing[a] °F	°C	Annealing[b] Temperature °F	°C	Rate of Cooling max °F/hr	°C/hr	Hardness HB
M1, M10	Do not normalize		1500-1600	815-870	40	22	207-235
M2	Do not normalize		1600-1650	870-900	40	22	212-241
M3, M4	Do not normalize		1600-1650	870-900	40	22	223-255
M7	Do not normalize		1500-1600	815-870	40	22	217-255
M30, M33	Do not normalize		1600-1650	870-900	40	22	235-269
M34, M35	Do not normalize		1600-1650	870-900	40	22	235-269
M36, M41	Do not normalize		1600-1650	870-900	40	22	235-269
M42, M46	Do not normalize		1600-1650	870-900	40	22	235-269
M48	Do not normalize		1600-1650	870-900	40	22	285-311
M62	Do not normalize		1600-1650	870-900	40	22	262-285
T1	Do not normalize		1600-1650	870-900	40	22	217-255
T4	Do not normalize		1600-1650	870-900	40	22	229-269
T5	Do not normalize		1600-1650	870-900	40	22	235-277
T6	Do not normalize		1600-1650	870-900	40	22	248-293
T8	Do not normalize		1600-1650	870-900	40	22	229-255
T15	Do not normalize		1600-1650	870-900	40	22	241-277
M50	Do not normalize		1525-1550	830-845	40	22	197-235
M52	Do not normalize		1525-1550	830-845	40	22	197-235
H10, H11	Do not normalize		1550-1650	845-900	40	22	192-229
H12, H13	Do not normalize		1550-1650	845-900	40	22	192-229
H14	Do not normalize		1600-1650	870-900	40	22	207-235
H 19	Do not normalize		1600-1650	870-900	40	22	207-241
H21, H22	Do not normalize		1600-1650	870-900	40	22	207-235
H23	Do not normalize		1600-1650	870-900	40	22	212-255

HEAT TREATING REQUIREMENTS FOR TOOL STEELS (Continued)

ASTM Spec.	Preaheat Temperature		Austenitizing Temperature[a]				Quenching Medium	Tempering Temperature[b]		Hardness HRC, min
			Salt Bath		Controlled Atmosphere Furnace					
A 600 Type	**°F**	**°C**	**°F**	**°C**	**°F**	**°C**		**°F**	**°C**	
T5	1500-1600	816-871	2330	1277	2350	1288	Oil or Salt	1025	552	63
T6	1500-1600	816-871	2330	1277	2350	1288	Oil or Salt	1025	552	63
T8	1500-1600	816-871	2330	1277	2350	1288	Oil or Salt	1025	552	63
T15	1500-1600	816-871	2240	1227	2260	1238	Oil or Salt	1000	538	65
A 681 Type										
H10	1450	788	1850	1010	1875	1024	Air	1025	552	55
H11	1450	788	1825	996	1850	1010	Air	1025	552	53
H12	1450	788	1825	996	1850	1010	Air	1025	552	53
H13	1450	788	1825	996	1850	1010	Air	1025	552	52
H14	1450	788	1900	1038	1925	1052	Air	1025	552	55
H19	1450	788	2150	1177	2175	1191	Air	1025	552	55
H21	1450	788	2150	1177	2175	1191	Air	1025	552	52
H22	1450	788	2150	1177	2175	1191	Air	1025	552	53
H23	1500	816	2275	1246	2300	1260	Oil	1200	649	42
H24	1450	788	2200	1204	2225	1218	Air	1025	552	55
H26	1550	843	2275	1246	2300	1260	Air	1025	552	58
H42	1450	788	2175	1191	2200	1204	Air	1025	552	60
A2	1450	788	1725	941	1750	954	Air	400	204	60
A4	1250	677	1550	843	1575	857	Air	400	204	61
A6	1200	649	1525	829	1550	843	Air	400	204	58
A7	1500	816	1750	954	1775	968	Air	400	204	63

HARDNESS REQUIREMENTS FOR TOOL STEELS (Continued)			
ASTM A 681 Type (Cont'd)	**Annealed, HB**	**Cold Drawn, HB**	**Cold Drawn Annealed, HB**
O6	229	241	---
O7	241	255	---
S1	229	255	---
S2	217	241	---
S4	229	255	---
S5	229	255	---
S6	229	255	---
S7	229	255	---
L2	197	241	---
L6	235	262	---
P6	212	---	---
P20	a	---	---
P21	a	---	---

a. Normally furnished in prehardened condition.

SELECTED PROPERTIES OF TOOL STEELS (Continued)

Type	Major Factors[a]			Working[f] Hardness HRC	Depth[b] of Hardening	Finest Grain Size at Full Hardness	As-Quenched Surface Hardness HRC	Core Hardness HRC[g]
	Wear Resistance	Toughness	Hot Hardness					
Low-Carbon Mold Steels								
For machined cavities								
P20	1[c]	8	2[c]	30-50	M	7½	52-54	45-50
P21	1	8	4	36-39	D	---	22-26	22-26
Water-Hardening Tool Steels								
W1	2-4	3-7	1	58--65	S	9	65-67	38-43
W2	2-4	3-7	1	58-65	S	9	65-67	38-43
W5	3-4	3-7	1	58-65	S	9	65-67	38-43

a. Rating range from 1 (low) to 9 (high).
b. S - shallow; M - medium; D - deep.
c. After carburizing.
d. AISI M3 Class 1.
e. AISI M3 Class 2.
f. Usual working hardness.
g. Core hardness related to 1 in (25 mm) diameter round.
Note: Wear resistance increases with increasing carbon content. Toughness decreases with increasing carbon content and depth of hardening.

Chapter 17

WROUGHT STAINLESS STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

WROUGHT STAINLESS STEELS (Continued)	
ASTM Spec.	**Title**
Others (Continued)	
B 649	Ni-Fe-Cr-Mo-Cu Low-Carbon Alloy (UNS N08904), Ni-Fe-Cr-Mo-Cu-N Low-Carbon Alloys (UNS N08925, UNS N08031, and UNS N08926) and Cr-Ni-Fe-N Low-Carbon Alloy (UNS R20033) Bar and Wire
B 688	Chromium-Nickel-Molybdenum-Iron (UNS N08366 and UNS N08367) Plate, Sheet, and Strip
B 691	Iron-Nickel-Chromium-Molybdenum Alloys (UNS N08366 and UNS N08367) Rod, Bar, and Wire
B 709	Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08028) Plate, Sheet, and Strip

ASTM SPECIFICATIONS AND WROUGHT PRODUCT FORMS FOR MARTENSITIC STAINLESS STEELS

UNS No.	Alloy	Plate, Sheet, Strip	Bar, Shape	Wire	Bar	Forgings	Piping, Fittings
S40300	Type 403	A 176	A 276, A 479/A 479M	A 580/A 580M	---	---	---
S41000	Type 410	A 240/A 240M	A 276, A 479/A 479M	A 493, A 580/A 580M	---	---	A 815/A 815M
S41003	---	A 240/A 240M	---	---	---	---	---
S41008	Type 410S	A 240/A 240M	---	---	---	---	---
S41026	---	---	---	---	---	---	A 182/A 182M
S41040	Type 410Cb, XM-30	---	A 276, A 479/A 479M	---	A 565	A 565	---
S41400	Type 414	---	A 276, A 479/A 479M	A 580/A 580M	---	---	---
S41425	AF913	---	A 276, A 479/A 479M	---	A 314	A 473	---
S41500	F6NM, wrought CA-6NM	A 240/A 240M	A 276, A 479/A 479M	---	---	---	A 815/A 815M
S41600	Type 416	A 895	---	A 581/A 581M	A 582/A 582M	---	---
S41610	XM-6	---	---	A 581/A 581M	A 582/A 582M	---	---
S41623	Type 416Se	A 895	---	A 581/A 581M	A 582/A 582M	---	---
S41800	Type 615	---	---	---	A 565	A 565	---
S42000	Type 420	A 176	A 276	A 580/A 580M	---	---	---

ASTM SPECIFICATIONS AND WROUGHT PRODUCT FORMS FOR AUSTENITIC STAINLESS STEELS/CORROSION-RESISTANT (Continued)						
UNS No.	**Alloy**	**Flat-Rolled**	**Long Products**	**Tubing**	**Pipe**	**Testing**
S30403	Type 304L	A 480, A 240, A 793	A 484, A 276, A 479, A 493, A 580, A555	A 450, A 249, A 269, A 270, A 778	A 530, A 312, A 358	A 262, E 112
S30451	Type 304N	A 480, A 240	A 484, A 276, A 479	A 450, A 249	A 530, A 312, A 358	E 112
S30433	302HQ	---	A 493	---	---	E 112
S30500	Type 305	A 480, A 240	A 484, A 276, A 493, A 580, A 555	A 450, A 249	---	E 112
S31600	Type 316	A 480, A 240, A 793	A 484, A 276, A 479, A 493, A 580, A 555	A 450, A 249, A 269, A 270	A 530, A 312, A 358	A 262, E 112
S31603	Type 316L	A 480, A 240, A 793	A 484, A 276, A 479, A 493, A 580, A 555	A 450, A 249, A 269, A 270, A 778	A 530, A 312, A 358	A 262, E 112
S31703	317L	A 480, A 240	A 484	A 450, A 249, A 778	A 530, A 312	A 262, E 112
S31726	---	A 480, A 240	A 484, A 276, A 479	A 450, A 249, A 269	A 530, A 312, A 358	E 112

ASTM SPECIFICATIONS AND WROUGHT PRODUCT FORMS FOR AUSTENITIC STAINLESS STEELS/HEAT-RESISTANT						
UNS No.	**Alloy**	**Flat-Rolled**	**Long Products**	**Tubing**	**Pipe**	**Testing**
S30409	Type 304H	A 480, A 240	A 484, A 276, A 479, A 182	A 450, A 249	A 530, A 312, A 358	A 262, E 112
S32100	Type 321	A 480, A 240	A 484, A 276, A 479, A 580, A 182, A 555	A 450, A 249, A 269	A 530, A 312, A 358, A 778	A 262, E 112
S34700	Type 347	A 480, A 240	A 484, A 276, A 479, A 580, A 182, A 555	A 450, A 249, A 269	A 530, A 312, A 358, A 778	A 262, E 112
S31609	Type 316H	A 480, A 240	A 484, A 276, A 182	A 450, A 249	A 530, A 312, A 358	E 112
S30815	253 MA	A 480, A 240	A 484, A 276, A 479, A 182	A 450, A 249	A 530, A 312, A 358	E 112
S30900	Type 309	---	A 276	---	---	---
S30908	Type 309S	A 480, A 240	A 484, A 276, A 479, A 580, A 555	A 450, A 249	A 530, A 312, A 358	A 262, E 112
S30909	Type 309H	A 480, A 240	A 484, A 276	A 450, A 249	A 530, A 312	E 112
S31000	Type 310	---	A 276	---	---	---
S31008	Type 310S	A 480, A 240	A 484, A 276, A 479, A 580, A 555	A 450, A 249	A 530, A 312, A 358	A 262, E 112
S31009	Type 310H	A 480, A 240	A 484, A 276	A 450, A 249	A 530, A 312	E 112

CHEMICAL COMPOSITION OF WROUGHT MARTENSITIC STAINLESS STEELS (Continued)									
	C	**Mn**	**Si**	**S**	**P**	**Cr**	**Ni**	**Mo**	**Other**
UNS S41003									
A 240 Plate, Sheet, Strip	0.030	1.50	1.00	0.030	0.040	10.5-12.5	1.50	---	N 0.030
UNS S41008 - Type 410S									
A 240 Plate, Sheet, Strip	0.08	1.00	1.00	0.030	0.040	11.5-13.5	0.60	---	---
A 815 Piping Fittings	0.08	1.00	1.00	0.030	0.040	11.5-13.5	0.60	---	---
UNS S41040 - Type 410Cb									
A 276 Bar, Shape	0.18	1.00	1.00	0.030	0.040	11.0-13.0	---	---	Cb 0.05-0.30
A 479 Bar, Shape	0.18	1.00	1.00	0.030	0.040	11.0-13.0	---	---	Cb 0.05-0.30
UNS S41045									
A 240 Plate, Sheet, Strip	0.030	1.00	1.00	0.030	0.040	12.0-13.0	0.50	---	N 0.030; Cb 9(C+N) to 0.60
UNS S41050									
A 240 Plate, Sheet, Strip	0.04	1.00	1.00	0.030	0.045	10.5-12.5	0.60-1.10	---	N 0.10
UNS S41400 - Type 414									
A 276 Bar, Shape	0.15	1.00	1.00	0.030	0.040	11.5-13.5	1.25-2.50	---	---
A 479 Bar, Shape	0.15	1.00	1.00	0.030	0.040	11.5-13.5	1.25-2.50	---	---
A 580 Wire	0.15	1.00	1.00	0.030	0.040	11.5-13.5	1.25-2.50	---	---
UNS S41425									
A 276 Bar, Shape	0.05	0.50-1.00	0.50	0.005	0.020	12.0-15.0	4.0-7.0	1.50-2.00	Cu 0.30
A 479 Bar, Shape	0.05	0.50-1.00	0.50	0.005	0.020	12.0-15.0	4.0-7.0	1.50-2.00	N 0.06-012; Cu 0.30
UNS S41500									
A 240 Plate, Sheet, Strip	0.05	0.50-1.00	0.60	0.030	0.030	11.5-14.0	3.5-5.5	0.50-1.00	---
A 276 Bar, Shape	0.05	0.50-1.00	0.60	0.030	0.030	11.5-14.0	3.5-5.5	0.50-1.00	---
A 815 Piping Fittings	0.05	0.50-1.00	0.60	0.030	0.030	11.5-14.0	3.5-5.5	0.50-1.00	W 0.50-1.00
UNS S42000 - Type 420									
A 276 Bar, Shape	≥ 0.15	1.00	1.00	0.030	0.040	12.0-14.0	---	---	---
A 580 Wire	≥ 0.15	1.00	1.00	0.030	0.040	12.0-14.0	---	---	---

MECHANICAL PROPERTIES OF WROUGHT FREE-MACHINING MARTENSITIC STAINLESS STEELS									
UNS No. - Common Name Product Form	**ASTM Specification**	**Heat Treat Condition[a]**	**Tensile Strength**		**Yield Strength**		**% El**	**% RA**	**Hardness, max**
			ksi	**MPa**	**ksi**	**MPa**			
UNS S41600 - Type 416									
Wire	A 581	A	85-125	585-860	---	---	---	---	---
		T	115-145	790-1000	---	---	---	---	---
		H	140-175	965-1210	---	---	---	---	---
Bar, Plate, Sheet, Strip	A 582, A 895	A	---	---	---	---	---	---	262 HB
		T	---	---	---	---	---	---	248-302 HB
		H	---	---	---	---	---	---	293-352 HB
UNS S41610 - XM-6									
Wire and Wire Rods	A 581	T	115-145	790-1000	---	---	---	---	---
		H	140-175	965-1210	---	---	---	---	---
Bars	A 582	A	---	---	---	---	---	---	262 HB
		T	---	---	---	---	---	---	248-302 HB
		H	---	---	---	---	---	---	293-352 HB
UNS S41623 - Type 416Se									
Wire and Wire Rods	A 581	A	85-125	585-860	---	---	---	---	---
		T	115-145	790-1000	---	---	---	---	---
		H	140-175	965-1210	---	---	---	---	---
Bars	A 582	A	---	---	---	---	---	---	262 HB
		T	---	---	---	---	---	---	248-302 HB
		H	---	---	---	---	---	---	293-352 HB
Plate, Sheet, Strip	A 895	A	---	---	---	---	---	---	202
		T	---	---	---	---	---	---	248-302
		H	---	---	---	---	---	---	293-352
UNS S42020 - Type 420F									
Bars	A 582	A	---	---	---	---	---	---	---
Plate, Sheet, Strip	A 895	A	---	---	---	---	---	---	262

MECHANICAL PROPERTIES OF WROUGHT FREE-MACHINING MARTENSITIC STAINLESS STEELS (Continued)									
UNS No. - Common Name Product Form	**ASTM Specification**	**Heat Treat Condition[a]**	**Tensile Strength**		**Yield Strength**		**% El**	**% RA**	**Hardness, max**
			ksi	**MPa**	**ksi**	**MPa**			
UNS S42023 - Type 420FSe									
Bars	A 582	A	---	---	---	---	---	---	---
		T	---	---	---	---	---	---	248-302 HB
Plate, Sheet, Strip	A 895	A	---	---	---	---	---	---	262
		T	---	---	---	---	---	---	248-302
UNS S44020 - Type 440F									
Bars	A 582	A	---	---	---	---	---	---	285
UNS S44023 - Type 440F Se									
Bars	A 582	A	---	---	---	---	---	---	285

CHEMICAL COMPOSITION OF WROUGHT FERRITIC STAINLESS STEELS									
	C	**Mn**	**Si**	**S**	**P**	**Cr**	**Ni**	**Mo**	**Other**
UNS S32803									
A 240 Plate, Sheet, Strip	0.015	0.50	0.55	0.0035	0.020	28.0-29.0	3.0-4.0	1.80-2.50	N 0.020; (C+N) 0.030; Cb 12(C+N) min, 0.15-0.50
UNS S40500 - Type 405									
A 240 Plate, Sheet, Strip	0.08	1.00	1.00	0.030	0.040	11.5-14.5	0.60	---	Al 0.10-0.30
A 276 Bar, Shape	0.08	1.00	1.00	0.030	0.040	11.5-14.5	0.50	---	Al 0.10-0.30
A 479 Bar, Shape	0.08	1.00	1.00	0.030	0.040	11.5-14.5	0.50	---	Al 0.10-0.30
A 580 Wire	0.08	1.00	1.00	0.030	0.040	11.5-14.5	---	---	Al 0.10-0.30
UNS S40910									
A 240 Plate, Sheet, Strip	0.030	1.00	1.00	0.020	0.040	10.5-11.7	0.50	---	N 0.030; Ti 6(C+N) to 0.50; Cb 0.17

Chapter 18

CAST STAINLESS STEELS:

AMERICAN SPECIFICATION TITLES & DESIGNATIONS, CHEMICAL COMPOSITIONS & MECHANICAL PROPERTIES

STAINLESS STEEL CASTINGS	
ASTM Spec.	**Title**
A 217/A 217M	Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service
A 297/A 297M	Steel Castings, Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application
A 351/A 351M	Castings, Austenitic, Austenitic-Ferritic (Duplex), for Pressure-Containing Parts
A 352/A 352M	Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service
A 356/A 356M	Steel Castings, Carbon, Low Alloy, and Stainless Steel, Heavy-Walled for Steam Turbines
A 447/A 447M	Steel Castings, Chromium-Nickel-Iron Alloy (25-12 Class), for High-Temperature Service
A 451	Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service
A 452	Centrifugally Cast Austenitic Steel Cold-Wrought Pipe for High-Temperature Service (Discontinued 1995)
A 487/A 487M	Steel Castings Suitable for Pressure Service
A 608	Centrifugally Cast Iron-Chromium-Nickel High-Alloy Tubing for Pressure Application at High Temperatures
A 703/A 703M	Steel Castings, General Requirements, for Pressure-Containing Parts
A 743/A 743M	Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application
A 744/A 744M	Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service
A 747/A 747M	Steel Castings, Stainless, Precipitation Hardening
A 757/A 757M	Steel Castings, Ferritic and Martensitic, for Pressure-Containing and Other Applications, for Low-Temperature Service
A 799/A 799M	Steel Castings, Stainless, Instrument Calibration, for Estimating Ferrite Content
A 800/A 800M	Steel Castings, Austenitic Alloy, Estimating Ferrite Content Thereof
A 890/A 890M	Castings, Iron-Chromium-Nickel-Molybdenum Corrosion-Resistant, Duplex (Austenitic/Ferritic) for General Application

CHEMICAL COMPOSITION OF CORROSION-RESISTANT CAST STAINLESS STEELS[a] (Continued)

Grade	UNS	ASTM Spec.	C	Si	Cr	Ni	Other	Similar[b] Wrought
CN-3MN	---	A 743, A 744	0.03	1.00	20.0-22.0	23.5-25.5	6.00-7.00 Mo, 0.75 Cu, 0.18-0.26 N	AL-6XN
CN-7M	---	A 351, A 743, A 744	0.07	1.50	19.0-22.0	27.5-30.5	2.0-3.0 Mo, 3.0-4.0 Cu	---
CN-7MS	---	A 743, A744	0.07	2.50-3.50	18.0-20.0	22.0-25.0	2.5-3.0 Mo, 1.5-2.0 Cu	---
E3N	J91550	A 757	0.06	1.00	11.5-14.0	3.5-4.5	0.40-1.0 Mo, 0.50 Cu, 0.10 W	---
CD6MN	J93371	A 890 Gr 3A	0.06	1.00	24.0-27.0	4.00-6.00	1.75-2.50 Mo, 0.15-0.25 N	---
CD3MN	J92205	A 890 Gr 4A	0.03	1.00	21.0-23.5	4.5-6.5	2.5-3.5 Mo, 1.00 Cu, 0.10-0.30 N	2205
CE3MN	J93404	A 890 Gr 5A	0.03	1.00	24.0-26.0	6.0-8.0	4.0-5.0 Mo, 0.10-0.30 N	2507

a. Although manganese, sulphur and phosphorous contents are not listed in this table due to limited space, they are specified; see appropriate ASTM standard for more details.

b. Similar wrought designations are listed only as a guide for comparison to cast grades; they are not equivalent.

All values are maximums, unless otherwise specified.

CHEMICAL COMPOSITION OF HEAT-RESISTANT CAST STAINLESS STEELS[a]

Grade	UNS	ASTM Specification	C	Mn	P	S	Si	Cr	Ni
HC	J92605	A 297	0.50	1.00	0.04	0.04	2.00	26.0-30.0	4.00
HC30	J92613	A 608	0.25-0.35	0.5-1.0	0.04	0.04	0.50-2.00	26-30	4.0
HD	J93005	A 297	0.50	1.50	0.04	0.04	2.00	26.-30.0	4.0-7.0
HD50	J93015	A 608	0.45-0.55	1.50	0.04	0.04	0.50-2.00	26-30	4-7
HE	J93403	A 297	0.20-0.50	2.00	0.04	0.04	2.00	26.0-30.0	8.0-11.0
HE35	J93413	A 608	0.30-0.40	1.50	0.04	0.04	0.50-2.00	26-30	8-11
HF	J92603	A 297	0.20-0.40	2.00	0.04	0.04	2.00	18.0-23.0	8.0-12.0
HF30	J92803	A 608	0.25-0.35	1.50	0.04	0.04	0.50-2.00	19-23	9-12
HH	J93503	A 297, A 447	0.20-0.50	2.00	0.04	0.04	2.00	24.0-28.0	11.0-14.0

TYPICAL ROOM-TEMPERATURE MECHANICAL PROPERTIES OF HEAT-RESISTANT CAST ALLOYS (Continued)

Grade	Condition	Tensile Strength		Yield Strength		% Elongation	Hardness, HB
		ksi	MPa	ksi	MPa		
HE	Aged[a]	90	620	55	380	10	270
HF	As-cast	92	635	45	310	38	165
	Aged[a]	100	690	50	345	25	190
HH, type 1	As-cast	85	585	50	345	25	185
	Aged[a]	86	595	55	380	11	200
HH, type 2	As-cast	80	550	40	275	15	180
	Aged[a]	92	635	45	310	8	200
HI	As-cast	80	550	45	310	12	180
	Aged[a]	90	620	65	450	6	200
HK	As-cast	75	515	50	345	17	170
	Aged[b]	85	585	50	345	10	190
HL	As-cast	82	565	52	360	19	192
HN	As-cast	68	470	38	260	13	160
HP	As-cast	71	490	40	275	11	170
HT	As-cast	70	485	40	275	10	180
	Aged[b]	75	515	45	310	5	200
HU	As-cast	70	485	40	275	9	170
	Aged[c]	73	505	43	295	5	190
HW	As-cast	68	470	36	250	4	185
HW	Aged[d]	84	580	52	360	4	205
HX	As-cast	65	450	36	250	9	176
	Aged[c]	73	505	44	305	9	185

a. Aging treatment: 24 hours at 1400°F (760°C), furnace cool. b. Aging treatment: 24 hours at 1400°F (760°C), air cool. c. Aging treatment: 48 hours at 1800°F (980°C), air cool. d. Aging treatment: 48 hours at 1800°F (980°C), furnace cool. All values are maximums, unless otherwise specified.

Chapter 19

PHYSICAL PROPERTIES:

THE ELEMENTS, CARBON, ALLOY & STAINLESS STEELS

PHYSICAL PROPERTIES OF THE ELEMENTS

Element	Sym.	Atomic No.	Atomic Wt.	Electrons In Shell							Melting Pt. °C	Boiling Pt. °C	Density[a]	Val.[b]
				K	L	M	N	O	P	Q				
Actinium	Ac	89	227	2	8	18	32	18	9	2	1600	---	---	---
Aluminum	Al	13	26.98	2	8	3	---	---	---	---	660.2	2060	s 2.699	3+
Americium	Am	95	241	2	8	18	32	24	9	2	---	---	---	---
Antimony	Sb	51	121.8	2	8	18	18	5	---	---	630.5	1440	s 6.62	5+
Argon	Ar	18	39.95	2	8	8	---	---	---	---	-189.4	-185.8	g 1.784 L 1.40 s 1.65	Inert
Arsenic	As	33	74.92	2	8	18	5	---	---	---	814 (36 atm.)	610	s 5.73	3+ 5+
Astatine	At	85	210	2	8	18	32	18	7	---	---	---	---	---
Barium	Ba	56	137.3	2	8	18	18	8	2	---	704	1640	s 3.5	2+
Berkelium	Bk	97	249	2	8	18	32	26	9	2	---	---	---	---
Beryllium	Be	4	9.01	2	2	---	---	---	---	---	1350	1530	s 1.85	2+
Bismuth	Bi	93	209.0	2	8	18	32	18	5	---	271.3	1420	s 9.80	---
Boron	B	5	10.81	2	3	---	---	---	---	---	2300	2550	s 2.3	3+
Bromine	Br	35	79.91	2	8	15	7	---	---	---	-7.2	19.0	s 3.12	
Cadmium	Cd	48	112.4	2	8	18	18	2	---	---	320.9	765	s 8.65	2+
Calcium	Ca	20	40.08	2	8	8	2	---	---	---	850	1440	s 1.55	2+
Californium	Cf	98	252	2	8	18	32	27	9	2	---	---	---	---
Carbon	C	6	12.01	2	4	---	---	---	---	---	~3500	4200(?)	s 3. 51	4+
Cesium	Cs	55	132.9	2	8	18	18	8	1	---	28	690	s 1.9	1+
Chlorine	Cl	17	35.45	2	8	7	---	---	---	---	-101	-34.7	g 3.214 L 1.557 s 1.9	1-
Chromium	Cr	24	52.00	2	8	13	1	---	---	---	1890	2500	s 7.19	3+
Cobalt	Co	27	58.93	2	8	15	2	---	---	---	1495	2900	s 8.9	2+

PHYSICAL PROPERTIES OF THE ELEMENTS (Continued)

Element	Sym.	Atomic No.	Atomic Wt.	Electrons In Shell							Melting Pt. °C	Boiling Pt. °C	Density[a]	Val.[b]
				K	L	M	N	O	P	Q				
Zinc	Zn	30	65.37	2	8	18	2	---	---	---	419.46	906	s 7.133	2+
Zirconium	Zr	40	91.22	2	8	18	10	2	---	---	1750	---	s 6.5	4+

a. Density measured in g - g/l; L g/cm^3; s g/cm^3; g - gas; L - liquid; s - solid.
b. Most common valence.

DENSITIES OF SELECTED CARBON & ALLOY STEELS

Iron & Carbon Steel	**g/cm^3**	**lb/in.^{3}**
Pure iron	7.874	0.2845
Ingot iron	7.866	0.2842
Wrought iron	7.7	0.28
Gray cast iron	7.15[a]	0.258[a]
Malleable iron	7.27[b]	0.262[b]
0.06% C steel	7.871	0.2844
0.23% C steel	7.859	0.2839
0.435% C steel	7.844	0.2834
1.22% C steel	7.830	0.2829
Low-Carbon Chromium-Molybdenum Steels		
0.5% Mo steel	7.86	0.283
1Cr-0.5% Mo steel	7.86	0.283
1.25Cr-0.5% Mo steel	7.86	0.283
2.25Cr-1.0% Mo steel	7.86	0.283
5Cr-0.5Mo% Steel	7.78	0.278
7Cr-0.5Mo% steel	7.78	0.278
9Cr-1Mo% steel	7.67	0.276

COEFFICIENTS OF LINEAR EXPANSION OF CARBON & ALLOY STEELS[a,j] (Continued)

SAE	Condition	20-100°C 68-212°F	20-200°C 68-392°F	20-300°C 68-572°F	20-400°C 68-752°F	20-500°C 68-932°F	20-600°C 68-1112°F	20-700°C 68-1292°F
1023	Unknown	12.2[b]	---	---	13.5[b]	---	14.4[b]	---
1025	Annealed	12.0[b]	---	---	13.5[b]	---	14.4[b]	---
1026	Annealed	12.0[b]	---	---	13.5[b]	---	14.4[b]	---
1029	Annealed	12.0[b]	---	---	13.5[b]	---	14.4[b]	---
1030	Annealed	11.7[b]	---	---	13.5[b]	---	14.4[b]	---
1035	Annealed	11.1	11.9	12.7	13.4	14.0	14.4	14.8
1037	Annealed	11.1[b]	---	---	13.5[b]	---	14.6[b]	---
1039	Annealed	11.1[b]	---	---	13.5[b]	---	14.6[b]	---
1040	Annealed	11.3	12.0	12.5	13.3	13.9	14.4	14.8
1043	Annealed	11.3[b]	---	---	13.5[b]	---	14.6[b]	---
1044	Annealed	11.1[b]	12.0[b]	---	13.3[b]	---	---	---
1045	Annealed	11.6[b]	12.3[b]	13.1[b]	13.7[b]	14.2[b]	14.7[b]	15.1[b]
1045	Annealed	11.2	11.9[c]	12.7[c]	13.5	14.1[c]	14.5[c]	14.8[c]
1046	Unknown	11.1[b]	---	---	13.5[b]	---	---	---
1050	Annealed	11.1[b]	12.0[b]	---	13.5[b]	---	---	---
1052	Annealed	11.3[c]	11.8[c]	12.7[c]	13.7[c]	14.5[c]	14.7[c]	15.0[c]
1053	Unknown	11.1[b]	---	---	13.5[b]	---	---	---
1055	Annealed	11.0	11.8	12.6	13.4	14.0	14.5	14.8
1060	Annealed	11.1[c]	11.9[c]	12.9[c]	13.5[c]	14.1 [c]	14.6[c]	14.9[c]
1064	Unknown	11.1[b]	---	---	13.5[b]	---	---	---
1065	Unknown	11.1[b]	---	---	13.5[b]	---	---	---
1070	Unknown	11.5[b]	---	---	13.3[b]	---	---	---
1078	Unknown	11.3[b]	---	---	13.3	---	---	---

SPECIFIC HEATS OF CARBON & ALLOY STEELS[e]

SAE	Condition	50-100°C	150-200°C	200-250°C	250-300°C	300-350°C	350-400°C	450-500°C	550-600°C	650-700°C
1008	Annealed	481	519	536	553	574	595	662	754	867
1010	Unknown	450	500	520	535	565	590	650	730	825
1015	Annealed	486	519	---	---	---	599	---	---	---
1016	Annealed	481	515	---	---	---	595	---	---	---
1017	Unknown	481[a]	---	---	---	---	---	---	---	---
1018	Annealed	486	519	---	---	---	599	---	---	---
1020	Unknown	486	519	---	---	---	599	---	---	---
1025	Annealed	486	519	532	557	574	599	662	749	846
1030	Annealed	486	519	---	---	---	599	---	---	---
1035	Annealed	486	519	---	---	---	586	---	---	---
1040	Annealed	486	519	---	---	---	586	---	---	---
1042	Annealed	486	515	528	548	569	586	649	708	770
1045	Annealed	486	519	---	---	---	586	---	---	---
1050	Annealed	486	519	---	---	---	590	---	---	---
1060	Unknown	502	544	---	---	---	---	---	---	---
1070	Unknown	490	532	---	---	---	---	---	---	---
1078	Annealed	490	532	548	565	586	607	670	712	770
1086	Unknown	500	532	---	---	---	---	---	---	---
1095	Unknown	461[b]	---	---	---	---	---	---	---	---
1117	Unknown	481	---	---	---	---	---	---	---	---
1140	Unknown	461[b]	---	---	---	---	---	---	---	---
1151	Unknown	502[b]	---	---	---	---	---	---	---	---
1522	Annealed	486	519	---	---	---	599	---	---	---
1524	Annealed	477	511	528	544	565	590	649	741	837
1561	Annealed	486	519	---	---	---	---	---	---	---
4032	Unknown	---	461[c]	---	---	---	---	---	---	---

ELECTRICAL RESISTIVITIES OF CARBON & ALLOY STEELS[e]

SAE	Condition	20°C	100°C	200°C	400°C	600°C	700°C	800°C	900°C	1000°C	1100°C	1200°C
1008	Annealed	0.142	0.190	0.263	0.458	0.734	0.905	1.081	1.130	1.165	1.193	1.216
1010	Unknown	0.143	---	---	---	---	---	---	---	---	---	---
1015	Annealed	0.159[a]	0.219	0.292	---	---	---	---	---	---	---	---
1016	Annealed	0.160[a]	0.220	0.290	---	---	---	---	---	---	---	---
1018	Annealed	0.159[a]	0.219	0.293	---	---	---	---	---	---	---	---
1020	Unknown	0.159[a]	0.219	0.292	---	---	---	---	---	---	---	---
1022	Annealed	0.159[a]	0.219	0.293	---	---	---	---	---	---	---	---
1025	Annealed	0.159[a]	0.219	0.292	0.487	0.758	0.925	1.094	1.136	1.167	1.194	1.219
1029	Annealed	0.160[a]	0.220	0.290	---	---	---	---	---	---	---	---
1030	Annealed	0.166	---	---	---	---	---	---	---	---	---	---
1035	Annealed	0.163[a]	0.217	---	---	---	---	---	---	---	---	---
1040	Annealed	0.160[a]	0.221	---	---	---	---	---	---	---	---	---
1042	Annealed	0.171	0.221	0.296	0.493	0.766	0.932	1.111	1.149	1.179	1.207	1.230
1043	Annealed	0.163[a]	0.219	---	---	---	---	---	---	---	---	---
1045	Annealed	0.162[a]	0.223	---	---	---	---	---	---	---	---	---
1046	Unknown	0.163[a]	0.224	---	---	---	---	---	---	---	---	---
1050	Annealed	0.163[a]	0.224	0.300	---	---	---	---	---	---	---	---
1055	Unknown	0.163[a]	0.224	---	---	---	---	---	---	---	---	---
1060	Unknown	0.180	---	---	---	---	---	---	---	---	---	---
1065	Unknown	0.163[a]	0.224	---	---	---	---	---	---	---	---	---
1070	Unknown	0.168[a]	0.230	---	---	---	---	---	---	---	---	---
1078	Annealed	0.180	0.232	0.308	0.505	0.772	0.935	1.129	1.164	1.191	1.214	1.231
1080	Unknown	0.180	---	---	---	---	---	---	---	---	---	---
1095	Unknown	0.180	---	---	---	---	---	---	---	---	---	---

PHYSICAL PROPERTIES OF WROUGHT STAINLESS STEELS[a]

SAE Type	Density g/cm^3 (lb/in.^{3})	Elastic Modulus GPa (10^6 psi)	Mean CTE[b] from 0°C (32°F) to:		Thermal Conductivity		Specific Heat at 0-100°C (32-212°F) J/kg°K (Btu/lb°F)	Electrical Resistivity ηΩm	Magnetic Permeability
			315°C (600°F) µm/m°C (µin./in.°F)	538°C (1000°F) µm/m°C (µin./in.°F)	at 100°C (212°F) W/m°K (Btu/ft h°F)	at 500°C (932°F) W/m°K (Btu/ft h°F)			
201	7.8 (0.28)	197 (28.6)	17.5 (9.7)	18.4 (10.2)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	690	1.02
202	7.8 (0.28)	---	18.4 (10.2)	19.2 (10.7)	16.2 (9.4)	21.6 (12.5)	500 (0.12)	690	1.02
205	7.8 (0.28)	197 (28.6)	17.9 (9.9)	19.1 (10.6)	---	---	500 (0.12)	---	---
301	8.0 (0.29)	193 (28.0)	17.2 (9.6)	18.2 (10. 1)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	720	1.02
302	8.0 (0.29)	193 (28.0)	17.8 (9.9)	18.4 (10.2)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	71-0	1.02
302B	8.0 (0.29)	193 (28.0)	18.0 (10.0)	19.4 (10.8)	15.9 (9.2)	21.6 (12.5)	500 (0.12)	720	1.02
303	8.0 (0.29)	193 (28.0)	17.8 (9.9)	18.4 (10.2)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	720	1.02
304	8.0 (0.29)	193 (28.0)	17.8 (9.9)	18.4 (10.2)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	720	1.02
304L	8.0 (0.29)	---	---	---	---	---	---	---	1.02
302Cu	8.0 (0.29)	193 (28.0)	17.8 (9-9)	---	11.2 (6.5)	21.5 (12.4)	500 (0.12)	720	1.02
304N	8.0 (0.29)	196 (28.5)	---	---	---	---	500 (0.12)	720	1.02
305	8.0 (0.29)	193 (28.0)	17.8 (9.9)	18.4 (10.2)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	720	1.02
308	8.0 (0.29)	193 (28.0)	17.8 (9.9)	18.4 (10.2)	15.2 (8.8)	21.6 (12.5)	500 (0.12)	720	---
309	8.0 (0.29)	200 (29.0)	16.6 (9.2)	17.2 (9.6)	15.6 (9.0)	18.7 (10.8)	500 (0.12)	780	1.02
310	8.0 (0.29)	200 (29.0)	16.2 (9.0)	17.0 (9.4)	14.2 (8.2)	18.7 (10.8)	500 (0.12)	780	1.02
314	7.8 (0.28)	200 (29.0)	15.1 (8.4)	---	17.5 (10.1)	20.9 (12.1)	500 (0.12)	770	1.02
316	8.0 (0.29)	193 (28.0)	16.2 (9.0)	17.5 (9.7)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	740	1.02
316L	8.0 (0.29)	---	---	---	---	---	---	---	1.02
316N	8.0 (0.29)	196 (28.5)	---	---	---	---	500 (0.12)	740	1.02
317	8.0 (0.29)	193 (28.0)	16.2 (9.0)	17.5 (9.7)	16.2 (9.4)	21.5 (12.4)	500 (0.12)	740	1.02
317L	8.0 (0.29)	200 (29.0)	---	18.1 (10.1)	14.4 (8.3)	---	500 (0.12)	790	---

Chapter 20

AMERICAN STANDARDS CROSS REFERENCES CARBON, ALLOY & STAINLESS STEELS

AMERICAN STANDARDS CROSS REFERENCES - REPHOSPHORIZED & RESULFURIZED CARBON STEELS			
UNS No.	**SAE**	**ASTM**	**AMS**
G12110	J1397 (1211)	A 29 (1211), A 108 (1211), A 510 (1211), A 576 (1211)	---
G12120	J403 (1212), J1397 (1212)	A 29 (1212), A 108 (1212), A 510 (1212), A 576 (1212)	5010
G12130	J403 (1213), J1397 (1213)	A 29 (1213), A 108 (1213), A 510 (1213), A 519 (1213), A 576 (1213)	---
G12134	---	A 29 (12L13), A 510 (12L13)	---
G12144	J403 (12L14), J1397 (12L14)	A 576 (12L14), A 108 (12L14), A 510 (12L14), A 519 (12L14), A 576 (12L14)	---
G12150	J403 (1215)	A 29 (1215), A 108 (1215), A 510 (1215), A 519 (1215), A 576 (1215)	5010

AMERICAN STANDARDS CROSS REFERENCES - CARBON-MANGANESE STEELS		
UNS No.	**SAE**	**ASTM**
G15130	J412 (1513)	A 29 (1513), A 510 (1513), A 576 (1513)
G15180	---	A 29 (1518), A 510 (1518), A 519 (1518), A 576 (1518)
G15220	J403 (1522), J412 (1522)	A 29 (1522), A 510 (1522), A 576 (1522)
H15211	J1268 (15B21H)	A 304 (15B21 H)
H15220	J1268 (1522H)	A 304 (1522 H)
G15240	J403 (1524), J412 (1524), J1397 (1524)	A 29 (1524), A 510 (1524), A 513 (1524), A 519 (1524), A 576 (1524), A 635 (1524), A 830
H15240	J1268 (1524H)	A 304 (15B24 H)
G15250	---	A 29 (1525), A 510 (1525), A 576 (1525)
G15260	J403 (1526), J412 (1526)	A 29 (1526), A 510 (1526), A 576 (1526)
H15260	J1268 (1526H)	A 304 (1526 H)
G15270	J403 (1527), J412 (1527)	A 29 (1527), A 510 (1527), A 513 (1527), A 576 (1527), A 830
G15330	J1249	---
G15340	J1249	---
H15351	J1268 (15B35H)	A 304 (15B35 H)
G15360	J412 (1536), J1397 (1536)	A 29 (1536), A 510 (1536), A 576 (1536), A 830
H15371	J1268 (15B37H)	A 304 (15B37 H)

AMERICAN STANDARDS CROSS REFERENCES - CHROMIUM-MOLYBDENUM STEELS (Continued)			
UNS No.	**SAE**	**ASTM**	**AMS**
H41350	J1268 (4135H)	A 304 (4135 H)	---
G41370	J404 (4137), J412 (4137), J1397 (4137)	A 29 (4137), A 320 (L7B, L72), A 322 (4137), A 519 (4137), A 752 (4137), A 829	---
H41370	J1268 (4137H)	A 304 (4137 H)	---
G41400	J404 (4140), J412 (4140), J1397 (4140)	A 29 (4140), A 193 (B7, B7M), A 194 (7, 7M), A 320 (L7, L7M, L7C), A 322 (4140), A 506 (4140), A 513 (4140), A 519 (4140), A 646 (4140), A 711, A 752 (4140), A 829,A 866 (4140)	6349, 6381, 6382, 6395, 6462, 6529, AMS-S-5621
H41400	J775 (NV 7), J1268 (4140H)	A 304 (4140 H)	---
G41420	J404 (4142), J412 (4142), J1397 (4142)	A 29 (4142), A 322 (4142), A 519 (4142), A 711, A 752 (4142), A 829	---
H41420	J1268 (4142H)	A 304 (4142 H), A 540 (B22)	---
G41450	J404 (4145), J412 (4145), J1397 (4145)	A 29 (4145), A 322 (4145), A 519 (4145), A 711, A 752 (4145), A 829, A 866 (4145)	---
H41450	J1268 (4145H)	A 304 (4145 H)	---
G41470	J412 (4147), J1249 (4147), J1397 (4142)	A 29 (4147), A 322 (4147), A 519 (4147),A 752 (4147)	---
H41470	J1268 (4147H)	A 304 (4147 H)	---
G41500	J404 (4150), J1397 (4150)	A 29 (4150), A 322 (4150), A 519 (4150), A 711, A 752 (4150), A 866 (4150)	---
H41500	J1268 (4150H)	A 304 (4150 H)	---
G41610	J412 (4161), J1249 (4161), J1397 (4161)	A 29 (4161), A 322 (4161), A 752 (4161)	---
H41610	J1268 (4161H)	A 304 (4161 H)	---

AMERICAN STANDARDS CROSS REFERENCES - STAINLESS STEELS (Continued)					
UNS	**SAE**	**ASTM**	**AMS**	**MIL**	**FED**
S30300	J412 (30303)	A 194 (303, 8F, 8FA), A 314 (303), A 320 (303, B8F, B8FA), A 473 (303), A 581 (303), A 582 (303), A 895 (303), F 593 (303), F594 (303), F738 (303), F836 (303), F837 (303), F880 (303), F899(303)	5640 (Type 1)	---	---
S30323	---	A 194 (303 Se, 8F, 8FA), A 314 (303 Se), A 320 (303 Se, B8F, B8FA), A 473 (303 Se), A 511 (303 Se), A 581 (303 Se), A 582 (303 Se), A 895 (303 Se), F 593 (303 Se), F 594 (303 Se), F 738 (303 Se), F 836 (303 Se), F 880 (303 Se)	5640 (Type 2), 5641, 5738	---	---
S30400	J405 (304), J412 (30304), J467 (304)	A 182 (304), A 193 (304, B8, B8A), A 194 (304, 8, 8A), A 213 (304), A 240 (304), A 249 (304), A 264 (304), A 269 (304), A 270 (304), A 276 (304), A 312 (304), A 313 (304), A 314 (304), A 320 (304, B8, B8A), A 336 (F304), A 358 (304), A 368 (304), A 376 (304), A376 (TP304), A 403 (304), A 409 (304), A 430 (304), A 473 (304), A 478 (304), A 479 (304), A 492 (304), A 493 (304), A 511 (304), A 554 (304), A 580 (304), A 632 (304), A 666 (304), A 688 (304), A 774 (304), A 774 (TP304), A 793 (304), A 813 (TP 304), A 814 (TP 304), A 851 (TP 304), A 908 (304), A 943 (TP304), A 965 (304), A 988 (304), F 593 (304), F 738 (304), F 836 (304), F 837 (304), F 879 (304), F 880 (304), F 899 (304)	5501, 5513, 5560, 5563, 5564, 5565, 5566, 5567, 5639, 5697, 5857, 5910, 5911, 5912, 5913, 5868, AMS-QQ-S-763 (304), AMS-T-6845 (304), AMS-T-8506 (304), AS7245	MIL-S-21149/6, MIL-S-24149/3, MIL-S-24249/6, MIL-T-5695, MIL-T-8504 (304)	---
S30403	J405 (304 L), J467 (304 L)	A 182 (304 L), A 213 (TP304 L), A 240 (304 L), A 249 (304 L), A 269 (304 L), A 270 (TP 304 L), A 276 (304 L), A 312 (304 L), A 314 (304 L), A 336 (F 304 L), A 358 (304 L), A 368 (304 L), A 403 (304 L), A 409 (304 L), A 473 (304 L), A 478 (304 L), A 479 (304 L), A 493 (304 L), A 511 (304 L), A 554 (304 L), A 580 (304 L), A 632 (304 L), A 666 (304 L), A 688 (304 L),	5511, 5569, 5584, 5647, AMS-QQ-S-763 (304 L) AMS-T-6845	MIL-S-4043	---

Chapter 21

INTERNATIONAL CROSS REFERENCES:

CARBON & ALLOY STEELS

1 Carbon Steels for General Use

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	**Name**	**Number**	**Specification**	**Grade**	**UNS #**	**Specification**	**Symbol**	**Specification**	**Name**
10016-2:1994	C4D	1.0300	A 29/A 29M-99	1005	G10050	---	---	---	---
10016-4:1994	C3D2	1.1110	J403 AUG95	1005	G10050	---	---	---	---
10016-2:1994	C7D	1.0313	A 29/A 29M-99	1006	G10060	---	---	---	---
10016-4:1994	C5D2	1.1111	J403 AUG95	1006	G10060	---	---	---	---
10016-2:1994	C9D	1.0304	A 29/A 29M-99	1008	G10080	---	---	---	---
10016-4:1994	C8D2	1.1113	A 108-99	1008	G10080	---	---	---	---
---	---	---	A 576-90	1008	G10080	---	---	---	---
---	---	---	J403 Aug95	1008	G10080	---	---	---	---
10016-2:1994	C10D	1.0310	A 29/A 29M-99	1010	G10100	G 4051 (1979)	S 10 C	683-11:1987	C 10
10016-4:1994	C10D2	1.1114	A 108-99	1010	G10100	G 4051 (1979)	S 09 CK	---	---
10084:1998	C10E	1.1121	A 576-90	1010	G10100	---	---	---	---
---	C10R	1.1207	J403 Aug95	1010	G10100	---	---	---	---
10016-2:1994	C12D	1.0311	A 29/A 29M-99	1012	G10120	G 4051 (1979)	S 12 C	---	---
10016-4:1994	C12D2	1.1124	A 576-90	1012	G10120	---	---	---	---
---	---	---	J403 AUG95	1012	G10120	---	---	---	---

1 Carbon Steels for General Use (Continued)

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	**Name**	**Number**	**Specification**	**Grade**	**UNS #**	**Specification**	**Symbol**	**Specification**	**Name**
10016-2:1994	C58D	1.0609	A 29/A 29M-99	1059	G10590	G 4051:1979	S 58 C	683-1:1987	C 60
	C60D	1.0610		1060	G10600	---	---		C 60 E 4
10016-4:1994	C58D2	1.1212	A 576-90	1060	G10600	---	---		C 60 M 2
	C60D2	1.1228	J403 AUG95	1060	G10600	---	---	---	---
10083-1:1991	2 C 60	---	---	---	---	---	---	---	---
	3 C 60	---	---	---	---	---	---	---	---
10083-2:1991	1 C 60	---	---	---	---	---	---	---	---
10016-2:1994	C62D	1.0611	A 29/A 29M-99	1064	G10640	---	---	---	---
	C66D	1.0612		1065	G10650	---	---	---	---
	C68D	1.0613	J403 AUG95	1065	G10650	---	---	---	---
10016-4:1994	C62D2	1.1222	---	---	---	---	---	---	---
	C66D2	1.1236	---	---	---	---	---	---	---
	C68D2	1.1232	---	---	---	---	---	---	---
10016-2:1994	C70D	1.0615	A 29/A 29M-99	1069	G10690	---	---	---	---
	C72D	1.0617		1070	G10700	---	---	---	---
10016-4:1994	C70D2	1.1251		1071	G10710	---	---	---	---
	C72D2	1.1242	A 576-90	1070	G10700	---	---	---	---
---	---	---	J403 AUG95	1070	G10700	---	---	---	---
10016-2:1994	C76D	1.0614	A 29/A 29M-99	1074	G10740	---	---	---	---
	C78D	1.0620		1075	G10750	---	---	---	---
10016-4:1994	C76D2	1.1253	---	---	---	---	---	---	---
	C78D2	1.1252	---	---	---	---	---	---	---

3 Alloy Steels for General Use (Continued)

3.3 Nickel Chromium Molybdenum (Ni Cr Mo) Steels

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	**Name**	**Number**	**Specification**	**Grade**	**UNS #**	**Specification**	**Symbol**	**Specification**	**Name**
---	---	---	---	---	---	G 4103:1979	SNCM 415	683-11:1987	17 NiCrMo 6
10084:1998	20NiCrMoS6-4	1.6571	A 29/A 29M-99	4320	G43200	G 4103:1979	SNCM 420	---	---
---	---	---	A 322-91 (1996)	4320	G43200	---	---	---	---
---	---	---	J404 APR94	4320	G43200	---	---	---	---
---	---	---	A 29/A 29M-99	4340	G43400	G 4103:1979	SNCM 439	---	---
---	---	---		E4340	G43406	---	---	---	---
---	---	---	A 322-91 (1996)	4340	G43400	---	---	---	---
---	---	---		E4340	G43406	---	---	---	---
---	---	---	J404 APR94	4340	G43400	---	---	---	---
---	---	---		E4340	G43406	---	---	---	---
10084:1998	20NiCrMo2-2	1.6523	A 29/A 29M-99	8620	G86200	G 4103:1979	SNCM 220	683-11:1987	20 NiCrMo 2
	20NiCrMoS2-2	1.6526	A 322-91 (1996)	8620	G86200	---	---		20 NiCrMoS 2
---	---	---	J404 APR94	8620	G86200	---	---	---	---
---	---	---	A 29/A 29M-99	8640	G86400	G 4103:1979	SNCM 240	683-1:1987	41 CrNiMo 2
---	---	---	A 322-91 (1996)	8640	G86400	---	---		41 CrNiMoS 2
---	---	---	J404 APR94	8640	G86400	---	---	---	---
10084:1998	14NiCrMo13-4	1.6657	A 29/A 29M-99	E9310	G93106	---	---	---	---

Chapter 22

INTERNATIONAL CROSS REFERENCES:

WROUGHT STAINLESS STEELS

1 Stainless Steels: Plate, Sheet and Strip

1.2 Ferritic Stainless Steels

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
10088-2:1995	X6CrAl13	1.4002	---	---	---	G 4304:1999	SUS405	---	---
---	---	---	---	---	---	G 4305:1999	SUS405	---	---
---	---	---	---	---	---	G 4312:1991	SUS405	---	---
10088-2:1995	X2CrTi12	1.4512	---	---	---	G 4312:1991	SUH409L	---	---
10088-2:1995	X6Cr17	1.4016	---	---	---	G 4304:1999	SUS430	---	---
---	---	---	---	---	---	G 4305:1999	SUS430	---	---
---	---	---	---	---	---	G 4312:1991	SUS430	---	---
10088-2:1995	X2CrTi17	1.4520	---	---	---	G 4304:1999	SUS430LX	---	---
	X3CrTi17	1.4510	---	---	---	G 4305:1999	SUS430LX	---	---
	X3CrNb17	1.4511	---	---	---	---	---	---	---
10088-2:1995	X6CrMo17-1	1.4113	---	---	---	G 4304:1999	SUS434	---	---
---	---	---	---	---	---	G 4305:1999	SUS434	---	---
10088-2:1995	X2CrMoTi18-2	1.4521	---	---	---	G 4304:1999	SUS444	---	---
---	---	---	---	---	---	G 4305:1999	SUS444	---	---
---	---	---	A 176-99	446	S44600	G 4312:1991	SUH446	4955:1994	X15CrN26

2 Stainless Steels: Bar

2.3 Austenitic Stainless Steels

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
---	---	---	A 276-00	201	S20100	G 4303:1998	SUS201	---	---
---	---	---	A 276-00	202	S20200	G 4303:1998	SUS202	---	---
10088-3:1995	X10CrNi18-8	1.4310	---	---		G 4303:1998	SUS301	---	---
---	---	---	A 276-00	302	S30200	G 4303:1998	SUS302	---	---
---	---	---	---	---	---	G 4318:1998	SUS302	---	---
10088-3:1995	X8CrNiS18-9	1.4305	A 582/A 582M-95	303	S30300	G 4303:1998	SUS303	---	---
---	---	---	---	---	---	G 4318:1998	SUS303	---	---
---	---	---	A 582/A 582M-95	303Se	S30323	G 4303:1998	SUS303Se	---	---
---	---	---	---	---	---	G 4318:1998	SUS303Se	---	---
10088-3:1995	X5CrNi18-10	1.4301	A 276-00	304	S30400	G 4303:1998	SUS304	---	---
---	---	---	---	---	---	G 4311:1991	SUS304	---	---
---	---	---	---	---	---	G 4318:1998	SUS304	---	---
10088-3:1995	X2CrNi18-9	1.4307	A 276-00	304L	S30403	G 4303:1998	SUS304L	---	---
---	---	---	---	---	---	G 4318:1998	SUS304L	---	---
---	---	---	A 276-00	304N	S30451	G 4303:1998	SUS304N1	---	---
10088-3:1995	X2CrNiN18-10	1.4311	A 276-00	304LN	S30453	G 4303:1998	SUS304LN	---	---
---	---	---	A 276-00	XM-21	S30452	G 4303:1998	SUS304N2	---	---
10088-3:1995	X4CrNi18-12	1.4303	A 276-00	305	S30500	G 4303:1998	SUS305	---	---
---	---	---	---	---	---	G 4318:1998	SUS305	---	---

Chapter 23

INTERNATIONAL CROSS REFERENCES:

CASTINGS

1 Cast Carbon Steels

1.1 Cast Carbon Steel for General and Structural Applications

USA – SAE/ASTM			Japan - JIS		International - ISO		Germany - DIN		France - AFNOR		UK – BSI BS	
Spec	**Grade**	**UNS #**	**Spec**	**Symbol**	**Spec**	**Name**	**Spec**	**Name**	**Spec**	**Name**	**Spec**	**Grade**
---	---	---	G 5101:1991	SC 360	---	---	1681:1985	GS-38 1.0420	---	---	---	---
A 27/A 27M-95 (2000)	U-60-30	J02500	G 5101:1991	SC 410	3755:1991	200-400	---	---	NF A 32-054:1994	GE230	3100:1991 AMD.1:1992	A1
	60-30	J03000	G 5102:1991	SCW 410		200-400W	---	---		G16Mn5	---	---
A 27/A 27M-95 (2000)	65-35	J03001	G 5101:1991	SC 450	3755:1991	230-450	1681:1985	GS-45 1.0446	---	---	---	---
A 958-00	SC 1020 Cl. 65/35	---	G 5102:1991	SCW 450		230-450W	---	---	---	---	---	---
	SC 1025 Cl. 65/35	---	---	---	---	---	---	---	---	---	---	---
	SC 1030 Cl. 65/35	---	---	---	---	---	---	---	---	---	---	---
A 27/A 27M-95 (2000)	70-36	J03501	G 5101:1991	SC 480	3755:1991	270-480	---	---	NF A 32-054:1994	GE280	3100:1991 AMD.1:1992	A2
	70-40	J02501	G 5102:1991	SCW 480		270-480W	---	---	---	---	---	---
A 958-00	SC 1020 Cl. 70/36	---	---	---	---	---	---	---	---	---	---	---
	SC 1025 Cl. 70/36	---	---	---	---	---	---	---	---	---	---	---
	SC 1030 Cl. 70/36	---	---	---	---	---	---	---	---	---	---	---
	SC 1040 Cl. 70/36	---	---	---	---	---	---	---	---	---	---	---

3 Cast Alloy Steels

3.2. Cast Alloy Steels for Pressure Purposes at High Temperatures

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Spec	**Name**	**Number**	**Spec**	**Grade**	**UNS #**	**Spec**	**Symbol**	**Spec**	**Name**
10213-2:1996	G20Mo5	1.5419	A 217/A 217M-99	WC1	J12524	G 5151:1991	SCPH 11	4991:1994	C28H
10213-2:1996	G17CrMo5-5	1.7357	A 217/A 217M-99	WC6	J12072	G 5151:1991	SCPH 21	4991:1994	C32H
10213-2:1996	G17CrMoV5-10	1.7706	A 389/A 389M-93 (1998)	C24	J12092	G 5151:1991	SCPH 23	4991:1994	C35BH
10213-2:1996	G17CrMo9-10	1.7379	A 217/A 217M-99	WC9	J21890	G 5151:1991	SCPH 32	4991:1994	C34AH
---	---	---	A 487/A487M-93 (1998)	8 Cl. ABC	J22091	---	---		C34BH
10213-2:1996	GX15CrMo5	1.7365	A 217/A 217M-99	C5	J42045	G 5151:1991	SCPH 61	4991:1994	C37H
---	---	---	A 217/A 217M-99	C12	J82090	---	---	4991:1994	C38H

3.3 Cast Alloy Steels for Pressure Purposes at Low Temperatures

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Spec	**Name**	**Number**	**Spec**	**Grade**	**UNS #**	**Spec**	**Symbol**	**Spec**	**Name**
10213-3:1996	G18Mo5	1.5422	A 352/A 352M-93 (1998)	LC1	J12522	G 5152:1991	SCPL 11	---	---
10213-3:1996	G9Ni10	1.5636	A 757/A 757M-00	B2N, B2Q	J22501	G 5152:1991	SCPL 21	---	---
---	---	---	A 352/A 352M-93 (1998)	LC2	J22500	---	---	---	---
10213-3:1996	G9Ni14	1.5638	A 757/A 757M-00	B3N, B3Q	J31500	G 5152:1991	SCPL 31	4991:1994	C43L
---	---	---	A 352/A 352M-93 (1998)	LC3	J31550	---	---	---	---
10213-3:1996	G17NiCrMo13-6	1.6781	A 352/A 352M-93 (1998)	LC2-1	J42215	---	---	4991:1994	C43E2aL
---	---	---	A 757/A 757M-00	E3N	J42065	---	---		C43E2bL

Chapter 24

INTERNATIONAL CROSS REFERENCES:

FORGINGS

1 Carbon Steel Forgings

1.2 Carbon Steel Forgings for Piping, Pressure Vessel and Components

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	**Steel Name**	**Steel Number**	**Specification**	**Grade**	**UNS Number**	**Specification**	**Symbol**	**Specification**	**Steel Name**
10222-4:1999	P285QH	1.0478	---	---	---	---	---	9327-4:1999	P 28, PH 28
	P285NH	1.0477	---	---	---	---	---		PL 28
10222-2:1999	P245GH	1.0352	A 181/A 181M-00	60	K03502	G 3202:1988 (1991)	SFVC 1	---	---
---	---	---	A 266/A 266M-99	1	---	G 3205:1988	SFL 1	---	---
---	---	---	A 350/A 350M-00	LF1, Cl 1	K03009	---	---	---	---
10222-2:1999	P280GH	1.0426	A 541/A 541M-95 (1999)	1	---	G 3202:1988 (1991)	SFVC 2 A	9327-4:1999	P 35, PH 35
10222-4:1999	P355QH	1.0571		1A	---		SFVC 2 B		PL 35, PLH 35
10222-2:1999	P305GH	1.0436	A 105/A 105M-98	---	K03504	G 3205:1988	SFL 2	---	---
10222-4:1999	P355NH	1.0565	A 266/A 266M-99	2	K03506	---	---	---	---
---	---	---		4	K03017	---	---	---	---
---	---	---	A 181/A 181M-00	70	K03502	---	---	---	---
---	---	---	A 350/A 350M-00	LF2, Cl 1	K03011	---	---	---	---
---	---	---		LF2, Cl 2		---	---	---	---
---	---	---	A 508/A 508M-95 (1999)	1	K13502	---	---	---	---
---	---	---		1a	K13502	---	---	---	---
10222-4:1999	P420QH	1.8936	---	---	---	---	---	9327-4:1999	P 42, PH 42
	P420NH	1.8932	---	---	---	---	---		PL 42, PLH 42

2 Alloy Steel Forgings

2.2 Alloy Steel Forgings for Piping, Pressure Vessel and Components (Continued)

2.2.8 9Cr-1Mo Alloy Steel

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
10222-2:1999	X10CrMoVNb9-1	1.4903	A 182/A 182M-00	F 9	K90941	G 3203:1988	SFVA F 9	---	---
---	---	---	A 336/A 336M-99	F9	---	---	---	---	---

2.2.9 11Cr-½Ni-1Mo Alloy Steel

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
10222-2:1999	X20CrMoV11-1	1.4922	---	---	---	---	---	9327-2:1999	X20CrMoV12-1
---	---	---	---	---	---	---	---	---	---

2.2.10 Ni Alloy Steel

European Union - EN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
10222-3:1999	12Ni14	1.5637	A 350/A 350M-00	LF3	K32025	G 3205:1988	SFL 3	9327-3:1999	12Ni14G1
---	---	---	---	---	---	---	---		12Ni14G2
10222-3:1999	X12Ni5	1.5680	---	---	---	---	---	9327-3:1999	12Ni19
10222-3:1999	X8Ni9	1.5662	---	---	---	---	---	9327-3:1999	X8Ni9

3 Stainless Steel Forgings

3.4 Precipitation-Hardening Stainless Steel Forgings

European Union - CEN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
10250-4:1999	X5CrNiCuNb16-4	1.4542	---	---	---	G 3214:1991	SUS F 630	---	---

3.5 Duplex (Ferritic-Austenitic) Stainless Steel Forgings

European Union - CEN			USA – SAE/ASTM			Japan - JIS		International - ISO	
Specification	Steel Name	Steel Number	Specification	Grade	UNS Number	Specification	Symbol	Specification	Steel Name
10250-4:1999	X3CrNiMoN27-5-2	1.4460	A 182/A 182M-00	F 50	S31200	---	---	---	---
10250-4:1999	X2CrNiMoN22-5-3	1.4462	A 182/A 182M-00	F 51	S31803	---	---	9327-5:1999	X2CrNiMoN22-5-3
10222-5:1999	X2CrNiMoN22-5-3	1.4462		F 60	S32205	---	---	---	---
10250-4:1999	X2CrNiMoN25-7-4	1.4410	A 182/A 182M-00	F 53	S32750	---	---	---	---
10222-5:1999	X2CrNiMoN25-7-4	1.4410	---	---	---	---	---	---	---
10250-4:1999	X2CrNiMoCuWN27-7-4	1.4501	A 182/A 182M-00	F 55	S32760	---	---	---	---
10250-4:1999	X2CrNiMoCuN25-6-3	1.4507	A 182/A 182M-00	F 59	S32520	---	---	---	---
10250-4:1999	X2CrNiN23-4	1.4362	---	---	---	---	---	9327-5:1999	X2CrNiN23-4

Appendix 1

HARDNESS CONVERSION TABLES

APPROXIMATE HARDNESS CONVERSION NUMBERS FOR NONAUSTENITIC STEELS[a, b]

Rockwell C 150 kgf Diamond HRC	Vickers HV	Brinell 3000 kgf 10mm ball HB	Knoop 500 gf HK	Rockwell A 60 kgf Diamond HRA	Rockwell Superficial Hardness			Approximate Tensile Strength ksi (MPa)
					15 kgf Diamond HR15N	30 kgf Diamond HR30N	45 kgf Diamond HR45N	
68	940	---	920	85.6	93.2	84.4	75.4	---
67	900	---	895	85.0	92.9	83.6	74.2	---
66	865	---	870	84.5	92.5	82.8	73.3	---
65	832	739[d]	846	83.9	92.2	81.9	72.0	---
64	800	722[d]	822	83.4	91.8	81.1	71.0	---
63	772	706[d]	799	82.8	91.4	80.1	69.9	---
62	746	688[d]	776	82.3	91.1	79.3	68.8	---
61	720	670[d]	754	81.8	90.7	78.4	67.7	---
60	697	654[d]	732	81.2	90.2	77.5	66.6	---
59	674	634[d]	710	80.7	89.8	76.6	65.5	351 (2420)
58	653	615	690	80.1	89.3	75.7	64.3	338 (2330)
57	633	595	670	79.6	88.9	74.8	63.2	325 (2240)
56	613	577	650	79.0	88.3	73.9	62.0	313 (2160)
55	595	560	630	78.5	87.9	73.0	60.9	301 (2070)
54	577	543	612	78.0	87.4	72.0	59.8	292 (2010)
53	560	525	594	77.4	86.9	71.2	58.6	283 (1950)
52	544	512	576	76.8	86.4	70.2	57.4	273 (1880)
51	528	496	558	76.3	85.9	69.4	56.1	264 (1820)
50	513	482	542	75.9	85.5	68.5	55.0	255 (1760)
49	498	468	526	75.2	85.0	67.6	53.8	246 (1700)
48	484	455	510	74.7	84.5	66.7	52.5	238 (1640)
47	471	442	495	74.1	83.9	65.8	51.4	229 (1580)
46	458	432	480	73.6	83.5	64.8	50.3	221 (1520)

APPROXIMATE HARDNESS CONVERSION NUMBERS FOR NONAUSTENITIC STEELS [a, b] (Continued)

Rockwell B 100 kgf 1/16" ball HRB	Vickers HV	Brinell 3000 kgf 10 mm HB	Knoop 500 gf HK	Rockwell A 60 kgf Diamond HRA	Rockwell Superficial hardness			Approximate Tensile Strength ksi (MPa)
					15 kgf 1/16" ball HR15T	30 kgf 1/16" ball HR30T	45 kgf 1/16" ball HR45T	
76	139	139	152	47.3	85.3	67.1	48.8	67 (460)
75	137	137	150	46.8	85.0	66.4	47.8	66 (455)
74	135	135	147	46.3	84.7	65.7	46.8	65 (450)
73	132	132	145	45.8	84.3	65.1	45.8	64 (440)
72	130	130	143	45.3	84.0	64.4	44.8	63 (435)
71	127	127	141	44.8	83.7	63.7	43.8	62 (425)
70	125	125	139	44.3	83.4	63.1	42.8	61 (420)
69	123	123	137	43.8	83.0	62.4	41.8	60 (415)
68	121	121	135	43.3	82.7	61.7	40.8	59 (405)
67	119	119	133	42.8	82.4	61.0	39.8	58 (400)
66	117	117	131	42.3	82.1	60.4	38.7	57 (395)
65	116	116	129	41.8	81.8	59.7	37.7	56 (385)
64	114	114	127	41.4	81.4	59.0	36.7	---
63	112	112	125	40.9	81.1	58.4	35.7	---
62	110	110	124	40.4	80.8	57.7	34.7	---
61	108	108	122	40.0	80.5	57.0	33.7	---
60	107	107	120	39.5	80.1	56.4	32.7	---
59	106	106	118	39.0	79.8	55.7	31.7	---
58	104	104	117	38.6	79.5	55.0	30.7	---
57	103	103	115	38.1	79.2	54.4	29.7	---
56	101	101	114	37.7	78.8	53.7	28.7	---
55	100	100	112	37.2	78.5	53.0	27.7	---
54	---	---	111	36.8	78.2	52.4	26.7	---
53	---	---	110	36.3	77.9	51.7	25.7	---

APPROXIMATE HARDNESS CONVERSION VALUES FOR AUSTENITIC STEELS[a]

Rockwell B 100 kgf 1/16" ball HRB	Brinell Indentation Diameter, mm	Brinell 3000 kgf 10 mm Ball HB	Rockwell A 60 kgf Diamond HRA	Rockwell Superficial Hardness		
				15 kgf 1/16" ball HR15T	30 kgf 1/16" ball HR30T	45 kgf 1/16" ball HR45T
100	3.79	256	61.5	91.5	80.4	70.2
99	3.85	248	60.9	91.2	79.7	69.2
98	3.91	240	60.3	90.8	79.0	68.2
97	3.96	233	59.7	90.4	78.3	67.2
96	4.02	226	59.1	90.1	77.7	66.1
95	4.08	219	58.5	89.7	77.0	65.1
94	4.14	213	58.0	89.3	76.3	64.1
93	4.20	207	57.4	88.9	75.6	63.1
92	4.24	202	56.8	88.6	74.9	62.1
91	4.30	197	56.2	88.2	74.2	61.1
90	4.35	192	55.6	87.8	73.5	60.1
89	4.40	187	55.0	87.5	72.8	59.0
88	4.45	183	54.5	87.1	72.1	58.0
87	4.51	178	53.9	86.7	71.4	57.0
86	4.55	174	53.3	86.4	70.7	56.0
85	4.60	170	52.7	86.0	70.0	55.0
84	4.65	167	52.1	85.6	69.3	54.0
83	4.70	163	51.5	85.2	68.6	52.9
82	4.74	160	50.9	84.9	67.9	51.9
81	4.79	156	50.4	84.5	67.2	50.9
80	4.84	153	49.8	84.1	66.5	49.9

a. All relative hardness values in this table are averages of tests on various metals whose different properties prevent establishment of exact mathematical conversions. These values are consistent with ASTM A 370-91 for austenitic steels. It is recommended that ASTM standards A 370, E 140, E 10, E 18, E 92, E 110 and E 384, involving hardness tests on metals, be reviewed prior to interpreting hardness conversion values.

Appendix

2

SI UNIT CONVERSIONS

METRIC CONVERSION FACTORS					
To Convert From	**To**	**Multiply By**	**To Convert From**	**To**	**Multiply By**
Angle			**Mass per unit length**		
degree	rad	1.745 329 E -02	lb/ft	kg/m	1.488 164 E + 00
Area			lb/ft	kg/m	1.785 797 E + 01
$in.^2$	mm^2	6.451 600 E + 02	**Mass per unit time**		
$in.^2$	cm^2	6.451 600 E + 00	lb/h	kg/s	1.259 979 E - 04
$in.^2$	m^2	6.451 600 E - 04	lb/min	kg/s	7.559 873 E - 03
ft^2	m^2	9.290 304 E - 02	lb/s	kg/s	4.535 924 E - 01
Bending moment or torque			**Mass per unit volume (includes density)**		
lbf - in.	N - m	1.129 848 E - 01	g/cm^3	kg/m^3	1.000 000 E + 03
lbf - ft	N - m	1.355 818 E + 00	lb/ft^3	g/cm^3	1.601 846 E - 02
kgf - m	N - m	9.806 650 E + 00	lb/ft^3	kg/m^3	1.601 846 E + 01
ozf - in.	N - m	7.061 552 E - 03	$lb/in.^3$	g/cm^3	2.767 990 E + 01
Bending moment or torque per unit length			$lb/in.^3$	kg/m^3	2.767 990 E + 04
lbf - in./in.	N - m/m	4.448 222 E + 00	**Power**		
lbf - ft/in.	N - m/m	5.337 866 E + 01	Btu/s	kW	1.055 056 E + 00
Corrosion rate			Btu/min	kW	1.758 426 E - 02
mils/yr	mm/yr	2.540 000 E - 02	Btu/h	W	2.928 751 E - 01
mils/yr	µ/yr	2.540 000 E + 01	erg/s	W	1.000 000 E - 07
Current density			ft - lbf/s	W	1.355 818 E + 00
$A/in.^2$	A/cm^2	1.550 003 E - 01	ft - lbf/min	W	2.259 697 E - 02
$A/in.^2$	A/mm^2	1.550 003 E - 03	ft - lbf/h	W	3.766 161 E - 04
A/ft^2	A/m^2	1.076 400 E + 01	hp (550 ft - lbf/s)	kW	7.456 999 E - 01
Electricity and magnetism			hp (electric)	kW	7.460 000 E - 01
gauss	T	1.000 000 E - 04			

METRIC CONVERSION FACTORS (Continued)					
To Convert From	**To**	**Multiply By**	**To Convert From**	**To**	**Multiply By**
Electricity and magnetism (Continued)			**Power density**		
maxwell	μWb	1.000 000 E - 02	$W/in.^2$	W/m^2	1.550 003 E + 03
mho	S	1.000 000 E + 00	**Pressure (fluid)**		
Oersted	A/m	7.957 700 E + 01	atm (standard)	Pa	1.013 250 E + 05
Ω - cm	Ω - m	1.000 000 E - 02	bar	Pa	1.000 000 E + 05
Ω circular - mil/ft	μΩ - m	1.662 426 E - 03	in. Hg (32°F)	Pa	3.386 380 E + 03
Energy (impact other)			in. Hg (60°F)	Pa	3.376 850 E + 03
ft - lbf	J	1.355 818 E + 00	$lbf/in.^2$ (psi)	Pa	6.894 757 E + 03
Btu (thermochemical)	J	1.054 350 E + 03	torr (mm Hg, 0°C)	Pa	1.333 220 E + 02
cal (thermochemical)	J	4.184 000 E + 00	**Specific heat**		
kW - h	J	3.600 000 E + 06	Btu/lb - °F	J/kg - K	4.186 800 E + 03
W - h	J	3.600 000 E + 03	cal/g - °C	J/kg - K	4.186 800 E + 03
Flow rate			**Stress (force per unit area)**		
ft^3/h	L/min	4.719 475 E - 01	$tonf/in.^2$ (tsi)	MPa	1.378 951 E + 01
ft^3/min	L/min	2.831 000 E + 01	kgf/mm^2	MPa	9.806 650 E + 00
gal/h	L/min	6.309 020 E - 02	ksi	MPa	6.894 757 E + 00
gal/min	L/min	3.785 412 E + 00	$lbf/in.^2$ (psi)	MPa	6.894 757 E - 03
Force			MN/m^2	MPa	1.000 000 E + 00
lbf	N	4.448 222 E + 00	**Temperature**		
kip (1000 lbf)	N	4.448 222 E + 03	°F	°C	5/9 (°F - 32)
tonf	kN	8.896 443 E + 00	R	K	5/9
kgf	N	9.806 650 E + 00	**Temperature interval**		
			°F	°C	5/9
Force per unit length			**Thermal conductivity**		
lbf/ft	N/m	1.459 390 E + 01	Btu - in./s - ft^2 - °F	W/m - K	5.192 204 E + 02
lbf/in.	N/m	1.751 268 E + 02	Btu/ft - h - °F	W/m - K	1.730 735 E + 00

METRIC CONVERSION FACTORS (Continued)					
To Convert From	**To**	**Multiply By**	**To Convert From**	**To**	**Multiply By**
Mass per unit area			**Volume (Continued)**		
oz/in.^{2}	kg/m^2	4.395 000 E + 01	gal (U.S. liquid)	m^3	3.785 412 E - 03
oz/ft^2	kg/m^2	3.051 517 E - 01	**Volume per unit time**		
oz/yd^2	kg/m^2	3.390 575 E - 02	ft^3/min	m^3/s	4.719 474 E - 04
lb/ft^2	kg/m^2	4.882 428 E + 00	ft^3/s	m^3/s	2.831 685 E - 02
			in.^{3}/min	m^3/s	2.731 177 E - 07
			Wavelength		
			A	nm	1.000 000 E - 01

THE GREEK ALPHABET		
Α, α - Alpha	Ι, ι - Iota	Ρ, ρ - Rho
Β, β - Beta	Κ, κ - Kappa	Σ, σ - Sigma
Γ, γ - Gamma	Λ, λ - Lambda	Τ, τ - Tau
Δ, δ - Delta	Μ, μ - Mu	Υ, υ - Upsilon
Ε, ε - Epsilon	Ν, ν - Nu	Φ, ϕ - Phi
Ζ, ξ - Zeta	Ξ, ξ - Xi	Χ, χ - Chi
Η, η - Eta	Ο, ο - Omicron	Ψ, ψ - Psi
Θ, θ - Theta	Π, π - Pi	Ω, ϖ - Omega

SI PREFIXES			
Prefix	**Symbol**	**Exponential Expression**	**Multiplication Factor**
exa	E	10^{18}	1 000 000 000 000 000 000
peta	P	10^{15}	1 000 000 000 000 000
tera	T	10^{12}	1 000 000 000 000
giga	G	10^{9}	1 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1 000
hecto	h	10^{2}	100
deka	da	10^{1}	10
Base Unit	---	10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000 001
nano	n	10^{-9}	0.000 000 001
pico	p	10^{-12}	0.000 000 000 001
femto	f	10^{-15}	0.000 000 000 000 001
atto	a	10^{-18}	0.000 000 000 000 000 001

Appendix

3

DECIMAL EQUIVALENTS OF FRACTIONS, SHEET METAL GAGE CONVERSIONS, AND WIRE GAGE CONVERSIONS

DECIMAL EQUIVALENT OF FRACTIONS		
Fraction (in.)	**Decimal (in.)**	**Millimeter (mm)**
1/64	0.015 625	0.396 875
1/32	0.031 250	0.793 750
3/64	0.046 875	1.190 625
1/16	0.062 500	1.587 500
5/64	0.078 125	1.984 375
3/32	0.093 750	2.381 250
7/64	0.109 375	2.778 125
1/8	0.125 000	3.175 000
9/64	0.140 625	3.571 875
5/32	0.156 250	3.968 750
11/64	0.171 875	4.365 625
3/16	0.187 500	4.762 500
13/64	0.203 125	5.159 375
7/32	0.218 750	5.556 250
15/64	0.234 375	5.953 125
1/4	0.250 000	6.350 000
17/64	0.265 625	6.746 875
9/32	0.281 250	7.143 750
19/64	0.296 875	7.540 625
15/16	0.312 500	7.937 500
21/64	0.328 125	8.334 375
11/32	0.343 750	8.731 250
23/64	0.359 375	9.128 125
3/8	0.375 000	9.525 000
25/64	0.390 625	9.921 875
13/32	0.406 250	10.318 750
27/64	0.421 875	10.715 625

DECIMAL EQUIVALENT OF FRACTIONS (Continued)

Fraction (in.)	Decimal (in.)	Millimeter (mm)
7/16	0.437 500	11.112 500
29/64	0.453 125	11.509 375
15/32	0.468 750	11.906 250
31/64	0.484 375	12.303 125
1/2	0.500 000	12.700 000
33/64	0.515 625	13.096 875
17/32	0.531 250	13.493 750
35/64	0.546 875	13.890 625
9/16	0.562 500	14.287 500
37/64	0.578 125	14.684 375
19/32	0.593 750	15.081 250
39/64	0.609 375	15.478 125
5/8	0.625 000	15.875 000
41/64	0.640 625	16.271 875
21/32	0.656 250	16.668 750
43/64	0.671 875	17.065 625
11/16	0.687 500	17.462 500
45/64	0.703 125	17.859 375
23/32	0.718 750	18.256 250
47/64	0.734 375	18.653 125
3/4	0.750 000	19.050 000
49/64	0.765 625	19.446 875
25/32	0.781 250	19.843 750
51/64	0.796 875	20.240 625
13/16	0.812 500	20.637 500
27/32	0.843 750	21.431 250
53/64	0.828 125	21.034 375

Appendix
4

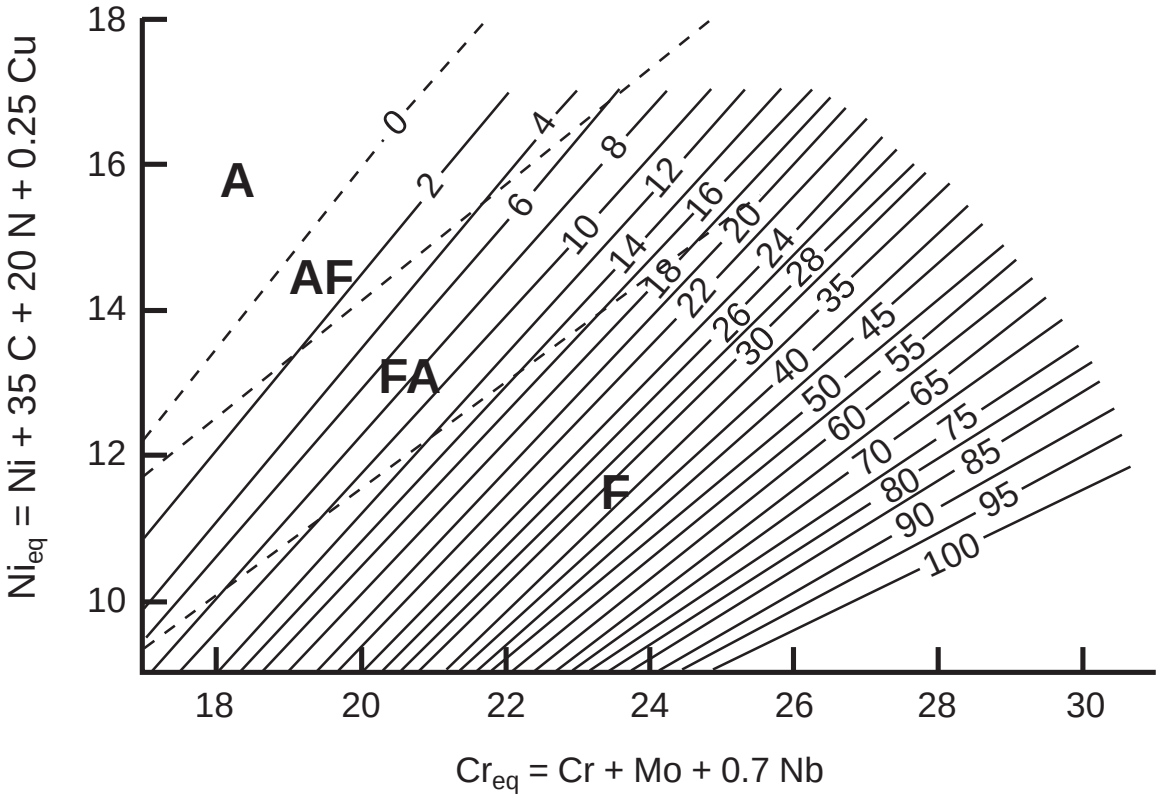
AMERICAN PIPE DIMENSIONS

DIMENSIONS OF WELDED AND SEAMLESS PIPE

Nominal Pipe Size, in.	Outside Diameter	Nominal Wall Thickness (in.) For						
		Schedule 5S	Schedule 10S	Schedule 10	Schedule 20	Schedule 30	Schedule Standard	Schedule 40
1/8	0.405	---	0.049	---	---	---	0.068	0.068
1/4	0.540	---	0.065	---	---	---	0.088	0.088
3/8	0.675	---	0.065	---	---	---	0.091	0.091
1/2	0.840	0.065	0.083	---	---	---	0.109	0.109
3/4	1.050	0.065	0.083	---	---	---	0.113	0.113
1	1.315	0.065	0.109	---	---	---	0.133	0.133
1 1/4	1.660	0.065	0.109	---	---	---	0.140	0.140
1 1/2	1.900	0.065	0.109	---	---	---	0.145	0.145
2	2.375	0.065	0.109	---	---	---	0.154	0.154
2 1/2	2.875	0.083	0.120	---	---	---	0.203	0.203
3	3.5	0.083	0.120	---	---	---	0.216	0.216
3 1/2	4.0	0.083	0.120	---	---	---	0.226	0.226
4	4.5	0.083	0.120	---	---	---	0.237	0.237
5	5.563	0.109	0.134	---	---	---	0.258	0.258
6	6.625	0.109	0.134	---	---	---	0.280	0.280
8	8.625	0.109	0.148	---	0.250	0.277	0.322	0.322
10	10.75	0.134	0.165	---	0.250	0.307	0.365	0.365
12	12.75	0.156	0.180	---	0.250	0.330	0.375	0.406
14 O.D.	14.0	0.156	0.188	0.250	0.312	0.375	0.375	0.438
16 O.D.	16.0	0.165	0.188	0.250	0.312	0.375	0.375	0.500
18 O.D.	18.0	0.165	0.188	0.250	0.312	0.438	0.375	0.562
20 O.D.	20.0	0.188	0.218	0.250	0.375	0.500	0.375	0.594
22 O.D.	22.0	0.188	0.218	0.250	0.375	0.500	0.375	---
24 O.D.	24.0	0.218	0.250	0.250	0.375	0.562	0.375	0.688
26 O.D.	26.0	---	---	0.312	0.500	---	0.375	---

Appendix
5

DELTA FERRITE (FN) DIAGRAM

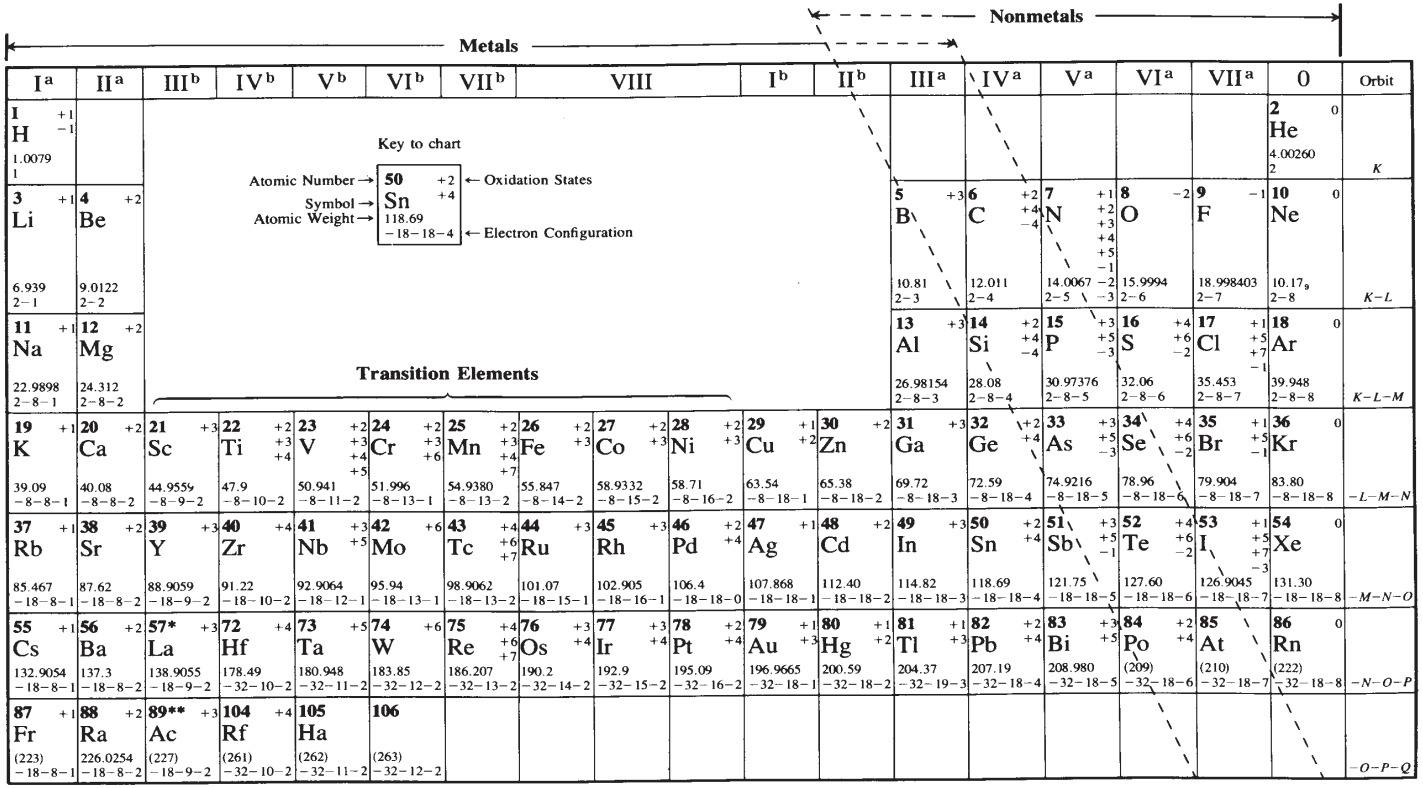


CASTI Metals Black Book – North American Ferrous Data (Fifth Edition)

Appendix
6

PERIODIC TABLE

Periodic Table of the Elements



Appendix

7

CASTI ENGINEERING AND SCIENTIFIC WEB PORTAL - SELECTED LINKS

The *CASTI* Group of Companies has launched an information-packed Engineering and Scientific Web Portal containing thousands of technical web site links in a fully searchable database and grouped within specific categories. This web portal also contains many links to free engineering software and technical articles. We invite you to visit our engineering and scientific web portal at http://www.casti.ca.

Engineering Associations	
Canada	
AETTN - Association of Engineering Technicians and Technologists of Newfoundland	http://www.netfx.iom.net/aettn
APEGBC - Association of Professional Engineers and Geoscientists of British Columbia	http://www.apeg.bc.ca
APEGGA - Association of Professional Engineers, Geologists, and Geophysicists of Alberta	http://www.apegga.com
APEGM - Association of Professional Engineers and Geoscientists of Manitoba	http://www.apegm.mb.ca
APEGN - Association of Professional Engineers and Geologists of Newfoundland	http://www.apegn.nf.ca/
APEGNB - Association of Professional Engineers and Geoscientists of NewBrunswick	http://www.apegnb.com
APEGS - Association of Professional Engineers and Geoscientists of Saskatchewan	http://www.apegs.sk.ca
APENS - Association of Professional Engineers of Nova Scotia	http://www.apens.ns.ca
APEPEI - Association of Professional Engineers of Prince Edward Island	http://www.apepei.com
APEY - Association of Professional Engineers of Yukon	http://www.apey.yk.ca
ASET - Alberta Society of Engineering Technologists	http://www.aset.ab.ca
ASTTBC - Applied Science Technologists and Technicians of British Columbia	http://www.asttbc.org
CCPE - Canadian Council of Professional Engineers	http://www.ccpe.ca
CCTT - Canadian Council of Technicians and Technologists	http://www.cctt.ca
CTTAM - Certified Technicians and Technologists Association of Manitoba	http://www.cttam.com
NAPEGG - Association of Professional Engineers, Geologists and Geophysicists of the Northwest Territories (representing NWT and Nunavut Territory)	http://www.napegg.nt.ca
OACETT - Ontario Association of Certified Engineering Technicians and Technologists	http://www.oacett.org
OIQ - Ordre des ingénieurs du Québec	http://www.oiq.qc.ca
OTPQ - Ordre des Technologues Professionnels du Québec	http://www.otpq.qc.ca
PEO - Professional Engineers Ontario	http://www.peo.on.ca
SASTT - Saskatchewan Applied Science Technologists and Technicians	http://www.sastt.sk.ca
SCETTNS - Society of Certified Engineering Technicians and Technologists of Nova Scotia	http://www.scettns.ns.ca/
United States - National	
ABET - Accreditation Board for Engineering and Technology	http://www.abet.org
APC - American Plastics Council	http://www.plasticsresource.com

Engineering Associations (Continued)	
United States - National (Continued)	
EIA - Electronic Industries Association	http://www.eia.org
NAS - National Academy of Engineering	http://www.nas.edu/
National Science Foundation	http://www.nsf.gov/
NCEES - National Council of Examiners for Engineering and Surveying	http://www.ncees.org/
NICET - National Institute for Certification in Engineering Technology	http://www.nicet.org/
NSPE - National Society of Professional Engineers	http://www.nspe.org/
SEMA - Specialty Equipment Market Association	http://www.sema.org
US Army Corps of Engineers	http://www.hq.usace.army.mil/hqhome/
United States - State	
ASPE - Alabama Society of Professional Engineers	http://www.aspe-al.com
AZSPE - Arizona Society of Professional Engineers	http://www.azspe.org
CEC - Consulting Engineers Council of Ohio	http://www.cecohio.org
CEPP - Connecticut Engineers in Private Practice	http://www.ctengineers.org
CSPE - California Society of Professional Engineers	http://www.cspe.com
DCSPE - District of Columbia Society of Professional Engineers	http://www.free-4u.com/district_of_columbia_society_of_professional_engineers.htm
FES - Florida Engineering Society	http://www.fleng.org
GSPE - Georgia Society of Professional Engineers	http://www.gspe.org
HSPE - Hawaii Society of Professional Engineers	http://www.eng.hawaii.edu/~hspe
IES - Iowa Engineering Society	http://www.iaengr.org
ISPE - Idaho Society of Professional Engineers	http://home.rmci.net/ispe
ISPE - Illinois Society of Professional Engineers	http://www.ilspe.com/
KCE - Kansas Consulting Engineers	http://www.kce.org
KEC - Kentucky Engineering Center	http://www.kyengcenter.org/
MES - Mississippi Engineering Society	http://www.msengsoc.org
MnSPE - Minnesota Society of Professional Engineers	http://www.mnspe.org
MSPE - Maryland Society of Professional Engineers	http://www.mdspe.org/

Engineering Associations (Continued)	
United States - State (Continued)	
MSPE - Michigan Society of Professional Engineers	http://www.voyager.net/mspe/
MSPE - Missouri Society of Professional Engineers	http://www.mspe.org
NeSPE - Nebraska Society of Professional Engineers	http://www.nespe.org
NHSPE - New Hampshire Society of Professional Engineers	http://www.nhspe.org
NJSPE - New Jersey Society of Professional Engineers	http://www.njspe.org
NMSPE - New Mexico Society of Professional Engineers	http://www.swcp.com/~nmspe
NYSSPE - New York State Society of Professional Engineers	http://www.nysspe.org
OSPE - Oklahoma Society of Professional Engineers	http://www.ospe.org
PEC - Professional Engineers of Colorado	http://www.qadas.com/pec
PENC - Professional Engineers of North Carolina	http://www.penc.org
PEO - Professional Engineers of Oregon	http://www.pro-engineers-oregon.org
PSPE - Pennsylvania Society of Professional Engineers	http://www.pspe.org
SCSPE - South Carolina Society of Professional Engineers	http://www.scspe.org
SDES - South Dakota Engineering Society	http://www.sdes.org
TSPE - Tennessee Society of Professional Engineers	http://www.tnspe.org
TSPE - Texas Society of Professional Engineers	http://www.tspe.org
USPE - Utah Society of Professional Engineers	http://www.inovion.com/~jamesski/USPE/
VSPE - Vermont Society of Professional Engineers	http://www.geocities.com/capecanaveral/4625/index.html
VSPE - Virginia Society of Professional Engineers	http://www.us.net/vspe
WSPE - Wisconsin Society of Professional Engineers	http://www.wspe.org
Other	
ENGC - Engineering Council (UK)	http://www.engc.org
ENGVA - European Natural Gas Vehicle Association	http://www.engva.org

Government	
Canada - Federal	
Geological Survey of Canada	http://www.nrcan.gc.ca/gsc
National Energy Board	http://www.neb.gc.ca
Natural Resources Canada	http://www.nrcan.gc.ca
Canada - Provincial	
Alberta Boilers Safety Association	http://www.albertaboilers.com
Alberta Environment	http://www.gov.ab.ca/env
Alberta Energy and Utilities Board	http://www.eub.gov.ab.ca
BC Ministry of Energy and Mines	http://www.gov.bc.ca/em
BC Oil and Gas Commission	http://www.ogc.gov.bc.ca
Manitoba Industry, Trade and Mines - Mineral Resources Division	http://www.gov.mb.ca/itm/mrd
Natural Resources Conservation Board	http://www.gov.ab.ca/nrcb
New Brunswick Safety Code Services	http://www.gnb.ca/PS-SP/english/indexe.shtml
Nova Scotia Department of Enviroment and Labour - Public Safety Division	http://www.gov.ns.ca/enla/psafe
Saskatchewan Energy and Mines	http://www.gov.sk.ca/enermine
Yukon Department of Energy, Mines and Resources	http://www.emr.gov.yk.ca
Yukon Geoology Program	http://www.geology.gov.yk.ca
United States - National	
National Petroleum Technology Office	http://www.npto.doe.gov
U.S. Department of the Interior	http://www.doi.gov/bureaus.html
U.S. Department of Energy	http://www.energy.gov
U.S. Energy Information Administration	http://www.eia.doe.gov
U.S. Environmental Protection Agency	http://www.epa.gov

Government (Continued)	
United States - State	
Alabama State Oil and Gas Board	http://www.ogb.state.al.us
Alaska Oil & Gas Conservation Commission	http://www.state.ak.us/local/akpages/ADMIN/ogc/homeogc.htm
California Energy Commission	http://www.energy.ca.gov
Colorado Oil & Gas Conservation Commission	http://oil-gas.state.co.us/
Indiana State Boiler and Pressure Vessel Safety Division	http://www.ai.org/sema/osbc_boiler.html
Kansas Geological Survey	http://www.kgs.ukans.edu
Louisiana Department of Natural Resources	http://www.dnr.state.la.us/index.ssi
Louisiana State Fire Marshall Boiler Division	http://www.dps.state.la.us/sfm/index.htm
Maryland Bureau of Mines	http://www.mde.state.md.us/wma/minebur/index.html
Minnesota Code Administration and Boiler Inspection Services	http://www.doli.state.mn.us/code.html
Montana Bureau of Mines and Geology	http://www.mbmg.mtech.edu
Nebraska State Boiler Inspection Program	http://www.dol.state.ne.us/nwd/center.cfm?pricat=2&subcat=2c&action=boiler
Nevada Bureau of Mines and Geology	http://www.nbmg.unr.edu
New Mexico Bureau of Geology and Mineral Resources	http://geoinfo.nmt.edu
New Mexico Oil Conservation Division	http://www.emnrd.state.nm.us/ocd
North Carolina Geological Survey	http://www.geology.enr.state.nc.us/
North Carolina State Department of Labor Boiler Safety Bureau	http://www.dol.state.nc.us/boiler.htm
North Dakota State Boiler Inspection Program	http://www.state.nd.us/ndins/deptprog/boiler.html
Oklahoma Energy Resources Board	http://www.oerb.com
Oklahoma Marginal Well Commission	http://www.state.ok.us/~marginal
Oregon State Boiler Program	http://www.cbs.state.or.us/bcd/sws/boilerhome.htm
Texas State Boiler Law	http://www.license.state.tx.us/boilers/blrlaw.htm
Texas, Railroad Commission of Texas	http://www.rrc.state.tx.us
Utah State Safety Division	http://www.ind-com.state.ut.us/Safety_Division/safety_division.htm
Wyoming Oil & Gas Conservation Commission	http://wogcc.state.wy.us

Industry Associations	
Boiler and Pressure Vessels	
ABSA - Alberta Boilers Safety Association	http://www.albertaboilers.com
PVRC - Pressure Vessel Research Council	http://www.forengineers.org/pvrc/index.htm
VMA - Valve Manufacturers Association of America	http://www.vma.org
Construction	
AEM - Association of Equipment Manufacturers	http://www.aem.org
CCA - Canadian Construction Association	http://www.cca-acc.com
CCPA - Canadian Concrete Pipe Association	http://www.ccpa.com
CII - Construction Industry Institute	http://construction-institute.org
DCA - Distribution Contractors Association	http://www.dca-online.org
MCAA - Mechanical Contractors Association of America	http://www.mcaa.org
NASTT - North American Society for Trenchless Technology	http://www.nastt.org
NUCA - National Utility Contractors Association	http://www.nuca.com
NUCA - National Utility Contractors Association	http://www.nuca.com
OAA - Ontario Association of Architects	http://www.oaa.on.ca
OAHI - Ontario Associations of Home Inspectors	http://www.oahi.com
PLCA - Pipe Line Contractors Association	http://www.plca.org
RMPCA - Rocky Mountain Pipeline Contractors Association	http://www.rmpca.com
Engineering and Science	
AAES - American Association of Engineering Societies	http://www.aaes.org
ACEC - American Council of Engineering Companies	http://www.acec.org
AIChE - American Institute of Chemical Engineers	http://www.aiche.org
Alberta Synchrotron Institute	http://alpha.asi.ualberta.com/MainPage.htm
Association of Engineers and Architects in Israel	http://www.engineers.org.il
ASAE - American Society of Agricultural Engineers	http://www.asae.org
Bureau International des Poids et Mesures	http://www.bipm.org
CEN - Canadian Engineering Network	http://www.transenco.com

Industry Associations (Continued)	
Engineering and Science (Continued)	
CEO - Consulting Engineers of Ontario	http://www.ceo.on.ca
CTI - Cooling Technology Institute	http://www.cti.org
Electric Power Research Institute	http://www.epri.com
IACET - International Association of Continuing Education and Training	http://www.iacet.org
IEEE - Institute of Electrical and Electronics Engineers	http://www.ieee.org
IES - Institute of Environmental Sciences	http://www.bangor.ac.uk/ies/ies.html
IIE - Institute of Industrial Engineers	http://www.iienet.org
ISI - Institute of Scientific Information	http://www.isinet.com
Israel Association for Automatic Control	http://www.technion.ac.il/~iaac
Israel Association for Computational Methods in Mechanics	http://www.iacmm.org.il
Israel Institute of Chemical Engineers	http://www.iiche.org.il
Israeli Society for Medical and Biological Engineering	http://www.eng.tau.ac.il/eng/associations/ISMBE
ITI - Information Technology Institute	http://www.iti.com
NAPE - National Association of Power Engineers	http://www.powerengineers.com
NEIC - National Engineering Information Council	http://www.asee.org/neic
NGVC - Natural Gas Vehicle Coalition	http://www.ngvc.org
RIA - Robotic Industries Association	http://www.robotics.org
Metals and Materials	
AA - Aluminum Association, Inc.	http://www.aluminum.org
AAEC - Asia Aluminum Extrusion Council	http://asia-aec.org
ACI - American Concrete Institute	http://www.aci-int.net
AISE - Association of Iron and Steel Engineers	http://www.aise.org
AISI - American Iron and Steel Institute	http://www.steel.org
BIMRMU - Brockhouse Institute for Materials Research, McMaster University	http://www.science.mcmaster.ca/bimr/general.html
CD - Corrosion Doctors	http://corrosion-doctors.org
CDA - Copper Development Association	http://www.copper.org

Industry Associations (Continued)	
Metals and Materials (Continued)	
CIMM - Canadian Institute for Mining and Metallurgy	http://www.cim.org
CISA - Casting Industry Suppliers Association	http://www.cisa.org
CMI - Cast Metals Institute	http://www.castmetals.com
Corrosion Source	http://www.corrosionsource.com
CSPA - Canadian Steel Producers Association	http://www.canadiansteel.ca
DDC - Diecasting Development Council	http://www.diecasting.org/ddc
DIMG - Ductile Iron Marketing Group	http://www.ductile.org/dimg
FIRST - Foundry Industry Recycling Starts Today	http://www.foundryrecycling.org
ICI - Investment Casting Institute	http://www.investmentcasting.org
ICRI - Iron Casting Research Institute	http://www.ironcasting.org
IISI - International Iron & Steel Institute	http://www.worldsteel.org
ILSR - Institute for Local Self-Reliance	http://www.ilsr.org
IMA - International Molybdenum Association	http://www.imoa.org.uk
IMechE - The Institution of Mechanical Engineers	http://www.imeche.org
IoM - Institute of Materials	http://www.instmat.co.uk
ITA - International Titanium Association	http://www.titanium.org
MTI - Materials Technology Institute of the Chemical Process Industries	http://www.mti-link.org
NADCA - North American Die Casting Association	http://www.diecasting.org
NAPCA - National Association of Pipe Coating Applicators	http://www.napca.com
NASS - National Association of Steel Stockholders	http://www.nass.org.uk/index.htm
NiDI - Nickel Development Institute	http://www.nidi.org
NFFS - Non-Ferrous Founders' Society	http://www.nffs.org
SBI - Swedish Institute of Steel Construction	http://www.algonet.se/~sbi
SFSA - Steel Founders' Society of America	http://www.sfsa.org
SMA - Steel Manufacturers Association	http://steelnet.org/sma/index.html
SRI - Steel Recycling Institute	http://www.recycle-steel.org

Industry Associations (Continued)	
Metals and Materials (Continued)	
SSPC - Steel Structures Painting Council	http://www.sspc.org
Oil and Gas	
AAPG - American Association of Petroleum Geologists	http://www.aapg.org
AGA - American Gas Association	http://www.aga.com
APGA - American Public Gas Association	http://www.apga.org
API - American Petroleum Institute	http://www.api.org
CAODC - Canadian Association of Oil Well Drilling Contractors	http://www.caodc.ca
CAPL - Canadian Association of Petroleum Landmen	http://www.landman.ca
CAPP - Canadian Association of Petroleum Producers	http://www.capp.ca
CEPA - Canadian Energy Pipeline Association	http://www.cepa.com
CGA - Canadian Gas Association	http://www.cga.ca
CGPSA - Canadian Gas Processors Suppliers Association	http://www.cgpsa.com
CHOA - Canadian Heavy Oil Association	http://www.choa.ab.ca
CPSC - Canadian Petroleum Safety Council	http://www.psc.ca
GMRC - Gas Machinery Research Council	http://www.gmrc.org
GPA - Gas Processors Association	http://gasprocessors.com
IADC - International Association of Drilling Contractors	http://www.iadc.org
IGT - Institute of Gas Technology	http://www.igt.org
IP - Institute of Petroleum	http://www.petroleum.co.uk
IPAA - Independent Petroleum Association of America	http://www.ipaa.org
MEA - Midwest Energy Association	http://midwestenergy.org
NGSA - Natural Gas Supply Association	http://ngsa.org
NOIA - The National Ocean Industries Association	http://www.noia.org
NPC - National Petroleum Council	http://www.npc.org
NPGA - National Propane Gas Association	http://www.npga.org
PA - PETROassist.com	http://www.petroassist.com

Industry Associations (Continued)	
Oil and Gas (Continued)	
PCF - Petroleum Communication Foundation	http://www.pcf.ab.ca
PPDM - Public Petroleum Data Model	http://www.ppdm.org
PSAC - Petroleum Services Association of Canada	http://www.psac.ca
PTTC - Petroleum Technology Transfer Council	http://www.pttc.org
SEGA - Southeastern Gas Association	http://www.segas.org
SEPAC - Small Explorers and Producers Association of Canada	http://www.sepac.ca
WSPA - Western States Petroleum Association	http://www.wspa.org
Standards and Quality	
AMRA - Automatic Meter Reading Association	http://www.amra-intl.org
CSA International	http://www.csa-international.org
EECS - Electrical Equipment Certification Service	http://www.hse.gov.uk/eecs
MECS - Mining Equipment Certification Service	http://www.hse.gov.uk/eecs/eecsmecs.htm
MSS - Manufacturers Standardization Society of the Valve and Fittings Industry Inc.	http://www.mss-hq.com/
IPQ - Instituto Português da Qualidade	http://www.ipq.pt/
NIST - National Institute of Standards and Technology	http://www.nist.gov/welcome.html
NNI - Netherlands Normalisatie	http://www.nni.nl/
SMRP - Society for Maintenance and Reliability Professionals	http://www.smrp.org/
SSPC - The Society for Protective Coatings	http://www.sspc.org/
USM - Standards and Metrology Institute (Slovenija)	http://www.usm.mzt.si/
Welding	
EWI - Edison Welding Institute	http://www.ewi.org/
HIWT - Hobart Institute of Welding Technology	http://www.welding.org/
PEWI - E O Paton Electric Welding Institute	http://www.stcu.kiev.ua/paton/
RWMA - Resistance Welder Manufacturers' Association	http://www.rwma.org/
TWI - The Welding Institute	http://www.twi.co.uk/

Industry Associations (Continued)	
Welding (Continued)	
WRC - Welding Research Council	http://www.forengineers.org/wrc

Metals Producers	
Nonferrous	
Alcan Aluminium Corporation	http://www.alcan.com
Alcoa Inc.	http://www.alcoa.com
AlcoTec Wire Corporation	http://www.alcotec.com
Brush Wellman Inc.	http://www.brushwellman.com
Coastal Aluminum Rolling Mills Inc.	http://www.coastalum.com
Columbia Falls Aluminum Company	http://www.cfaluminum.com
Deutsche Nickel AG	http://www.deutsche-nickel.de
Hydro Raufoss Automotive, N.A.	http://www.hydro.com
IMCO Recycling Inc.	http://www.imcorecycling.com
Kaiser Aluminum & Chemical Corp.	http://www.kaiseral.com
KB Alloys Inc.	http://www.kballoys.com
Magnesium Alloy Corp	http://www.magnesiumalloy.ca
Milward Alloys Inc.	http://www.milward.com
Minalex Corporation	http://www.minlex.com
Noranda Aluminum Inc.	http://www.noranda.ca
Northwest Aluminum Company	http://www.nwaluminum.com
Ormet Corporation	http://www.ormet.com
Precision Coil, Inc.	http://www.precisioncoil.com
Ritchey Metals Company Inc.	http://www.ritcheymetals.com/
Scepter Inc.	http://www.scepterinc.com
Shieldalloy Metallurgical Corp.	http://www.metallurg.com
Southwire Co.	http://www.southwire.com

Metals Producers (Continued)	
Nonferrous (Continued)	
United Aluminum Corp	http://www.unitedaluminum.com
Valimet Inc.	http://www.valimet.com
Wabash Alloys	http://www.wabashalloys.com
Stainless Steel and Nickel Alloy Producers	
Allegheny Technologies Incorporated	http://www.alleghenytechnologies.com
Inco Limited	http://www.incoltd.com
Inco Special Products	http://www.incospp.com
Krupp Thyssen Nirosta GmbH	http://www.nirosta.de
Krupp VDM GmbH	http://www.kruppvdm.de
LTV Steel	http://www.ltvsteel.com
Rolled Alloys	http://www.rolledalloys.com
Sandvik Steel	http://www.steel.sandvik.com
Special Metals Corporation	http://www.specialmetals.com
Sumitomo Metal Industries	http://www.sumikin.co.jp
Steel and Steel Alloy Producers	
A. Finkl & Sons Company	http://www.finkl.com
ACME Metals Incorporated	http://www.acme-metals.com
AK Steel Corporation	http://www.aksteel.com
Algoma Steel Inc.	http://www.algoma.com
Allegheny Ludlum	http://www.alleghenyludlum.com
Allvac	http://www.allvac.com
Altos Hornos de Mexico, S.A. de C.V.	http://www.ahmsa.com
Ameristeel	http://www.ameristeel.com
Atlas Specialty Steels	http://www.atlassteels.com
Bayou Steel	http://www.bayousteel.com
Berg Steel Pipe Corporation	http://www.bergpipe.com

Metals Producers (Continued)	
Steel and Steel Alloy Producers (Continued)	
Beta Steel Corporation	http://www.betasteelcorp.com/
Bethlehem Steel Corporation	http://www.bethsteel.com
Birmingham Steel	http://www.birminghamsteel.com
California Steel Industries, Inc.	http://www.californiasteel.com
Cargill Steel	http://www.cargillsteel.com
Carpenter Technology Corporation	http://www.cartech.com
Chaparral Steel	http://www.chaparralsteel.com
Chicago Heights Steel	http://www.steelnet.org/chsteel
Citisteel USA, Inc.	http://www.citisteel.com
Cleveland-Cliffs Inc.	http://www.cleveland-cliffs.com
CMC Steel Group	http://www.cmcsg.com
Connecticut Steel	http://www.ctsteelco.com
Copper Development Organization	http://www.copper.org
Co-Steel Raritan	http://www.costeel.com
Deacero, S.A. de C.V.	http://www.deacero.com
Dofasco Inc.	http://www.dofasco.ca
Electralloy	http://www.electralloy.com
G.O. Carlson, Inc.	http://www.gocarlson.com
Gallatin Steel Company	http://www.gallatinsteel.com
Geneva Steel	http://www.geneva.com
Georgetown Steel	http://www.gscrods.com
Granite City Pickling & Warehousing	http://www.gcpw.com
Grupo Villacero	http://www.villacero.com
Harsco Corporation	http://www.harsco.com
Huntco Steel Inc	http://www.huntcosteel.com
Hylsamex, S. A. de C.V.	http://www.hylsamex.com

Metals Producers (Continued)	
Steel and Steel Alloy Producers (Continued)	
IPSCO Inc.	http://www.ipsco.com
Ispat Inland Inc. (Formerly Inland Steel Industries, Inc.)	http://www.inland.com
Ispat International	http://www.ispat.com
Ispat Mexicana, S.A. deIspat Mexicana, S.A. de C.V.	http://www.ispat.co.uk
J&L Specialty Steel, Inc.	http://www.jlspecialty.com
J&L Structural Inc.	http://www.jlstructural.com
Krupp VDM GmbH	http://www.kruppvdm.de/Index.ASP
Marion Steel Co.	http://www.marionsteel.com
McDonald Steel	http://www.mcdonaldsteel.com
Mexinox S.A. de C.V.	http://www.mexinox.com.mx
National Steel Corporation	http://www.nationalsteel.com
North Star Steel	http://www.cargillsteel.com/divisions/nss/nss_index.shtml
Nucor	http://www.nucor.com
Precision Specialty Metals, Inc.	http://www.psm-inc.com
Republic Technologies International	http://www.repsteel.com
Rouge Industries, Inc.	http://www.rougesteel.com
Sandmeyer Steel Company	http://www.sandmeyersteel.com
Sheffield Steel Corp.	http://www.sheffieldsteel.com
Shenango Incorporated	http://www.shenango.com
Slater Steel-Fort Wayne SpecialtyAlloys Div.	http://www.slater.com
Special Metals Corporation	http://www.specialmetals.com
Stelco Inc.	http://www.stelco.com
Sumitomo Metal Industries	http://www.sumitomometals.co.jp/e
Techalloy Company, Inc.	http://www.techalloy.com
The Timken Company	http://www.timken.com
Thyssen Inc., NA	http://www.tincna.com

Metals Producers (Continued)	
Steel and Steel Alloy Producers (Continued)	
United States Steel Corporation	http://www.ussteel.com
USS-POSCO Industries	http://www.uss-posco.com
WCI Steel, Inc.	http://www.wcisteel.com
Weirton Steel Corporation	http://www.weirton.com
Wheeling-Pittsburgh Steel Corporation	http://www.wpsc.com

National Standards Bodies	
AENOR - Asociación Espanola de Normalización y Certificación	http://www.aenor.es
AFNOR - Association Française de Normalisation	http://www.afnor.fr
ANSI - American National Standards Institute	http://www.ansi.org
ASTM - American Society for Testing and Materials	http://www.astm.org
BSI - British Standards Institute	http://www.bsi-global.com
CEN - Comité Européen de Normalisation (European Committee For Standardization)	http://www.cenorm.be
CSA - Canadian Standards Association	http://www.csa.ca
CSNI - Czech Republic	http://www.csni.cz
DIN - Deutsches Institut fur Normung	http://www.din.de
DS - Dansk Standard	http://www.ds.dk
DSP - US Military Defence Standardization Program	http://www.dsp.dla.mil/
ELOT - Hellenic Organization for Standardization	http://www.elot.gr
ETSI - European Telecommunications Standards Institute	http://www.etsi.fr
IBN - Institut Belge De Normalisation	http://www.ibn.be
IPQ - Instituto Português da Qualidade	http://www.ipq.pt
ISO - International Organization for Standardization	http://www.iso.org
IST - Icelandic Standards	http://www.stri.is
JISC - Japanese Industrial Standards Committee	http://www.jisc.go.jp

National Standards Bodies (Continued)	
JSA - Japanese Standards Association	http://www.jsa.or.jp
NIST - National Institute of Standards and Technology	http://www.nist.gov/welcome.html
NNI - Netherlands Normalisatie Instituut	http://www.nni.nl
NORSOK - Norsk Sokkels Konkuranseposisjon (Norway)	http://www.nts.no
NSAI - National Standards Authority of Ireland	http://www.nsai.ie
NSF - Norges Standardiseringsforbund (Norway)	http://www.standard.no
NTS - Norsk Teknologisenter	http://www.nts.no
ON - Österreichisches Normungsinstitut (Austrian Standards Institute)	http://www.on-norm.at
SA - Standards Australia	http://www.standards.com.au
SASO - Saudi Arabian Standards Organisation	http://www.saso.org
SCC - Standards Council of Canada	http://www.scc.ca
SFS - Suomen Standardisoimisliitto r.y. (Findland)	http://www.sfs.fi
SIRIM - Berhad (Malaysia)	http://www.sirim.my
SIS - Standardiseringen i Sverige	http://www.sis.se
SNV - Swiss Association for Standardization	http://www.snv.ch
SNZ - Standards New Zealand	http://www.standards.co.nz
SPRING - Standards, Productivity and Innovation for Growth (Singapore)	http://www.spring.gov.sg
UNI - Ente Nazionale Italiano di Unificazione	http://www.unicei.it

Scientific Data and Units	
Materials	
Crystal Lattice Structures - Institut Laue-Langevin	http://www.ill.fr/dif/3D-crystals
Crystal Lattice Structures - US Naval Research Laboratory	http://cst-www.nrl.navy.mil/lattice
Material Physics Theory - US Naval Research Laboratory	http://cst-www.nrl.navy.mil/gallery
Material Properties - Apache Point Observatory	http://www.apo.nmsu.edu/Telescopes/SDSS/eng.papers/19950926_ConversionFactors/19950926_MProperties.html
Material Properties - Crucible Materials Corporation	http://www.crucibleservice.com

Scientific Data and Units (Continued)	
Materials (Continued)	
Material Properties for Composites - MIL-17	http://www.mil17.org
Material Properties - Ferro Ceramic Grinding Inc.	http://www.ferroceramic.com/tables/t_01.htm
Material Properties - MatWeb	http://www.matls.com/search/SearchProperty.asp
Material Properties - Plastics USA	http://www.plasticsusa.com/matchar.html
Material Properties- Swedish Ceramics Institute	http://www.keram.se/ke00007.htm
Material Properties, Periodic Table - Atlantic Equipment Engineers	http://www.micronmetals.com
Material Properties, Unit Conversion, Periodic Table, Formulas - eFunda (Engineering Fundamentals)	http://www.efunda.com
Material Properties, Unit Conversion, Periodic Table - Metal Suppliers Online	http://www.suppliersonline.com/research
Material Properties, Unit Conversion, Periodic Table - Principle Metals Online	http://www.principalmetals.com
Material Properties, Unit Conversion, Thermodynamics Data - MAYA	http://www.mayahtt.com/tmwiz/default.htm
Materials Properties Databases - CINDAS (Purdue University)	http://mpho.www.ecn.purdue.edu/MPHO/CRDA_Handbooks
Material Properties Databases - NIST	http://www.nist.gov/srd/materials.htm
Mechanical Properties - Online Metals	http://www.onlinemetals.com/property_search.cfm?step=1
Metalurgical Data, Glossary, Unit Conversion - Timken	http://www.timken.com/timken_ols/steel/handbook
Metalurgical Data, Periodic Table, Unit Conversion - All Metals & Forge	http://www.steelforge.com/infoservices/infoservices.asp
Phase Diagrams - Georgia Tech ASM/TMS Joint Student Chapter	http://cyberbuzz.gatech.edu/asm_tms/phase_diagrams
Phase Diagrams - Scientific Group Thermodata Europe	http://klara.met.kth.se/pd
Plastics - Material Selection Guides	http://www.endura.com
Surfaces of Materials Database - National Institute of Standards and Technology	http://www.nist.gov/srd/surface.htm
Thermoplastic Material Selection Guide - Actech Inc.	http://www.actech-inc.com/engmrgt.htm
Unit Conversion, Periodic Table, and other Scientific References - PhysLink.com	http://www.physlink.com/Reference/Index.cfm

Scientific Data and Units (Continued)	
Periodic Tables	
All Metals & Forge	http://www.steelforge.com/infoservices/infoservices.asp
Metal Suppliers Online	http://www.suppliersonline.com/research
Atlantic Equipment Engineers	http://www.micronmetals.com
eFunda	http://www.efunda.com
Principle Metals Online	http://www.principalmetals.com
PhysLink.com	http://www.physlink.com/Reference/PeriodicTable.cfm
Web Elements	http://www.webelements.com
Physics	
Atomic and Molecular Physics Databases - NIST	http://www.nist.gov/srd/phys.htm
Ionization, Nuclear Physics, and Condensed Matter Data - NIST	http://physics.nist.gov/PhysRefData/contents-misc.html
Molecular Spectroscopic Data - NIST	http://physics.nist.gov/PhysRefData/contents-mol.html
Physical Constants - NIST	http://physics.nist.gov/cuu/Constants/index.html
Physical Reference Data - NIST	http://physics.nist.gov/PhysRefData/contents.html
X-Ray and Gamma-Ray Data – NIST	http://physics.nist.gov/PhysRefData/contents-xray.html
X-ray Data - Berkeley Laboratories	http://www-cxro.lbl.gov/optical_constants
Units of Measurement	
Definitions, Conversions - The Foot Rule	http://www.omnis.demon.co.uk
Definitions, Conversions, History - Bureau International des Poids et Mesures (BIPM)	http://www.bipm.fr
Definitions, Conversions, History - Centre for Innovation in Mathematics Teaching	http://www.ex.ac.uk/cimt/dictunit/dictunit.htm
Definitions, Conversions, History - Center for Mathematics and Science Education	http://www.unc.edu/~rowlett/units/index.html
Definitions, Conversions, History of English Weights and Measures	http://home.clara.net/brianp
Definitions, Conversions, History of International System of Units (SI) - NIST	http://physics.nist.gov/cuu/Units/index.html
Legal Information on Weights, Measures, and Standard Time - Cornell University	http://www.law.cornell.edu/uscode/15/ch6.html

Scientific Data and Units (Continued)	
Units of Measurement - Uncertainty	
Essentials of Expressing Measurement Uncertainty - NIST	http://physics.nist.gov/cuu/Uncertainty/index.html
European Co-operation for Accreditation - Expressions of the Uncertainty of Measurements in Calibration	http://www.european-accreditation.org/documents.html#EA4
Expression of Uncertainty in Measurement - Teknologisk Institut	http://www.gum.dk
Guide to the Expression of Uncertainty in Measurement - Metrodata GmbH	http://www.metrodata.de
Uncertainty Analyzer Software - QUAMETEC Corp.'s	http://www.quametec.com/UA.htm

Standards Associations, Societies and Boards	
A-Pex International (Japan)	http://www.a-pex.co.jp
A2LA - American Association for Laboratory Accreditation	http://www.a2la2.net
ABINEE - Brazilian Electrical & Electronic Equipment Industry Association	http://www.abinee.org.br
ABNT - Associacion Brasileira de Normas Technicas	http://www.abnt.org.br
ABS - American Bureau of Shipping	http://www.eagle.org
ACIL - American Council of Independent Laboratories	http://www.acil.org
MTL-ACTS Testing Labs	http://www.mtl-acts.com
ADLNB - Association of Designated Laboratories & Notified Bodies(Telecom)	http://www.adlnb.com
ANCE - Asociacion Nacional de Normalizacion y Certificacion del Sector Electrico (Mexico - in Spanish)	http://rtn.net.mx/ance
APAVE - (France)	http://www.apave.com
ASME - American Society of Mechanical Engineers	http://www.asme.org
ASSE - American Society of Safety Engineers	http://www.asse.org
ASTM - American Society for Testing and Materials	http://www.astm.org
BEAB - British Electrotechnical Approvals Board	http://www.beab.co.uk
BEC - Belgian Electrotechnical Committee	http://www.bec-ceb.be
BIS - Bureau of Indian Standards	http://www.bis.org.in
BMSI - Bureau of Standards, Metrology and Inspection (Taiwan)	http://www.bsmi.gov.tw/english/e_n_hpg.htm

Standards Associations, Societies and Boards (Continued)	
CANENA - Council for Harmonization of Electrotechnical Standardization of the Nations of the Americas	http://www.canena.org
CCIC - China National Import and Export Commodities Inspection Corp.	http://www.ccic.com
CCL - Communication Certification Laboratory	http://www.cclab.com
CCPS - Center for Chemical Process Safety	http://www.aiche.org/ccps
CDRH - Center for Devices and Radiological Health (FDA)	http://www.fda.gov/cdrh/index.html
CEPEL - Centro de Pequisas de Energia Electrica (Brazil)	http://www.cepel.br
CESI - China Electronic Standardization Institute	http://www.cesi.ac.cn
CPSC - US Consumer Product Safety Commission	http://www.cpsc.gov
CSBTS - China State Bureau of Technical Supervision	http://www.csbts.cn.net/english/index.htm
CSA - Canadian Standards Association International	http://www.csa-international.org
CSCE - Canadian Society for Civil Engineering	http://www.csce.ca
DZNM - State Office for Standardization and Metrology (Croatia)	http://www.dznm.hr
ECMA - European Organization for Standardizing Information & Communication Systems	http://www.ecma.ch
EFTA - European Free Trade Association	http://www.efta.int/structure/main/index.html
ENEC - European Norms Electrical Certification	http://www.enec.com
ETSI - European Telecommunications Standards Institute	http://www.etsi.fr
Europort - Standards Publication Source	http://www.europort.com
FONDONORMA - Standards and Certification Organization (Venezuela)	http://www.fondonorma.org.ve
NETC - National Electronics Testing Centre (Ireland)	http://www.netc.ie
Global Engineering Documents	http://www.global.ihs.com
Gosstandart of Russia - State Committee of the Russion Federation for Standardization and Metrology	http://www.gost.ru
HART Communication Foundation	http://www.hartcomm.org
Hydraulic Institute	http://www.pumps.org
IAEI - International Association of Electrical Inspectors	http://www.iaei.org

Standards Associations, Societies and Boards (Continued)	
IEC - International Electrotechnical Commission	http://www.iec.ch
IECEE - International Electrotechnical Commission of Electrical Equipment	http://www.iecee.org
IETF - The Internet Engineering Task Force	http://www.ietf.org
IHS - Information Handling Services	http://www.ihs.com/
IMQ - Instituto Italiano Del Marchio Di Qualita' (Italy)	http://www.imq.it
INEN - Instituto Ecuatoriano de Normalizacion (Ecuador)	http://www.inen.gov.ec
INN - Instituto Nacional de Normalización (Chile)	http://www.inn.cl
IPQ - Instituto Português da Qualidade (Portugal)	http://www.ipq.pt
IPT - Instituto de Pequisas Technologicas (Brazilian Test Lab)	http://www.ipt.br
IRAM - Instituto Argentino de Normalización (Argentinea)	http://www.iram.com.ar
ISA - Intrumentation, Systems and Automation Society	http://www.isa.org
ISO - International Standards Organization	http://www.iso.ch
IST - Icelandic Standards (Iceland)	http://www.stri.is
ITIC - Information Technology Industry Council	http://www.itic.org
JIS - Japan Industrial Standards Committee	http://www.jisc.org
KEBS - Kenya Bureau of Standards	http://www.kebs.org
LIA - Laser Institute of America	http://www.laserinstitute.org/safety_bulletin/lsib/index.htm
MSHA - Mine Safety and Health Administration	http://www.msha.gov
MSS - Manufacturers Standardization Society of the Valve and Fittings Industry Inc.	http://www.mss-hq.com
MSZT - Magyar Szabványügyi Testület (Hungary)	http://www.mszt.hu
NACLA - National Cooperation for Laboratory Accreditation	http://www.nacla.net
NBIC - National Board of Boiler and Pressure Vessel Inspectors	http://www.nationalboard.org
NEC - Mike Holt's NEC Internet Connection	http://www.mikeholt.com
NEC - Newton's International Electrical Journal (NEC and related matters)	http://www.electrician.com
NEMA - National Electrical Manufacturer's Association	http://www.nema.org
NESF - National Electrical Safety Foundation (U.S.)	http://www.nesf.org

Standards Associations, Societies and Boards (Continued)	
NFPA - National Fire Protection Association	http://www.nfpa.org
NHTSA - National Highway Transportation Safety Agency (U.S.)	http://www.nhtsa.dot.gov
NIST - National Institute of Standards & Technology (Website)	http://www.nist.gov
NLSI - National Lightning Safety Institute	http://www.lightningsafety.com
NPL - National Physical Laboratory (U.K.)	http://www.npl.co.uk
NRTL - Nationally Recognized Testing Labs (includes scope of recognitions)	http://www.osha-slc.gov/dts/otpca/nrtl/index.html
NSAI - National Standards Authority of Ireland	http://www.nsai.ie
NSC - National Safety Council	http://www.nsc.org
NSF - Norges Standiseringsforbund (Norway)	http://www.standard.no
NSSN - National Standards System Network	http://www.nssn.org
NTSSS - North Texas System Safety Society	http://www.flash.net/~rcade
OSHA - Occupational Safety and Health Administration	http://www.osha.gov
PTB - Physikalisch Technische Bundesanstalt (Germany)	http://www.ptb.de
SABS - South African Bureau of Standards	http://www.sabs.co.za
SAQI - State Administration of Import and Export Commodity Inspection of the P.R.C. (China)	http://www.ciq.gov.cn
SCC - Standards Council of Canada	http://www.scc.ca
SEE - Service de l'Energie de l'Etat (Luxembourg)	http://www.etat.lu/SEE
SEMI - Semiconductor Equipment and Materials International	http://www.semi.org
SES - Standards Engineering Society	http://ses-standards.org
SESKO - Finnish Electrotechnical Standards Association (Findland)	http://www.sesko.fi/english.htm
SEV - Swiss Electrotechnical Association	http://www.sev.ch
SFS - Suomen Standardisoimisliitto r.y. (Findland)	http://www.sfs.fi
SII - Standards Institution of Israel	http://www.iso.co.il/sii
SIRIM - Berhad (Malaysia)	http://www.sirim.my
SMIS - Standards & Metrology Institute of Slovenia	http://www.usm.mzt.si
SNV - Schweizerische Normen Vereinigung (Switzerland)	http://www.snv.ch

Standards Associations, Societies and Boards (Continued)	
SP - Swedish National Testing & Research Institute	http://www.sp.se
SPRING - Standards, Productivity and Innovation for Growth (Singapore)	http://www.spring.gov.sg
SSS - System Safety Society	http://www.system-safety.org
STAMEQ - Directorate for Standards and Quality (Vietnam)	http://www.tcvn.gov.vn
Standards Australia	http://www.standards.com.au
FICORA - Finnish Communications Regulatory Authority (Finland)	http://www.ficora.fi
TISI - Thai Industrial Standards Institute	http://www.tisi.go.th/
TÜV America	http://www.tuvam.com
UBS - Uganda Bureau of Standards	http://www.unbs.org
UNI - Italian National Standards Body	http://www.unicei.it
UTE - Union technique de l'Electricite (France)	http://www.ute-fr.com
VDE - Verband Der Elektrotechnik Elektronik Informationstechnik e.V. (Germany)	http://www.vde.com
VNIIS - All-Russian Scientific and Research Institute for Certification of GOSSTANDARDT of Russia	http://www.vniis.ru
WSSN - World Standards Services Network	http://www.wssn.net

CURRENT ASTM STANDARD SPECIFICATIONS FOR FERROUS METALS	
ASTM Spec.	**Title**
A 1-00	Standard Specification for Carbon Steel Tee Rails
A 2-90(1997)	Standard Specification for Carbon Steel Girder Rails of Plain, Grooved, and Guard Types
A 3-01	Standard Specification for Steel Joint Bars, Low, Medium, and High Carbon (Non-Heat-Treated)
A 6/A 6M-01b	Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
A 20/A 20M-01b	Standard Specification for General Requirements for Steel Plates for Pressure Vessels
A 21-94(1999)	Standard Specification for Carbon Steel Axles, Non-Heat-Treated and Heat-Treated, for Railway Use
A 27/A 27M-95(2000)	Standard Specification for Steel Castings, Carbon, for General Application
A 29/A 29M-99e1	Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for
A 31-00	Standard Specification for Steel Rivets and Bars for Rivets, Pressure Vessels
A 36/A 36M-01	Standard Specification for Carbon Structural Steel
A 47/A 47M-99	Standard Specification for Ferritic Malleable Iron Castings
A 48/A 48M-00	Standard Specification for Gray Iron Castings
A 49-01	Standard Specification for Heat-Treated Carbon Steel Joint Bars, Microalloyed Joint Bars, and Forged Carbon Steel Compromise Joint Bars
A 53/A 53M-01	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A 65-01	Standard Specification for Steel Track Spikes
A 66-01	Standard Specification for Steel Screw Spikes
A 67-00	Standard Specification for Steel Tie Plates, Low-Carbon and High-Carbon Hot-Worked
A 74-98	Standard Specification for Cast Iron Soil Pipe and Fittings
A 82-01	Standard Specification for Steel Wire, Plain, for Concrete Reinforcement
A 99-82(2000)	Standard Specification for Ferromanganese
A 100-93(2000)	Standard Specification for Ferrosilicon
A 101-93(2000)	Standard Specification for Ferrochromium
A 102-93(2000)	Standard Specification for Ferrovanadium
A 105/A 105M-01	Standard Specification for Carbon Steel Forgings for Piping Applications
A 106-99e1	Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service
A 108-99	Standard Specification for Steel Bars, Carbon, Cold-Finished,

CURRENT ASTM STANDARD SPECIFICATIONS FOR FERROUS METALS (Continued)	
ASTM Spec.	**Title**
A 786/A 786M-00b	Standard Specification for Hot-Rolled Carbon, Low-Alloy, High-Strength Low-Alloy, and Alloy Steel Floor Plates
A 787-01	Standard Specification for Electric-Resistance-Welded Metallic-Coated Carbon Steel Mechanical Tubing
A 788-02	Standard Specification for Steel Forgings, General Requirements
A 789/A 789M-01a	Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service
A 790/A 790M-01	Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe
A 792/A 792M-02	Standard Specification for Steel Sheet, 55 % Aluminum-Zinc Alloy-Coated by the Hot-Dip Process
A 793-96(2001)	Standard Specification for Rolled Floor Plate, Stainless Steel
A 794-97	Standard Specification for Commercial Steel (CS), Sheet, Carbon (0.16% Maximum to 0.25% Maximum), Cold-Rolled
A 795-00	Standard Specification for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Use
A 801/A 801M-99	Standard Specification for Iron-Cobalt High Magnetic Saturation Alloys UNS R30005 and K92650
A 803/A 803M-01	Standard Specification for Welded Ferritic Stainless Steel Feedwater Heater Tubes
A 805-93(1998)	Standard Specification for Steel, Flat Wire, Carbon, Cold-Rolled
A 808/A 808M-00a	Standard Specification for High-Strength, Low-Alloy Carbon, Manganese, Columbium, Vanadium Steel of Structural Quality with Improved Notch Toughness
A 809-98	Standard Specification for Aluminum-Coated (Aluminized) Carbon Steel Wire
A 810-01	Standard Specification for Zinc-Coated (Galvanized) Steel Pipe Winding Mesh
A 811-97	Standard Specification for Soft Magnetic Iron Parts Fabricated by Powder Metallurgy (P/M) Techniques
A 813/A 813M-01	Standard Specification for Single- or Double-Welded Austenitic Stainless Steel Pipe
A 814/A 814M-01a	Standard Specification for Cold-Worked Welded Austenitic Stainless Steel Pipe
A 815/A 815M-01a	Standard Specification for Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings
A 817-00	Standard Specification for Metallic-Coated Steel Wire for Chain-Link Fence Fabric and Marcelled Tension Wire
A 818-91(2001)	Standard Specification for Coppered Carbon Steel Wire
A 820-01	Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
A 821/A 821M-99	Standard Specification for Steel Wire, Hard Drawn for Prestressing Concrete Tanks
A 822-90(2000)	Standard Specification for Seamless Cold-Drawn Carbon Steel Tubing for Hydraulic System Service
A 823-99	Standard Specification for Statically Cast Permanent Mold Gray Iron Castings
A 824-01	Standard Specification for Metallic-Coated Steel Marcelled Tension Wire for Use With Chain Link Fence

Appendix

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CURRENT ASTM STANDARDS LIST FOR FERROUS METAL

Appendix

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DISCONTINUED ASTM STANDARDS LIST FOR FERROUS METAL

DISCONTINUED ASTM FERROUS METAL STANDARDS (Continued)	
Discontinued	**Replaced By**
A 59 (1966)	A 689 – Carbon and Alloy Steel Bars for Springs
A 60 (1966)	A 552 – Discontinued 1974; Replaced by A 689 – Carbon and Alloy Steel Bars for Springs
A 61 (1969)	A 616 – Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
A 62 (1949)	No Replacement
A 63 (1941)	A 237 – Discontinued 1975; Replaced by A 668 – Steel Forgings, Carbon and Alloy, for General Industrial Use A 238 – Discontinued 1989; Replaced by A 730 – Forgings, Carbon and Alloy Steel, for Railway Use
A 64 (1937)	E 30 – Discontinued 1995; No Replacement
A 68 (1975)	A 689 – Carbon and Alloy Steel Bars for Springs
A 69 (1927)	No Replacement
A 70 (1947)	A 285 – Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength
A 71 (1937)	No Replacement
A 72 (1972)	No Replacement
A 73 (1972)	No Replacement
A 75 (1921)	A 47 – Ferritic Malleable Iron Castings
A 76 (1981)	A 183 – Carbon Steel Track Bolts and Nuts
A 77 (1935)	No Replacement
A 78 (1947)	A 283 – Low and Intermediate Tensile Strength Carbon Steel Plates
A 79 (1921)	A 84 – Discontinued 1972; No Replacement
A 80 (1927)	A 107 – Discontinued 1968; Replaced by A 575 – Steel Bars, Carbon, Merchant Quality, M-Grades, and A 576 – Steel Bars, Carbon, Hot-Wrought, Special Quality A 108 – Steel Bars, Carbon, Cold Finished, Standard Quality
A 81 (1972)	No Replacement
A 83 (1967)	A 192 – Seamless Carbon Steel Boiler Tubes for High-Pressure Service
A 84 (1972)	No Replacement
A 85 (1953)	No Replacement
A 86 (1963)	No Replacement
A 87 (1947)	A 27 – Steel Castings, Carbon, for General Application

DISCONTINUED ASTM FERROUS METAL STANDARDS (Continued)	
Discontinued	**Replaced By**
A 535 (1998)	No Replacement
A 538/A 538M (1989)	No Replacement
A 544 (1991)	No Replacement
A 545 (1991)	No Replacement
A 546 (1991)	No Replacement
A 547 (1991)	No Replacement
A 548 (1991)	No Replacement
A 549 (1991)	No Replacement
A 552 (1974)	A 689 – Carbon and Alloy Steel Bars for Springs
A 557/A 557M (1995)	A 178 – Electric-Resistance-Welded Carbon Steel and Carbon-Manganese Steel Boiler and Superheater Tubes
A 558 (1969)	No Replacement
A 559 (1969)	No Replacement
A 566 (1984)	No Replacement
A 567/A 567M (1985)	No Replacement
A 568M (1991)	A 568/A 568M – General Requirements for Steel, Sheet, Carbon, and High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled
A 569/A 569M (2000)	A 1011/A 1011M - Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability
A 570/A 570M (2000)	A 1011/A 1011M - Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability
A 571M (2001)	A 571/A 571M - Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service
A 584 (2002)	No Replacement
A 590 (1984)	No Replacement
A 593 (1976)	No Replacement
A 594 (1986)	No Replacement
A 599 (1992)	A 599/A 599M - Tin Mill Products, Electrolytic Tin-Coated, Cold-Rolled Sheet
A 605/A 605M (1989)	No Replacement

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