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Metals Blue Book™

Welding Filler Metals

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CASTI Metals Data Book Series™

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Editor's Note

The American Welding Society (AWS) and other member societies of the International Institute of Welding (IIW) have received many inquiries concerning comparison classifications of filler metals produced in the industrialized countries of the world. The cross-referencing of AWS classifications with those of foreign specifications can be found in AWS publication, International Index of Welding Filler Metal Classifications, IFS-2002. Chapters 12 and 30 in this book are excerpts from this documents, published with permission from AWS. To obtain a complete copy of IFS-2002, contact AWS at www.aws.org or call (800) 443-9353.

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Dedication

To all the committee volunteers and their supporting companies, whose tireless efforts produce the world's filler metal standards.

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

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Our mission at *CASTI* Publishing Inc. is to provide industry and educational institutions with practical technical books at low cost. To do so, the book must have a valuable topic and be current with today's technology.

CASTI Metals Blue Book™ - Welding Filler Metals, Fourth Edition, is the third volume in *The Metals Data Book Series*™, containing over 600 pages with more than 200,000 pieces of welding filler metal data. Since accurate data entry of more than 200,000 numbers is contingent on normal human error, we extend our apologies for any errors that may have occurred. However, should you find errors, we encourage you to inform us so that we may keep our commitment to the continuing quality of the *CASTI Metals Data Book Series*™.

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Chapter 1

INTRODUCTION TO WELDING

Before the scientific era, the joining of metals was usually accomplished without fusion of the parent metal. Metals were fabricated in ancient times by riveting, brazing, soldering, and forge welding. None of these techniques involved melting of the metals that were joined.

Welding on an atomic scale, in the absence of melting, is prevented by the surface oxide layers and adsorbed gases present on virtually all metals. In the absence of such films, or via disruption of the film, intimate contact of the surfaces of two pieces of metal will cause welding of the two pieces into one. Very little pressure is required for truly clean metals. Welding can be accomplished by cleaning the surfaces to be joined in a hard vacuum (to prevent reoxidation). An alternative is to deform the metal mechanically while the surfaces to be joined are in contact, which causes the brittle oxide layer to break. Clean metal is exposed which will bond on contact. This is how forge welding is accomplished. Fluxing may assist in disrupting and dispersing the surface contaminants. Sand fluxes surface oxide in the forge welding of iron.

Welding involving melting of the parent metal requires the attainment of quite elevated temperatures in a concentrated area. This requirement is the primary reason why it took until nearly the dawn of the 20th century for fusion welding to appear. The precursors of fusion welding, namely brazing and soldering, involve the fusion of a filler metal which melts at a temperature *below* the bulk solidus of the parent metal and flows via capillary action into a narrow gap between the parent metal sections. It then solidifies to complete the joint. Soldering, initially using tin and tin-lead alloys, takes place at lower temperatures than does brazing; the American Welding Society arbitrarily differentiates between them at 450°C (840°F), leaving brazing as occurring from 450°C (840°F) up to near the melting temperature of the parent metal.

Processes using tin-based alloys in the lower temperature range are still referred to as soft soldering, probably because the filler metals are quite soft. Silver was one of the first brazing filler metals. Silver brazing takes place at temperatures in excess of 700°C (1290°F). The process is often referred to as silver soldering, or hard soldering, rather than brazing. This type of confusing labelling is not uncommon in the joining field, and it is necessary to keep a wary eye open. Part of the reason for such confusion may be that science has only recently discovered joining technology, and this has resulted in the retention of some inaccurate terminology from earlier times.

The history of the joining of materials is a long one, but can be conveniently divided into three eras. Prior to 1880, only forge welding took place, along with soldering and brazing - a *blacksmith* era. From 1880 to 1940, many advances were made and true fusion welding was possible, but most of the advances were accomplished by invention and inspired empirical observation. From 1940 to the present, scientific principles have played a significant role in the advancement of welding technology. The present emphasis on quality assurance and automated welding, including the use of robots, depends on the use of many scientific and engineering disciplines.

Welding metal together, without the use of a low melting filler metal, requires clean surfaces to allow atomic bonding. Mechanical deformation of two surfaces just prior to forcing the surfaces together disrupts the brittle oxide layer, exposing virgin metal and allowing pressure to weld the metal together. The first known joining of this type involved hammer welding of gold, which does not oxidize significantly, and therefore will readily weld to itself in the solid state with a little mechanical encouragement at ambient temperature. Gold also has a very low yield stress and is very ductile - it was and is regularly beaten into foil only 0.1 mm (0.004 in.) thick. Gold is now routinely welded by heating in a neutral (non-oxidizing) flame at relatively low temperature in order to remove adsorbed surface gases before pressure welding. Other precious metals are not as easy to pressure weld, because the surface oxides interfere with bonding of the metal atoms and higher yield stresses make large one-step deformation difficult.

Thus ferrous metals were not readily welded because of the tendency of iron to oxidize rapidly and also because of its high melting temperature and relatively high yield strength. The early welding of iron was probably accomplished in the solid state via hammering at high temperature, which in time has led to forge welding. This is still used for decorative iron work today. In forge welding, silica sand is used as a flux to remove oxide from the interface. Iron is one of the few metals whose oxide melts at a lower temperature than the pure metal, 1378°C (2500°F) and 1535°C (2800°F) respectively, providing the basis for at least some self-fluxing during heating. Adding silica sand forms iron silicates, which melt at even lower temperatures than the iron oxide. The main problem in the early days was achieving a temperature high enough to allow simultaneous flux/oxide melting and sufficient and easily accomplished deformation.

Early iron was smelted at about 1000°C and hammered at that temperature to consolidate the bloom. The yield stress of wrought iron is about 200 MPa (30 ksi) at ambient temperature, but drops to about 20 MPa (3 ksi) above 1000°C (1830°F). The appropriate temperature for welding is in the range of 1000-1200°C (1830-2190°F), which is possible in a blown charcoal fire. The melting point of the slag inclusions in iron is probably above 1000°C (1830°F), since it is largely fayalite orFe_2SiO_4 which melts at 1146°C (2050°F). The joining of iron by the forge or hammer welding process developed empirically until eventually quite large fabrications could be made by skilled artisans. Examples are stern plates of over 25 tonnes (28 tons) for ships. Total deformations of up to 30-35% were used. An identical process produced a propeller shaft which weighed more than 30 tonnes (33 tons) for Isambard Kingdom Brunel's "Great Eastern".

The appearance of steel in large quantities during the 19th century made life somewhat more complicated, since very little slag is present (in comparison with wrought iron), and only very skilled forge welders could join it without significant numbers of flaws appearing in the completed joint. Sand fluxing minimized the problem on small fabrications, but not in large ones, where total deformations were smaller and the risk of slag inclusions was greater. Steel, or carburized wrought iron, had traditionally been difficult to make with sufficient hardness and toughness together.

The history of scientific contributions to welding is quite recent and fairly short. The scientific development of welding processes was not common until the middle of the 20th century, but scientific investigations started much earlier. The use of electricity to weld metals together began with two of the foremost practical geniuses in scientific history, Sir Humphrey Davy and his student, Michael Faraday. In the first decade of the 19th century, Davy investigated the nature of electricity. At one point, he touched two carbon electrodes together and passed a current through them from a large battery. When the electrodes were drawn apart, the current jumped the gap, forming an electrical discharge. Its path from one electrode to the other was curved, not straight, hence the name *arc*. Faraday was involved in the derivation in 1831 of the principles required to make electric power sources. The introduction of practical generators and motors had to wait about 50 years between scientific principle and technological application. In 1856, Joule suggested the possible use of

Chapter 2

BASIC METALLURGY FOR WELDING

Heat Input

The rapid heat input and high energy density involved in welding causes very different thermal effects than do conventional heat treatments. Very rapid heating cycles (fractions of a second to a few seconds), high peak temperatures (in excess of the melting temperature) and relatively rapid cooling rates to ambient temperature (fractions of a second to many minutes) are all involved. A typical thermal cycle for an arc welding process is shown in Figure 2.1.

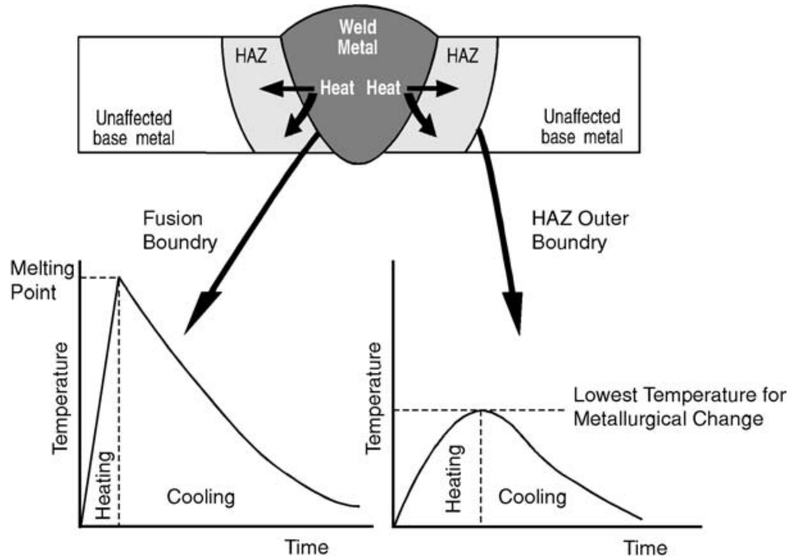

Figure 2.1 Thermal cycles in weld zones

The heat input of a given welding process is most easily defined for electric arc processes. It is simply arc voltage times arc current divided by welding speed. Since arcs lose some energy to the surrounding space by radiation, convection and conduction through gas and slag shielding media, less than 100% efficiency of energy transfer to the weld zone occurs.

$$\text{HEAT} = \frac{\text{x} \bullet \text{Volts} \bullet \text{Amps}}{\text{Welding Speed}}$$

where x = efficiency factor (typically between 40% and 95%).

However, for most welding procedures it is difficult to measure "x" reliably and all normal welding procedures are written without using a "x" factor, i.e. it is assumed to be 100%. In the SI system of units, the heat input is determined by measuring the welding speed in millimeters/second. Then the result is in Joules/mm, or if divided by 1000, kJ/mm. This is the most universally used description of heat input. Typical values for arc welding range from 0.1 to 10 kJ/mm (2.5-250 kJ/in).

Heating Rate

The effects of the rapid temperature rise during the initial heating cycle in welding have not been analyzed extensively, but do have some important implications. The most important is that any existing segregation of alloy elements or impurities in the base metal will not be evened out by diffusion, because the time available is too short. This can lead to a local region in the base metal right next to the fusion line where localized melting can occur. This is most likely where previous segregation in the base metal exists, for example at grain boundaries. These regions may contain higher than average concentrations of alloying elements and/or impurities, which cause a lowering of the melting temperature. The region is therefore called the Partially Melted Zone (PMZ). This localized, restricted area of melting may simply solidify again as the temperature falls after welding, or it may open up under stress to form a small crack, usually known as a liquation crack.

Peak Temperature

The high peak temperatures reached in welding (near or above the melting temperature of the base metal) are far in excess of temperatures in conventional heat treating processes. There are two major results:

1. Grain sizes in the heat-affected zone (HAZ) are large and are largest next to the fusion line at the weld metal. This increases hardenability in transformable steels and may concentrate impurities which are segregated to grain boundaries. This may lead to a form of hot cracking.

2. All traces of work hardening and prior heat treatment (e.g. tempering, age hardening) will be removed in at least part of the HAZ and the size of the region affected will be larger as the heat input rises.

Cooling Rate

The rapid cooling cycles for welding after solidification is complete are caused by the quenching effect of the relatively cold parent metal, which conducts heat away from the weld zone. Models involving the Laplace equation have been developed to predict cooling rates, but are beyond the scope of this book. Discussion of this equation and the developed models can be found in other publications.

However, the cooling rate must be evaluated, since important weld zone properties such as strength, toughness and cracking susceptibility are affected. As the cooling rate increases, i.e. as the temperature falls more rapidly, several important welding effects occur. In transformable metals, such as ferritic-martensitic steels or some titanium alloys, the high temperature phase in the weld metal, and particularly in the HAZ, is quenched. Since the actual cooling rate experienced at a given point varies with location and time after welding, some characterization is necessary. The most used technique is assessment of welding procedure tests, but this is expensive and not particularly useful in predicting the effect of changing variables such as heat input. In the welding of steels, the time spent dropping through a temperature range characteristic of transformation of austenite to martensite or other transformation product (e.g. bainite, ferrite + carbide) is becoming a standard test. The characteristic time is measured in seconds for a given weld metal or HAZ region to drop from 800 to 500°C (1470-930°F) and is often written as $Dt_{8\text{-}5}$. A large number signifies a slow cooling rate.

If weld zone properties are not as desired, it is possible, in some cases, to improve them by altering the cooling rate in the welding procedure. Two main methods are used. The first is heat input - higher heat input in a given situation slows down the cooling rate. Preheating, by warming the base material before welding, also slows down the cooling rate, with higher preheat leading to slower cooling rates. Combining preheat and heat input variations is called *Procedure Control*. Further control of cooling rate effects can be included in a welding procedure by defining a value for interpass welding temperature in multipass welding (effectively a preheat value for each succeeding pass), in order to ensure a cooling rate within a given range or 'window'. This idea will be revisited in discussions on welding various grades of steel.

Metallurgical Effects Of The Welding Thermal Cycle

Weld Metal Solidification

Solidification of weld metal takes place in an unusual manner in comparison with castings. The molten weld pool is contained within a *crucible* of solid metal of similar chemical composition. Since the melting temperature of the base metal is reached, the fusion line and adjacent HAZ experience very high temperatures for a short time. The result is rapid grain growth. These large grains act as nuclei and the weld metal solidifies against them and assume the crystallographic orientation of the atomic structure in the large HAZ grain. Only the grains with an orientation giving rapid growth into the weld metal produce dendrites, and the result is called *epitaxial growth*. There is a very thin region of melted base in the weld metal right next to the fusion line which, although 100% molten, is not stirred into the bulk of the molten pool during welding, due to viscous effects during mixing. This region is called the Melted Unmixed Zone (or MUZ) and is usually very narrow, typically 0.1 mm (0.004 in.) wide.

Since diffusion has not enough time to even out any differences with the weld metal chemistry, any segregations in the base metal will persist in this region. It is also a region in which any segregation produced in the weld metal may collect in a static region and also persist. Initial growth during solidification into this region is often planar, and cellular growth occurs as the growth rate increases. True columnar growth and dendrites form as faster growth continues in the bulk of the weld metal. As growth of dendrites proceeds into the molten weld pool, segregation of some of the alloy and residual elements in the weld pool occurs as the forming solid rejects some of the elements into the liquid due to a lower solubility in the solid state. As a result, the remaining liquid near the end of solidification can contain significantly higher levels of some elements. This can lead to the formation of cracks and fissures in the weld metal. One example is the concentration of S, P, O and C at grain boundaries in many ferrous and nickel alloys, which alone, or together with themselves and other elements, can form complex eutectics of low melting temperatures.

Growth of dendrites tends to follow the direction of heat flow, generally perpendicular to the freezing isotherm at a given instant and moving toward the welding heat source as it traverses the joint line. Consequently, at slow welding speeds, dendrites curve to follow the advancing solidification front in the elliptical weld pool. At high welding speeds, the pool is an elongated teardrop shape, and dendrites tend to grow straight toward the weld centreline. Thus any hot cracks formed at

Chapter 3

FLAWS AND DEFECTS IN THE WELD ZONE

The two main weldment zones are the weld metal, which is composed of melted base metal and (if present) filler metal and the other is the Heat-Affected Zone (HAZ), which is solely base metal which has been heated sufficiently to affect the properties of the base metal. These can be mechanical properties (strength, toughness), metallurgical (microstructure, grain size) or physical properties (hardness, electrical conductivity). The visible HAZ is made visible by metallurgical etching. The peak temperature experienced by the HAZ increases as the fusion line at the weld metal is approached. At distances well removed from the fusion line, outside the visible HAZ, there is also a region affected by lower peak temperatures experienced in the thermal cycle. This is called the non-visible HAZ, in which more subtle effects, such as changes in some physical properties, occur. Problems associated with welds in the weld metal and HAZ are caused by procedural (welding process) or metallurgical shortcomings. We will be concerned primarily with metallurgical problems, but some definition of the differences between process and metallurgical induced flaws is necessary, as is some definition of what a defective weld is.

Codes of fabrication and other welding documents use several words interchangeably to describe unacceptable areas in welds. The four most common are *imperfection*, *discontinuity*, *flaw* and *defect*. Before fracture mechanics were available and the concept of Fitness-for-Purpose did not exist, the use of any of these words to describe a problem region was acceptable. Now, however, such imprecision can lead to difficulties in interpretation, and some rationalization is called for. Let us try the following definitions of these words:

Imperfection/Discontinuity

Metallurgically, an imperfection is any lack of regularity in a three-dimensional lattice of atoms. In a metal, anything from a vacancy or dislocation to larger regions such as a grain boundary would qualify. The term discontinuity is better applied to a collection of imperfections (for example a grain boundary) which is normally undetectable by conventional inspection and non-destructive testing techniques. Neither an imperfection nor a discontinuity should be of concern in a material or fabrication. Many fabrication Codes and Standards use these words to describe large problems, such as cracks, which must be repaired.

Flaw

A flaw is a discontinuity detectable via destructive or nondestructive testing which is not likely to cause failure of the structure in the prevailing conditions. It can therefore be left in the structure without repair, if validated by fracture mechanics analysis. Some NDT techniques (RT,UT) can detect such innocuous flaws as grain boundaries in certain alloys, so some care is necessary in interpretation.

Defect

A defect is a flaw which is likely to cause structural failure under prevailing or anticipated operating conditions. It is also any flaw prohibited by a fabrication code or a customer specification. A given discontinuity may be a flaw in one structure, but a defect in another. ECA (Engineering Critical Analysis) involving fracture mechanics can help distinguish between flaws and defects. Otherwise, arbitrary workmanship criteria are used (a fixed size and/or type of flaw is a defect in all circumstances). Preventive maintenance is cheaper than catastrophic failure or replacement, so regular inspection is a required backup to ECA.

A somewhat cynical, but useful, engineering view is that all materials and fabrications are collections of imperfections. An acceptable material or fabrication is an organized or accidental collection of flaws suitable for a specific application (fitness-for-purpose). Scrap material, a fabrication requiring repair, or a scrapped fabrication, are unfortunate or unlucky collections of defects for a particular application.

Flaws and defects in a weld region can be two dimensional (e.g. cracks) or three dimensional (e.g. porosity). As a general rule, two dimensional flaws are at once more dangerous and more difficult to detect and are therefore more important, despite what some codes say about porosity. However, keep in mind that both two and three dimensional flaws cause stress concentrations (important for dynamic loading) and that extensive porosity can be indicative of a poor weld which may contain other, more dangerous, flaws.

Temper Embrittlement

Temper embrittlement is caused by the segregation of P, and to a lesser extent by Sn, As and Sb, to prior austenite grain boundaries during heat treatment or high-temperature service at temperatures <500°C (930°F). Cr and Ni tend to promote segregation, while Mo tends to minimize it. In the HAZ region of welded structures, it also appears that Mn and Si promote segregation in the HAZ. In weld metals, Mn is also a problem at levels in excess of only 0.10%. The suggested method to minimize cracking is to keep Mn and Si as low as possible. Mn can be held to about 0.5% in Cr-Mo steels, but not less. Si is also a problem to limit in weld metals, due to the need for deoxidation. The preferred method in modern steels is to limit P to less than 0.010%, or even 0.005%. It is not metallurgically feasible to reduce Sn and especially As and Sb, to levels lower that the ppm levels at which they appear now. Scrap containing Sn can be limited to other steels which are not exposed to conditions which promote temper embrittlement. There have been a few empirical rules derived to minimize the probability of temper embrittlement in weld zones, for base plates (HAZ) and the weld metal in Cr-Mo and Cr-Mo-V steels, which will be given in detail in Chapter 5 on Alloy Steels.

Chapter 4

CARBON STEELS

Carbon Steels

Carbon steels, or Carbon-Manganese (C-Mn) steels are alloys of carbon, manganese and iron dominated by the solid state eutectoid reaction at 0.8%C. General metallurgical information on these alloys is given in *The Metals Black Book* - Ferrous Metals. Related AWS Filler Metal Specifications are A5.1, 5.2, 5.17, 5.18, 5.20, 5.25 and 5.26. Carbon levels are in the range up to about 1.2%C maximum. Manganese is always present to control sulphur and prevent hot cracking. Steels may contain up to 2%Mn before it is considered a separate alloying element.

Structural Steels

Modern structural steels are largely Carbon-Manganese (C-Mn) or low alloy steels. C-Mn steels used for structures and machinery typically contain up to about 0.50% carbon, 1.7% manganese, 0.6% Silicon and occasionally a small amount of aluminum for grain size refinement. No other deliberate alloying elements are added, but chromium, nickel, molybdenum, copper and columbium can be present as residual elements.

In a given steel, the maximum achievable hardness in a severe quench (high cooling rate) is determined almost exclusively by the carbon content. The ability of the steel to achieve that maximum hardness is dependent on the cooling rate and the alloy content. Most alloying elements tend to diminish the rate of diffusion of carbon, which tends to promote lower temperature transformation products and thus increases hardenability, which describes how easily the steel can achieve maximum hardness in a section. The Jominy endquench hardness test is often used to assess this behaviour. Jominy data is often correlated with an Isothermal Transformation diagram (or Time-Temperature-Transformation diagram), which shows which transformation products occur for a steel cooled rapidly from about 900°C (1650°F) to a specified lower temperature, which temperature is then held until a transformation occurs. This does not happen often in practice, especially

2. Bersch & Koch - pipeline steel

$$CE = \%C + \frac{\%Mn + \%Si + \%Cr + \%Mo + \%V + \%Cu + \%Ni}{20}$$

3. Ito-Bessyo - for linepipe steels with carbon levels <0.15%

$$P_{cm} = \%C + \frac{\%Mn}{20} + \frac{\%Si}{30} + \frac{\%Cr}{20} + \frac{\%Mo}{15} + \frac{\%V}{10} + \frac{\%Cu}{20} + \frac{\%Ni}{60} + 5\%B$$

4. Yurioka CEN - combines IIW and P_{cm} formats

$$CEN = \%C + A(C) \times \{\frac{\%Mn}{6} + \frac{\%Si}{24} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Cu}{15} + \frac{\%Ni}{20} + \frac{\%Cb}{5} + 5\%B\}$$

where A(C) = 0.75 + 0.25{tanh[20(%C - 0.12)]}.

It can be seen from these formulae that the alloying elements have a lesser effect on carbon equivalent in microalloyed steels, since the divisor for most alloying elements is less than the value used in the IIW equation.

The Ito-Bessyo equation is the most popular for pipeline steels. The Yurioka equation is intended to combine the IIW and Ito-Bessyo equations to allow for the use of one equation for all carbon and microalloyed steels.

Microalloyed steels, although not prone to HAC, are somewhat more susceptible to HAC for a given hardness level than are C-Mn steels. This shows up as a problem with cracking at well below the 350 Hv10 level used as a minimum limit for C-Mn steels. Cracking can occur at hardness levels of 250 Hv10 or even less. The reasons for this behaviour are not simple. Residual stresses from cooling are higher, due to the higher yield stresses in both base and weld metals. Low sulphur levels have been connected to an increase in HAC and the reason initially proposed was that the increased number of inclusions as sulphur levels rose acted as hydrogen traps, reducing the risk of HAC. Some investigators advocated resulphurizing the steels, which would have compromised the gains in fracture toughness. Later it was shown that the reduced numbers of inclusions in low residual steels reduced the number of nucleation sites available to initiate austenite transformation during the cooling regime of the welding thermal cycle. As a result, low temperature transformation products were more likely in low residual steels, leading to martensite/bainite structures known to be more prone to HAC. The solution is procedure control based on slowing down the cooling rate. There is still the question of cracking at low hardness levels to address. While this problem is not entirely solved, it is possible that microstructures prone to HAC cannot be defined solely by hardness, as they can in C-Mn steels. HAC is more likely in a distorted ferrite lattice

Chapter 5

ALLOY STEELS

Alloy steels contain deliberate additions of one or more elements to modify the corrosion resistance, creep resistance, wear resistance, strength and/or toughness. Low alloy steels contain less than 5-6 wt% total alloy additions (again not including manganese and silicon), usually of chromium, nickel, molybdenum and vanadium. Some information states an upper level of 6%, but many modern alloys exceed that level and are still included in the low alloy classification. Examples are the high end of the Cr-Mo range (9%Cr-1%Mo) and the cryogenic Ni steel range (9%Ni). Alloy steels usually contain < 10% total alloy element content, not including C and Mn, but some exceed this level, for example, the austenitic manganese Hadfield steel, which contains 13%Mn, or the maraging steels, which contain 18%Ni plus deliberate additions of Mo, Ti and Cb. General metallurgical information on these alloys is given in the *CASTI Metals Black Book* - Ferrous Metals. Related AWS Filler Metal Specifications are A5.2, 5.5, 5.23 and 5.25, 5.26, 5.28 and 5.29.

The approach taken in this chapter will be to discuss the welding metallurgy of a few alloy steel systems, since it is not possible to give details for all of the alloy steels which are welded. The systems chosen will illustrate the fundamental aspects of welding metallurgy which apply in total or in part for any alloy steel.

Alloy steels are more hardenable than C-Mn and microalloyed steels. The main concerns in the HAZ are toughness, which can be reduced by a combination of large grain size and martensitic transformations, and HAC. Many alloy steels are in Zone III of the Graville Diagram, and as a result, need Procedure Control and PWHT to avoid HAC and optimize the strength/toughness ratio. In many cases, especially if carbon content is high, it is advisable to maintain the preheat until PWHT can be carried out, so that martensite is not formed in the weld area before PWHT.

Weld metals have their major problems with strength/toughness balance, HAC and, in some cases, hot cracking. As strength level increases, toughness tends to decrease. There are three ways to improve fracture toughness at a given strength level: reduce grain size, reduce inclusion population, and add nickel.

Average grain size is difficult to reduce in cast materials without using nucleants of some kind, and these are often inclusions. Therefore, if enough suitable inclusions are available to refine as-cast microstructures, the weld metal inclusion population is sufficient to decrease toughness. One method used to overcome this conundrum is *Temper Bead Welding*, which is a procedural device to maximize the amount of weld metal and prior HAZ which is grain refined by the heat input of the following passes in a multipass welding procedure. The procedure requires strict control of the heat input and size of each layer of weld (which may be one or more individual passes). The aim is to grain refine at least 80% of the previously deposited weld metal. The last pass is placed at ½ a pass width inside the fusion line to grain refine as much as possible of the final layer. This technique is used on repair welding of steam piping in power stations, where no PWHT is possible.

To reduce the inclusion population, welding processes involving non-inert gases and most fluxes cannot be used on high strength steels. Oxidation or reactions between weld metal deposits and gases or slags causes inclusion populations to rise. The processes of choice for the highest strength alloy steels are therefore GTAW and GMAW, with some use of EBW and LBW, with either vacuum or inert gas shielding.

HAC in weld metals is more of a problem in alloy steels than it is in C-Mn steels, especially High Strength Low Alloy (HSLA) steels. One reason for this is the higher susceptibility of as-cast microstructures, with large grain sizes and inherent alloy element segregation. Another is the failure of electrode compositions to keep pace with advances in base metal chemistry and the nature of producing the alloy steel weld metal deposits. The best situation exists for GTAW and GMAW processes, with some advances being made in FCAW with metal powder cores. These processes use electrode wires of similar alloy composition and cleanliness as the base metal, and do not oxidize or contaminate the weld metal with inclusions. Processes such as SMAW often add alloying elements as ferroalloys in the flux, using core wires made of plain carbon steels. Microsegregations and impurity elements are not as well controlled, which leads to the weld metal in some of these steels being more prone to HAC than is the HAZ, the opposite of the situation with C-Mn steels.

Nickel additions are made to many low alloy welding electrodes to improve toughness. Up to 5% is used in HSLA grades, and cryogenic steels have electrodes containing up to 12%. The exact reason for the improvement of ferritic (martensitic) alloy toughness with Ni used as a

Chapter 6

STAINLESS STEELS

All stainless steels contain 11.5% or more Cr and often contain significant amounts of other alloying elements such as Ni and Mo. Modern 'super' stainless steels have many other alloying elements added for specific properties and may contain less than 50%Fe. General metallurgical information on these alloys is given in the *CASTI Metals Black Book – North Amaerican Ferrous Metals*. Related AWS Filler Metal Specifications are A5.4, 5.9 and 5.22.

Stainless steels earned their name from steels evolved from early 20th century experiments on alloying, carried out mainly in England. It was observed that high Cr steels did not rust even when exposed to rain, and they were dubbed *stainless*. The early alloys contained levels of carbon sufficient to make martensitic transformation on cooling inevitable, so the early experimental steels were very brittle and essentially useless. When steels with more controlled carbon levels were made, a new family of steels was born. Although stainless due to the continuous layer of Cr oxide on the surface, these steels are not corrosion proof and can fail catastrophically in certain environments. Welding tends to make the situation worse in some instances. The alloys are also oxidation resistant at elevated temperatures. The welding metallurgy of these steels is discussed below starting with the simplest alloys, the original martensitic grades. This is followed by the increasingly more complicated grades; ferritic, austenitic, duplex, precipitation hardening and 'super' stainless steels. Since there are so many types of stainless steel, they are used for an enormous range of applications, including corrosion resistance, creep resistance, anti-magnetic applications, cryogenic applications and high strength applications. The alloying elements in stainless steels are classified as austenite stabilizers (C, Ni, Mn and N, but occasionally Cu and Co) or ferrite stabilizers (Cr, Mo, Si, Cb and many others). The balance between these competing austenite and ferrite stabilizing elements determines the microstructure of a given stainless steel.

Martensitic stainless steels contain between 11.5 and 18%Cr and from 0.12 to 1.2%C. Particular grades have some other small alloy additions,

Chapter 7

CAST IRONS

Cast irons are iron-carbon alloys dominated by the eutectic reaction at about 4.3%C. They contain > 2%C, significant amounts of Si, P and S in many cases, and can have large amounts of deliberate alloy additions for specific purposes, for example Cr, Ni, Si, Mo and Cu. General metallurgical information on these alloys is given in the *CASTI Metals Black Book – North American Ferrous Metals*. The related AWS Filler Metal Specification is A5.15.

Metallurgy Of Cast Irons

Cast iron is essentially pig iron from the blast furnace, whose composition has been modified by remelting and adding steel scrap and/or specific alloying elements in the form of ferro-alloys, e.g. ferro-silicon. A typical cast iron contains 3.0-3.8%C, 1.5-3.0%Si, 0.3-1.0%Mn, 0.05-0.25%P and 0.02-0.15%S. The high C and Si contents are a natural result of the blast furnace process. The actual concentration of these elements is important in determining the structure and properties of cast irons. Si, and other alloy and residual elements, modify the C-Fe phase diagram in two ways:

1. The C content of the eutectic and eutectoid are reduced (to 3.7% and 0.6% respectively at 2.0%Si).
2. The eutectic and eutectoid reactions are changed from invariant reactions at a single temperature to univariant reactions over a small range of temperatures.

Cast irons are significantly different from steels in microstructure as well as chemistry. Where steels have carbon in the form of carbide or dissolved in the matrix, cast irons have these and an additional phase - graphite. Although we tend to regard iron carbide in steels as an equilibrium phase, it is not. Given slow cooling rates during solidification or extended thermal treatments of solid cast iron, graphite will form directly or Fe_3C will transform to graphite and iron, which are the true equilibrium phases.

Chapter 8

NICKEL ALLOYS

Nickel alloys are of two types: solid solution alloys that can only be work hardened and precipitation hardened alloys. They are also intended for two application areas: resistance to corrosion and oxidation in specific media, or resistance to deformation (creep) and oxidation at high temperatures, as in jet engines. General metallurgical information on these alloys is given in *The Metals Red Book* - Nonferrous Metals. Related AWS Filler Metal Specifications are A5.11 and 5.14.

Nickel and its alloys have an *austenitic* face centered cubic crystal structure and, like austenitic stainless steel, have an aversion to sulfur. Hot cracking is therefore one of the major welding problems and all sulfur bearing compounds, oil, grease, paint, etc., must be scrupulously removed from the weld area. Temperature sensitive crayons used to be a prime culprit, but new formulations are sulfur free. Low melting point metals and alloys can also be a problem. Lead and bismuth and their alloys must be excluded from the weld zone. Silicon promotes hot cracking in some alloys, and minor additions of boron and zirconium can promote liquation cracking in the HAZ, particularly in the coarse grain region, where the minor elements collect on the grain boundaries.

Cleaning should be by vapor or solvent degreasing and by brushing with stainless steel brushes (not mild steel) for 25-50 mm (1-2 in.) outside the edge of the weld preparation. Repair welding of alloys which have been in service often requires more drastic cleaning. Grit or vapor blasting may be of help in this situation. Initial degreasing is often beneficial, by minimizing the risk of embedding grease, etc., in the surface during grit blasting or minimizing the contamination of wire brushes, which may transfer contamination to other surfaces.

Since many applications of nickel alloys involve corrosion, it is imperative that weld zones, both weld metal and HAZ, have equivalent or higher corrosion resistance, i.e. are cathodic to the base metal. If they are not, corrosion will concentrate on the weld zone, with catastrophic results in most cases. This problem is usually of more importance in the weld metal. If any doubt exists for a particular application, contact the manufacturer of the alloy and/or of the proposed filler metal for information. There can be corrosion problems in addition to overall weld metal chemistry that are caused by precipitation of carbides and/or intermetallic compounds. The carbide problem is analogous to 'sensitization' in stainless steels. Many subtle changes in the composition of certain nickel alloys has been done over the years to minimize these problems. Fine tuning has produced, among others UNS N10276 (Hastelloy* C-276), UNS N06022 (Hastelloy* C-22) and UNS N06455 (Hastelloy* C-4) alloys, all variations on the original C theme alloy. For example, UNS N10276 was an early low carbon version to minimize carbide formation. Sensitization is best avoided by using low heat input and stringer passes for multipass welds in thicker material. The less time spent in the 500-850°C (930-1560°F) range, the better. The low carbon variations of the alloys are immune if low heat input is used. Another, significantly less desirable solution, is to anneal the fabrication after welding at a temperature high enough to dissolve the carbides, about 900-1000°C (1650-1830°F). This carries the risk of thermal distortion of complex structures and possible reprecipitation of carbides on cooling, so low carbon and low heat inputs are preferred.

Precipitates are also a problem in the welding of precipitation hardened alloys intended for creep resistance at high temperatures. Alloy fine-tuning has also been done on these alloys to minimize the precipitation of intermetallic phases (e.g. σ, μ & χ) which embrittle the material. The precipitate used for hardening is $Ni_3(Al,Ti)$ for the most part. This is a very stable precipitate which takes extensive heat treatment to form and is difficult to dissolve completely in the short time of the welding thermal cycle. Welding these alloys can cause strain-age cracking in the HAZ due to strain concentration during cooling after welding in the narrow zone which is overaged or partly solution treated. As a result, the alloys are normally welded in the annealed (solution treated) condition and the completed fabrication is hardened with a PWHT.

The third possible welding problem is porosity, generally the result of carbon being oxidized during welding or of nitrogen absorption. Virtually all filler metals for nickel alloys contain elements to deoxidize and denitrify the deposited weld metal to avoid porosity. These are usually Al, Ti and Cb. Hydrogen is often added to the argon shielding gas for GTAW procedures (about 10%H_2), which minimizes nitrogen porosity. GMAW procedures do not respond well to similar additions, where hydrogen can cause porosity on its own. GMAW gas mixtures should be argon without oxidizing gas additions (CO_2 or O_2), although helium can be added to aid in smooth bead formation. SMAW is the other common process used, in which porosity is not a problem if consumables are

Chapter

9

REACTIVE & REFRACTORY ALLOYS

Reactive metals such as titanium and zirconium react with and readily dissolve the atmospheric gases oxygen, nitrogen and hydrogen at elevated temperature and as a result they become hardened and embrittled. Refractory metals do likewise, but are differentiated by very high melting temperatures and therefore by high application temperatures. They are also brittle at room temperature: examples are tungsten, tantalum, molybdenum and columbium alloys. General metallurgical information on these alloys is given in *The Metals Red Book* - Nonferrous Metals. Related AWS Filler Metal Specifications are A5.16 and 5.24.

Reactive Alloys

Welding of the reactive alloys requires isolation and protection from atmospheric gases above all other welding precautions. This can be accomplished at several levels, depending on the limit of contamination needed. Levels must be lowest for corrosion protection and may be slightly relaxed when only mechanical strength is required. Tough weld metals also require low contamination levels. Only inert gas processes should be used, with argon as the shielding gas. The dew point should be -60°C (-70°F) maximum. High purity argon or combinations of cold traps (for moisture) and hot traps (for oxygen and nitrogen) should be used in critical welds. GTAW is the best choice in most cases. GMAW should be treated with caution, due to the extra gas-metal reaction site at the electrode tip. EBW in vacuum, or argon shielded LBW are also used for some fabrications. The extent of reaction with atmospheric gases, notably oxygen, can be assessed by the colour of the weld zone after fabrication. The color indicates the thickness of the surface oxide layer, much like an oil film on a puddle of water shows differing colors in sunlight. A shiny, bright silvery, colour is ideal, but rarely achieved. A golden or straw colour indicates minimum contamination and good corrosion resistance. Various shades of blue, from light to dark, indicate thicker oxides and lower corrosion resistance. Purple, or worse yet, dull grey, oxides indicate significant contamination. The latter situation should not be tolerated for

Chapter 10

ALUMINUM & MAGNESIUM ALLOYS

General metallurgical information on aluminum and magnesium alloys is given in the *CASTI Metals Red Book – Nonferrous Metals*. Related AWS Filler Metal Specifications are A5.3, 5.10 and 5.19.

The welding metallurgy of aluminum and magnesium and their alloys is dominated by some shared characteristics. Both alloy systems melt at low temperatures, < 650°C (1200°F). This makes melting and welding fairly easy. Wrought alloys are welded best with inert gas shielded processes, GTAW, PAW or GMAW. Gases are pure Ar or Ar-He mixtures. Pure He can be used, but that is rare due to the cost and poor shielding efficiency (low density of the gas). Aluminum alloys of all compositions suffer mainly from hot cracking in the weld metal. There is some risk of liquation cracking in the HAZ, but it is quite unusual. Solidification cracks are minimized by choosing filler metal composition to avoid weld metal compositions close to the solid solubility limit of the primary alloying element(s) in the base metal. The 2xxx Cu alloys, the 7xxx Mg-Zn alloys and the 8xxx Li alloys give the most trouble.

For magnesium alloys, filler metals of similar chemical composition to the base metal are normal. Preheat is more common than it is with aluminum alloys, to help minimize residual stresses and therefore, weld metal cracking. PWHT is also more common, for the same purpose, and also for minimizing stress corrosion cracking in service.

The solubility of hydrogen is very high in the liquid compared to the solid in both aluminum and magnesium, with a ratio of about 50:1. The drop in solubility as temperature decreases is especially steep just above the melting temperature. This makes both alloy systems very prone to hydrogen porosity in the weld metal. The only remedy is to avoid hydrogen absorption during welding. It is essential to remove hydrocarbons such as oil and grease with solvent degreasing. It is also vital to avoid water on the surface of the metal, as a small amount can cause significant porosity, especially when welding outside. A preheat of about 50°C (120°F) is recommended to remove any condensation, even though aluminum alloys do not normally require it. It is also useful to run an arc on a scrap piece of metal when welding is initiated after a long shutdown, for example overnight. This helps to clear any condensation in the inert gas shielding lines, which can also contribute to startup porosity.

Both aluminum and magnesium react with the atmosphere to produce tightly adherent refractory oxides that melt at high temperatures (> 2000°C or 3630°F) and protect the underlying metal against corrosion. The oxides do not melt during welding and have to be dispersed or removed from the weld area to ensure full fusion. This is usually accomplished by the use of alternating current with the GTAW process and electrode positive polarity in the GMAW process. In both cases, when electrons pass from the base metal to the electrode on electrode positive polarity, the oxide on the weld pool surface is disrupted in a process called cathode sputtering. There may also be some oxide disruption from argon positive ion bombardment of the weld pool surface. Prior to welding, mechanical cleaning of the surface is also important. Oxide thickness should be minimized by scratch brushing, but only with stainless steel brushes. Carbon steel brushes will leave small particles of steel embedded in the surface, which will corrode. Stainless steel particles will not. Stainless brushes, manual or powered, should be designated for Al or Mg use and kept separate from other cleaning equipment to avoid contamination, especially in a shop where metals other than aluminum are fabricated. The stainless steel brushing can also help minimize porosity, since thick oxide can be hydrated, especially after long storage times.

Aluminum Alloys

Wrought alloys are welded into many types of fabricated items, from electric bus bars to railway hopper cars. Non heat treatable alloys are separated from heat treatable grades for welding. If an aluminum to be welded has an unknown history and the chemical composition is not obtainable, the filler metal of choice is ER4043, containing 5%Si. Virtually any aluminum alloy can be welded satisfactorily without cracking using this filler metal, but optimum properties (mechanical, anodizing response) may not be achieved. Peak cracking tendency in Al-Si alloys occurs at only 0.5%Si, so a large amount of dilution will have virtually no effect.

The 1xxx *pure* aluminum series have the best electrical conductivity and corrosion resistance of all Al alloys. Bus bars need filler metals of similar purity, typically 1040 or better, to maintain electrical continuity. For commercially pure alloys of 1060 type and up, ER1100 is the normal

Chapter 11

OTHER METALS AND ALLOYS

In this chapter, copper alloys and some other alloys which are not often welded will be considered. Some metals and alloys which should not be welded will also be mentioned. For these materials, other joining methods are preferable, for example bolting, adhesive bonding or brazing/soldering. General metallurgical information on these alloys is given in the *CASTI Metals Red Book – Nonferrous Metals*. Related AWS Filler Metal Specifications are A5.6, 5.7 and 5.8.

Copper Alloys

For the most part, copper and its alloys can be welded, but they have some peculiar characteristics which need to be addressed. Pure copper and slightly alloyed coppers have very high thermal diffusivity and are difficult to melt, even with electric arcs. Copper dissolves significant amounts of oxygen, which forms a copper-copper oxide eutectic. If any hydrogen is absorbed during welding, large quantities of steam porosity form. Porosity is also a problem in Cu-Ni alloys. Free machining copper alloys contain a variety of additions to improve chip formation, including lead, bismuth selenium and sulphur. All cause significant problems with solidification cracking which cannot be addressed with filler metal modifications. Welding is not recommended. In brasses, zinc fuming can be a problem at levels of Zn in excess of 15%.

Pure copper comes in three types: tough pitch copper, phosphor deoxidized and oxygen free high conductivity copper. All have very high thermal diffusivity and are difficult to melt. Although oxy-acetylene procedures can be used, total heat levels can cause welder discomfort. SMAW electodes are also available, but the flux residue is corrosive, and gas shielded arc welding (GTAW, PAW or GMAW) is preferable. ERCu fillers are appropriate. Preheat can help, as can the use of shielding gas modifications to increase heat input. In argon shielded processes, there are a few options, and one definite prohibition. Helium can be added to about 50% in argon to increase heat input, as can up to 30% of the diatomic gas nitrogen. High levels of nitrogen can cause some porosity in the weld metal. Hydrogen, which is also diatomic and is used to increase heat input for the welding of austenitic stainless steel, must not be used for tough pitch and nearly pure coppers due to the steam reaction with copper oxide. Deoxidation of the weld pool is also important to avoid porosity. Welding on phosphor deoxidized parent metal is best and filler metals often include deoxidants such as Mn, Si, Ti or Al. Ti and Al can also act as denitrifiers if Ar-N_2 shielding gases are used. High conductivity copper contains very low oxygen levels, and the main welding problem is loss of electrical conductivity in the weld metal due to the deoxidant additions. This conductivity loss can be minimized by using a special filler metal which is deoxidized with boron.

Brasses, i.e. alloys of copper and zinc, have low thermal diffusivity and can be arc welded easily with the GTAW process, as far as melting the alloy is concerned. Zinc fuming, however, is a problem that increases in severity as zinc content increases. Some relief can be obtained by using a phospher (tin) bronze (ERCuSn-A) or silicon bronze (ERCuSi-A) filler metals, or by welding in the overhead position, so that the weld metal recaptures the zinc fume. Brass filler metals (RCuZn) are available, but only for use with oxy-acetylene welding, not arc welding.

Alloys of copper and nickel are called cupronickels when copper rich. The most common compositions are 5-30% nickel. GTAW and GMAW processes are usual, using a similar filler composition, or the 30%Ni composition if not (ERCuNi). Thermal diffusivity is low, so fusion is easy. Since Ni is present, S and sulphur-bearing compounds must be excluded. Be wary of things like paint or crayon markings in the weld vicinity, and also of oil and grease. Lead contamination (from tooling) is to be avoided for the same reason.

Bronzes may be tin, silicon, or aluminum alloys of copper. All have low thermal diffusivity. Tin bronzes are rarely welded - if need be, phosphor or berylium bronze (ERCuSn-A) filler metal is used. Silicon bronzes can be easily welded using similar filler wire compositions, usually with inert gas shielded arc processes. High restraint may lead to hot cracking, so minimal restraint during fabrication is important. Aluminum bronzes are similar to Al alloys, in that the aluminum content is sufficient to form a continuous oxide film on the surface, which improves corrosion resistance. It also interferes with welding the same way, so inert gas processes, with alternating current for GTAW procedures, are mandatory. They are also similar to carbon steels, in that they can have a eutectoid reaction which can lead to martensitic transformation products and they can also be precipitation hardened. The composition for this behaviour is at approximately 9-10%Al. This alloy has low thermal diffusivity and excellent resistance to hot cracking in the weld metal using a similar composition of filler metal (ERCuAl-A3). Lower alloy levels, for example 7%Al, produce single phase alloys that are very prone to weld metal cracking. Using the 10%Al filler reduces weld metal cracking, but the

Chapter 12

INTERNATIONAL WELDING FILLER METAL DESIGNATION SYSTEMS

Introduction

Technical committees have long struggled with systems to identify materials in a consistent and logical manner. As new materials are brought to the market, the originator or the dominant producer identifies the product with its trade name. Names, such as "Monel," Stellite, Stainlend, Fleetweld, and many others, prevail for many years, even when additional producers of a comparable products make use of such names, often by reference in their product brochures. Differentiation of grades within a family are given letter or numeric designators following the established trade name; often these designators, like 800H, 347, 70-30, become well-known and widely accepted in industry. When specification committees seek consensus for designations, it is not uncommon to agree to use names and/or numerical designators which already prevail. When preparing specifications for multiple products within its scope, the adoption of designators then favor a consistent and logical system.

Many such systems occur in various national specifications. When specifications are cited in international trade, the designations sometimes become accepted in multinational markets. This has resulted in the use of the designations established in the filler metal specifications of the American Welding Society (AWS). The German DIN specifications have also been used in international trade and its designation systems are being suggested for use in ISO standards.

This section will consider the several designation systems and a method for making comparisons for similar products in national specification in many industrialized countries.

Identification of Filler Metals by Welding Processes

By far the greatest use of filler metals is for the various arc welding processes. The identification of the process usually appears in the definition of the scope and often in the title of the specification.

Most specifications include the covered electrodes for manual shielded metal arc welding (SMAW). Solid wires are generally used for gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and submerged arc welding (SAW). These processes also use composite (usually tubular) metal cored wires, similar to flux cored wires, but such wires contain no appreciable non-metallic ingredients, and thus are distinguished from the flux-containing tubular cored wires for flux cored arc welding (FCAW) and for electrogas welding (EGW). The electroslag welding (ESW) process uses a variety of filler metals, solid wires, composite wires, consumable tubes, strip and even plate filler metal.

The oxy-fuel welding processes also make use of filler metals, usually solid wires, though tubular composite wires are employed on rare occasions. Most of the solid wires which are found suitable for arc welding are also applicable in the oxy-fuel process.

Brazing filler metals are usually treated as a distinct class with many alloys and filler metal forms.

Designation Systems in National Specifications

Welding filler metals are generally defined by several attributes:

1. the mechanical properties of the welds which they produce,
2. the suitability of the filler metal for various applications,
3. the slag forming ingredients used in the manufacture, and/or
4. their metallic composition either that of the weld metal or of the filler metal itself.

To incorporate all of the properties of a filler metal in its designation often becomes unwieldy and awkward. There is a tension between causing the designation to completely define the product and simplicity for ease of understanding. The marketplace has usually dictated a preference for simplicity, rather than complexity. Compromises abound, however, as industry desires to distinguish between competing products for similar applications. What follows illustrates how designations appear in specifications found in various industrialized countries.

Chapter

13

CAST IRON FILLER METALS

AWS A5.15 CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL FOR SHIELDED METAL ARC

AWS A5.15 Classification[d]	UNS Number[e]	Composition, Weight Percent[a,b,c]
Shielded Metal Arc Welding Electrodes		
ENi-CI	W82001	C 2.0 Mn 2.5 Si 4.0 S 0.03 Fe 8.0 Ni[f] 85 min. Cu[g] 2.5 Al 1.0 Other Elements Total 1.0
ENi-CI-A	W82003	C 2.0 Mn 2.5 Si 4.0 S 0.03 Fe 8.0 Ni[f] 85 min. Cu[g] 2.5 Al 1.0-3.0 Other Elements Total 1.0
ENiFe-CI	W82002	C 2.0 Mn 2.5 Si 4.0 S 0.03 Fe Rem Ni[f] 45-60 Cu[g] 2.5 Al 1.0 Other Elements Total 1.0
ENiFe-CI-A	W82004	C 2.0 Mn 2.5 Si 4.0 S 0.03 Fe Rem Ni[f] 45-60 Cu[g] 2.5 Al 1.0-3.0 Other Elements Total 1.0
ENiFeMn-CI	W82006	C 2.0 Mn 10-14 Si 1.0 S 0.03 Fe Rem Ni[f] 35-45 Cu[g] 2.5 Al 1.0 Other Elements Total 1.0
ENiCu-A	W84001	C 0.35-0.55 Mn 2.3 Si 0.75 S 0.025 Fe 3.0-6.0 Ni[f] 50-60 Cu[g] 35-45 Other Elements Total 1.0
ENiCu-B	W84002	C 0.35-0.55 Mn 2.3 Si 0.75 S 0.025 Fe 3.0-6.0 Ni[f] 60-70 Cu[g] 25-35 Other Elements Total 1.0
Flux Cored Arc Welding Electrodes		
ENiFeT3-CI[h]	W82032	C 2.0 Mn 3.0-5.0 Si 1.0 S 0.03 Fe Rem Ni[f] 45-60 Cu[g] 2.5 Al 1.0 Other Elements Total 1.0

a. The weld metal, core wire, or the filler metal, as specified, shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements Total” in this table.

b. Single values are maximum, except where otherwise specified.

c. “Rem” stands for Remainder.

d. Copper-base filler metals frequently used in the braze welding of cast irons are no longer included in this specification. For information pertaining to these materials, see AWS A5.15 appendix A7.6.

e. SAE/ASTM Unified Numbering System for Metals and Alloys.

f. Nickel plus incidental cobalt.

g. Copper plus incidental silver.

h. No shielding gas shall be used for classification ENiFeT3-CI.

Chapter 14

CARBON AND LOW ALLOY STEEL FILLER METALS

AWS A5.1 CARBON STEEL ELECTRODE CLASSIFICATION

CARBON STEEL ELECTRODE CLASSIFICATION			
AWS A5.1 Classification	**Type of Covering**	**Welding Position[a]**	**Type of Current[b]**
E6010	High cellulose sodium	F, V, OH, H	dcep
E6011	High cellulose potassium	F, V, OH, H	ac or dcep
E6012	High titania sodium	F, V, OH, H	ac or dcen
E6013	High titania potassium	F, V, OH, H	ac, dcep or dcen
E6019	Iron Oxide titania potassium	F, V, OH, H	ac, dcep or dcen
E6020	High iron oxide	H-fillets, F	ac or dcen ac, dcep or dcen
E6022[c]	High iron oxide	F, H	ac or dcen
E6027	High iron oxide, iron powder	H-fillets, F	ac or dcen ac, dcep or dcen
E7014	Iron powder, titania	F, V, OH, H	ac, dcep or dcen
E7015[d]	Low hydrogen sodium	F, V, OH, H	dcep
E7016[d]	Low hydrogen potassium	F, V, OH, H	ac or dcep
E7018[d]	Low hydrogen potassium, iron powder	F, V, OH, H	ac or dcep
E7018M	Low hydrogen iron powder	F, V, OH, H	dcep
E7024[d]	Iron powder, titania	H-fillets, F	ac, dcep or dcen
E7027	High iron oxide, iron powder	H-fillets, F	ac or dcen ac, dcep or dcen
E7028[d]	Low hydrogen potassium, iron powder	H-fillets, F	ac or dcep
E7048[d]	Low hydrogen potassium, iron powder	F, OH, H, V-down	ac or dcep

a. The abbreviations indicate the welding positions as follows: F = Flat, H = Horizontal, H-fillets = Horizontal fillets, V-down = Vertical with downward progression, V = Vertical, OH = Overhead: For electrodes 3/16 in. (4.8 mm) and under, except 5/32 in. (4.0 mm) and under for classifications E7014, E7015, E7016, E7018 and E7018M.

AWS A5.29 CLASSIFICATION SYSTEM

The system for identifying the electrode classifications in this specification follows, for the most part, the standard pattern used in other AWS filler metal specifications.

Some of the classifications are intended to weld only in the flat and horizontal positions (E70T5-A1, for example). Others are intended for welding in all positions (E81T1-Ni1, for example). As in the case of covered elctrodes, the smaller sizes of flux cored electrodes are the ones used for the out-of-position work. Flux cored electrodes larger than 5/64 in. (2.0 mm) in diameter are usually used for horizontal fillets and flat position welding.

Optional supplemental designators are also used in this specification in order to identify electrode classifications that have met certain supplemental requirements as agreed to between the supplier and the purchaser. The optional supplemental designators are not part of the classification nor of its designation.

A generic example of the method of classification of electrodes is shown below.

EXXTX-XM JHZ

Mandatory Classification designators*
*(The combination of these constitutes the electrode classification.)

E	Designates an electrode.
First X	Indicates the minimum tensile strength (in ksi ÷ 10) of the weld metal when the weld metal is made in the manner prescribed by this specification. (Two digits may be required).
Second X	It is either 0 or 1. It indicates the positions of welding for which the electrode is intended. 0 is for the flat and horizontal positions only; 1 is for all positions.
T	Indicates that the electrode is a flux cored electrode.
Third X	It will be some number: 1, 4, 5, 6, 7, 8, 11 or the letter G. The number refers to the usability of the electrode (see A7 of AWS A5.29). The G indicates that the slag system and shielding gas are not specified.

AWS A5.29 CLASSIFICATION SYSTEM (Continued)

Fourth X	Designates the chemical composition of the deposited weld metal (see AWS A5.29 Table 4). Specific chemical compositions are not always identified with specific mechanical properties in the specification. A supplier is required by the specification to include the mechanical properties appropriate for a particular electrode in classification of that electrode. Thus, for example, a complete designation is E80T5-Ni3, EXXT5-Ni3 is not a complete classification. The letter G indicates that the chemical composition is not specified.
M	An "M" designator in this position indicates that the electrode is classified using 75-80% argon/bal CO_2 shielding gas. When the "M" designator does not appear, it signifies that either the shielding gas used for classification is CO_2, or that the electrode is a self shielding elctrode.

Optional Supplemental Designators

J	Designates that the electrode meets the requirements for improved toughness by meeting a requirement of 20 ft·lbf (27 J) at a test temperature of 20°F (11°C) lower than the temperature shown for that classification in Table 2 of AWS A5.29. Absence of the "J" indicates normal impact requirements as given in that table.
HZ	Designates that the electrode meets the requirements of the diffusible hydrogen test (an optional supplemental test of the weld metal with an average value not exceeding "Z" mL of H_2 per 100 g of deposited metal where "Z" is 4, 8, or 16). See Table 10 and A8.2 of AWS A5.29.

Chapter 15

STAINLESS STEEL WELDING FILLER METALS

AWS A5.4 CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL		
AWS A5.4 Classification[c]	**UNS Number[d]**	**Weight Percent [a,b]**
E209-XX[e]	W32210	C 0.06 Cr 20.5-24.0 Ni 9.5-12.0 Mo 1.5-3.0 Mn 4.0-7.0 Si 0.90 P 0.04 S 0.03 N 0.10-0.30 Cu 0.75
E219-XX	W32310	C 0.06 Cr 19.0-21.5 Ni 5.5-7.0 Mo 0.75 Mn 8.0-10.0 Si 1.00 P 0.04 S 0.03 N 0.10-0.30 Cu 0.75
E240-XX	W32410	C 0.06 Cr 17.0-19.0 Ni 4.0-6.0 Mo 0.75 Mn 10.5-13.5 Si 1.00 P 0.04 S 0.03 N 0.10-0.30 Cu 0.75
E307-XX	W30710	C 0.04-0.14 Cr 18.0-21.5 Ni 9.0-10.7 Mo 0.5-1.5 Mn 3.30-4.75 Si 0.90 P 0.04 S 0.03 Cu 0.75
E308-XX	W30810	C 0.08 Cr 18.0-21.0 Ni 9.0-11.0 Mo 0.75 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E308H-XX	W30810	C 0.04-0.08 Cr 18.0-21.0 Ni 9.0-11.0 Mo 0.75 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E308L-XX	W30813	C 0.04 Cr 18.0-21.0 Ni 9.0-11.0 Mo 0.75 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E308Mo-XX	W30820	C 0.08 Cr 18.0-21.0 Ni 9.0-12.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E308MoL-XX	W30823	C 0.04 Cr 18.0-21.0 Ni 9.0-12.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E309-XX	W30910	C 0.15 Cr 22.0-25.0 Ni 12.0-14.0 Mo 0.75 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E309L-XX	W30913	C 0.04 Cr 22.0-25.0 Ni 12.0-14.0 Mo 0.75 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E309Cb-XX	W30917	C 0.12 Cr 22.0-25.0 Ni 12.0-14.0 Mo 0.75 Cb (Nb) plus Ta 0.70-1.00 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E309Mo-XX	W30920	C 0.12 Cr 22.0-25.0 Ni 12.0-14.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E309-MoL-XX	W30923	C 0.04 Cr 22.0-25.0 Ni 12.0-14.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E310-XX	W31010	C 0.08-0.20 Cr 25.0-28.0 Ni 20.0-22.5 Mo 0.75 Mn 1.0-2.5 Si 0.75 P 0.03 S 0.03 Cu 0.75
E310H-XX	W31015	C 0.35-0.45 Cr 25.0-28.0 Ni 20.0-22.5 Mo 0.75 Mn 1.0-2.5 Si 0.75 P 0.03 S 0.03 Cu 0.75
E310Cb-XX	W31017	C 0.12 Cr 25.0-28.0 Ni 20.0-22.0 Mo 0.75 Cb (Nb) plus Ta 0.70-1.00 Mn 1.0-2.5 Si 0.75 P 0.03 S 0.03 Cu 0.75
E310Mo-XX	W31020	C 0.12 Cr 25.0-28.0 Ni 20.0-22.0 Mo 2.0-3.0 Mn 1.0-2.5 Si 0.75 P 0.03 S 0.03 Cu 0.75
E312-XX	W31310	C 0.15 Cr 28.0-32.0 Ni 8.0-10.5 Mo 0.75 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E316-XX	W31610	C 0.08 Cr 17.0-20.0 Ni 11.0-14.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E316H-XX	W31610	C 0.04-0.08 Cr 17.0-20.0 Ni 11.0-14.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75
E316L-XX	W31613	C 0.04 Cr 17.0-20.0 Ni 11.0-14.0 Mo 2.0-3.0 Mn 0.5-2.5 Si 0.90 P 0.04 S 0.03 Cu 0.75

CHEMICAL COMPOSITION REQUIREMENTS (Continued)

h. These classifications also will be included in the next revision of ANSI/AWS A5.28, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Metal Arc Welding*. They will be deleted from ANSI/AWS A5.9 in the first revision following publication of the revised ANSI/AWS A5.28 document.

AWS A5.9 CLASSIFICATION SYSTEM

The chemical composition of the filler metal is identified by a series of numbers and, in some cases, chemical symbols, the letters L, H, and LR, or both. Chemical symbols are used to designate modifications of basic alloy types, e.g., ER308Mo. The letter "H" denotes carbon content restricted to the upper part of the range that is specified for the standard grade of the specific filler metal. The letter "L" denotes carbon content in the lower part of the range that is specified for the corresponding standard grade of filler metal. The letters "LR" denote low residuals (see AWS A5.9 appendix A8.30).

The first two designators may be "ER" for solid wires that may be used as electrodes or rods; or they may be "EC" for composite cored or stranded wires; or they may be "EQ" for strip electrodes.

The three digit number such as 308 in ER308 designates the chemical composition of the filler metal.

Chapter

16

ALUMINUM & ALUMINUM ALLOY WELDING FILLER METALS

AWS A5.3 CHEMICAL COMPOSITION REQUIREMENTS FOR CORE WIRE (WEIGHT PERCENT)[a, b]

CHEMICAL COMPOSITION REQUIREMENTS FOR CORE WIRE (WEIGHT PERCENT)[a,b]		
AWS A5.3 Classification	**UNS Designation[c]**	**Composition, Weight Percent**
E1100	A91100	Si[d] Fe[d] Cu 0.05-0.20 Mn 0.05 Zn 0.10 Be 0.0008 Other Elements Each 0.05 Other Elements Total 0.15 Al 99.00 min[e]
E3003	A93003	Si 0.6 Fe 0.7 Cu 0.05-0.20 Mn 1.0-1.5 Zn 0.10 Be 0.0008 Other Elements Each 0.05 Other Elements Total 0.15 Al Remainder
E4043	A94043	Si 4.5-6.0 Fe 0.8 Cu 0.30 Mn 0.05 Mg 0.05 Zn 0.10 Ti 0.20 Be 0.0008 Other Elements Each 0.05 Other Elements Total 0.15 Al Remainder

a. The core wire, or the stock from which it is made, shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of work, the amount of those elements shall be determined to ensure that they do not exceed the limits specified for “Other Elements”.
b. Single values are maximum, except where otherwise specified.
c. SAE/ASTM Unified Numbering System for Metals and Alloys.
d. Silicon plus iron shall not exceed 0.95 percent.
e. The aluminum content for unalloyed aluminum is the difference between 100.00 percent and the sum of all other metallic elements present in amounts of 0.010 percent or more each, expressed to the second decimal before determining the sum.

TENSION TEST REQUIREMENTS[a]				
AWS A5.3 Classification	**ASME Section IX**		**Tensile Strength, min.**	
	SFA-No.	**F-No.**	**psi**	**MPa**
E1100	SFA-5.3	21	12000	80
E3003	SFA-5.3	21	14000	95
E4043	SFA-5.3	23	14000	95

a. Fracture may occur in either the base metal or the weld metal.

AWS A5.3 CLASSIFICATION SYSTEM

The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter E at the beginning of each classification designation stands for electrode. The numerical portion of the designation in this specification conforms to the Aluminum Association registration for the composition of the core wire used in the electrode.

Chapter

17

COPPER & COPPER ALLOY WELDING FILLER METALS

AWS A5.6 CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED METAL

CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED METAL			
AWS A5.6 Classification	**UNS Number**	**Common Name**	**Composition, Weight Percent[a,b]**
ECu	W60189	Copper	Cu including Ag remainder, Zn[f] Sn[f] Mn 0.10 Fe 0.20 Si 0.10 Ni[d,f] P[f] Al 0.10 Pb 0.02 Total Other Elements 0.50
ECuSi	W60656	Silicon bronze (copper silicon)	Cu including Ag remainder, Zn[f] Sn 1.5 Mn 1.5 Fe 0.50 Si 1.4 to 4.0 Ni[d,f] P[f] Al 0.01 Pb 0.02 Total Other Elements 0.50
ECuSn-A	W60518	Phosphor bronze (copper-tin)	Cu including Ag remainder, Zn[f] Sn 4.0-6.0 Mn[f] Fe 0.25 Si f Ni[d,f] P 0.05-0.35 Al 0.01 Pb 0.02 Total Other Elements 0.50
ECuSn-C	W60521	Phosphor bronze (copper-tin)	Cu including Ag remainder, Zn[f] Sn 7.0-9.0 Mn[f] Fe 0.25 Si f Ni[d,f] P 0.05-0.35 Al 0.01 Pb 0.02 Total Other Elements 0.50
ECuNi[e]	W60751	Copper nickel (70/30)	Cu including Ag remainder, Zn[f] Sn[f] Mn 1.00-2.50 Fe 0.40-0.75 Si 0.50 Ni[d] 29.0-33.0 P 0.020 Pb 0.02 Ti 0.50 Total Other Elements 0.50
ECuAl-A2	W60614	Aluminum bronze	Cu including Ag remainder, Zn[f] Sn[f] Mn[f] Fe 0.50-5.0 Si 1.5 Ni[d,f] Al 6.5-9.0 Pb 0.02 Total Other Elements 0.50
ECuAl-B	W60619	Aluminum bronze	Cu including Ag remainder, Zn[f] Sn[f] Mn[f] Fe 2.5-5.0 Si 1.5 Ni[d,f] Al 7.5-10.0 Pb 0.02 Total Other Elements 0.50
ECuNiAl	W60632	Nickel aluminum bronze	Cu including Ag remainder, Zn[f] Sn[f] Mn 0.50-3.5 Fe 3.0-6.0 Si 1.5 Ni[d] 4.0-6.0 Al 6.0-8.5 Pb 0.02 Total Other Elements 0.50
ECuMnNiAl	W60633	Manganese-nickel aluminum bronze	Cu including Ag remainder, Zn[f] Sn[f] Mn 11.0-13.0 Fe 2.0-6.0 Si 1.5 Ni[d] 1.0-2.5 Al 5.0-7.5 Pb 0.02 Total Other Elements 0.50

a. Analysis shall be made for the elements for which specific values or an "f" are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for 'total other elements' in the last column in the table.

CHEMICAL COMPOSITION REQUIREMENTS, PERCENT (Continued)

c. Classifications RBCuZn-A, RCuZn-B, RCuZn-C, and RBCuZn-D now are included in AWS A5.27-78, *Specification for Copper and Copper Alloy Gas Welding Rods.*
d. SAE/ASTM Unified Numbering System for Metals and Alloys.
e. Sulfur shall be 0.01 percent maximum for the ERCuNi classification.

STANDARD SIZES

	Diameter[a,b]		
AWS A5.7 Form	**in.**	**in.**	**mm**
Straight lengths	1/16	(0.062)	1.6
Straight lengths	5/64	(0.078)	2.0
Straight lengths	3/32	(0.092)	2.4
Coils, with or without support	1/8	(0.125)	3.2
Coils, with or without support	5/32	(0.156)	4.0
Coils, with or without support	3/16	(0.187)	4.8
Coils, with or without support	1/4	(0.250)	6.4
Wound on spools	0.020		0.5
Wound on spools	0.030		0.8
Wound on spools	0.035		0.9
Wound on spools	0.045		1.2
Wound on spools	0.062	(1/16)	1.6
Wound on spools	0.078	(5/64)	2.0
Wound on spools	0.094	(3/32)	2.4

a. Filler metal shall not vary more than ± 0.002 in. (0.05 mm) in diameter.
b. Other sizes, lengths, and forms may be supplied as agreed upon between the purchaser and supplier.

HARDNESS AND TENSILE STRENGTH OF COPPER AND COPPER ALLOY WELD METAL[a]						
AWS A5.7 Classification	ASME Section IX		Hardness Testing		Tensile strength, min.	
	SFA-No.	F-No.	Hardness	Testing Load	psi	MPa
ERCu	SFA-5.7	31	25 HRF		25 000	172
ERCuSi-A	SFA-5.7	32	80 to 100 HB	(500 kg load)	50 000	345
ERCuSn-A	SFA-5.7	33	70 to 85 HB	(500 kg load)	35 000	240
ERCuNi	SFA-5.7	34	60 to 80 HB	(500 kg load)	50 000	345
ERCuAl-A1	SFA-5.7	36	80 to 110 HB	(500 kg load)	55 000	380
ERCuAl-A2	SFA-5.7	36	130 to 150 HB	(3000 kg load)[b]	60 000	414
ERCuAl-A3	SFA-5.7	36	140 to 180 HB	(3000 kg load)[b]	65 000	450
ERCuNiAl	SFA-5.7	37	160 to 200 HB	(3000 kg load)[b]	72 000	480
ERCuMnNiAl	SFA-5.7	37	160 to 200 HB	(3000 kg load)[b]	75 000	515

a. Hardness values as listed above are average values for an as-welded deposit made with the filler metal specified. This table is included for information only.
b. Gas tungsten arc process only.

AWS A5.7 CLASSIFICATION SYSTEM

The specification classifies those copper and copper alloy filler metals used most extensively at the time of issuance of the specification. In AWS A5.7 appendix A4, the filler metals are arranged in five basic groups. The tensile properties, bend ductility, and soundness of welds produced with the filler metals classified within this specification frequently are determined during procedure qualification. It should be noted that the variables in the procedure (current, voltage, and welding speed), variables in shielding medium (the specific gas mixture or the flux), variables in the composition of the base metal and the filler metal influence the results which may be obtained. When these variables are properly controlled, however, the filler metal shall give sound welds whose strengths (determined by all-weld-metal tension tests) will meet or exceed the minimums shown in AWS A5.7 Table A1. Typical hardness properties are also included in AWS A5.7 Table A1. When supplementary tests for mechanical properties are specified, the procedures should be in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. The system for identifying the filler metal classification in this specification follows the standard pattern used in other AWS filler metal specifications. The letters ER at the beginning of a classification indicate that the bare filler metal may be used either as an electrode or as a welding rod.

The chemical symbol Cu is used to identify the filler metals as copper-base alloys. The additional chemical symbols, as the Si in ERCuSi, the Sn in ERCuSn, etc., indicate the principal alloying element of each group. Where more than one classification is included in a basic group, the individual classifications in the group are identified by the letters, A, B, C, etc., as in ERCuSn-A. Further subdividing is done by using 1, 2, etc., after the last letter, as the 2 in ERCuAl-2.

Chapter 18

MAGNESIUM ALLOY WELDING FILLER METALS

GUIDE TO THE CHOICE OF FILLER METAL FOR GENERAL PURPOSE WELDING

Base Metal	Base Metal[c]											
	AM100A	**AZ10A**	**AZ31B AZ31C**	**AZ61A**	**AZ63A**	**AZ80A**	**AZ81A**	**Z91C**	**AZ92A**	**EK41A**	**EZ33A**	**HK31A**
	Filler Metal[a,b]											
AM100A	AZ101A AZ92A	-	-	-	-	-	-	-	-	-	-	-
AZ10A	AZ92A	AZ61A AZ92A	-	-	-	-	-	-	-	-	-	-
AZ31B AZ31C	AZ92A	AZ61A AZ92A	AZ61A AZ92A	-	-	-	-	-	-	-	-	-
AZ61A	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A	-	-	-	-	-	-	-	-
AZ63A	c	c	c	c	AZ101A AZ92A	-	-	-	-	-	-	-
AZ80A	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A	c	AZ61A AZ92A	-	-	-	-	-	-
AZ81A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ61A AZ92A	-	-	-	-	-
AZ91C	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ101A AZ92A	-	-	-	-
AZ92A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ101A	-	-	-
EK41A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	-	-
EZ33A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	-
HK31A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
HM21A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
HM31A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A

Chapter 19

NICKEL & NICKEL ALLOY WELDING FILLER METALS

AWS A5.11 CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

Chemical Composition Requirements for Undiluted Weld Metal

AWS A5.11 Classification	UNS Number[c]	Composition, Weight Percent[a,b]
ENi-1	W82141	C 0.10 Mn 0.75 Fe 0.75 P 0.03 S 0.02 Si 1.25 Cu 0.25 Ni[d] 92.0 min. Al 1.0 Ti 1.0-4.0 Other Elements Total 0.50
ENi-Cu-7	W84190	C 0.15 Mn 4.00 Fe 2.5 P 0.02 S 0.015 Si 1.5 Cu Rem Ni[d] 62.0-69.0 Al 0.75 Ti 1.0 Other Elements Total 0.50
ENiCrFe-1	W86132	C 0.08 Mn 3.5 Fe 11.0 P 0.03 S 0.015 Si 0.75 Cu 0.50 Ni[d] 62.0 min. Cr 13.0-17.0 Cb+Ta 1.5-4.0[f] Other Elements Total 0.50
ENiCrFe-2	W86133	C 0.10 Mn 1.0-3.5 Fe 12.0 P 0.03 S 0.02 Si 0.75 Cu 0.50 Ni[d] 62.0 min. Co[e] Cr 13.0-17.0 Cb+Ta 0.5-3.0[f] Mo 0.50-2.50 Other Elements Total 0.50
ENiCrFe-3	W86182	C 0.10 Mn 5.0-9.5 Fe 10.0 P 0.03 S 0.015 Si 1.0 Cu 0.50 Ni[d] 59.0 min. Co[e] Ti 1.0 Cr 13.0-17.0 Cb+Ta 1.0-2.5[f] Other Elements Total 0.50
ENiCrFe-4	W86134	C 0.20 Mn 1.0-3.5 Fe 12.0 P 0.03 S 0.02 Si 1.0 Cu 0.50 Ni[d] 60.0 min. Cr 13.0-17.0 Cb Plus Ta 1.0-3.5 Mo 1.0-3.5 Other Elements Total 0.50
ENiCrFe-7	W86152	C 0.05 Mn 5.0 Fe 7.0-12.0 P 0.03 S 0.015 Si 0.75 Cu 0.50 Ni[d] Rem Co[e] Al 0.5 Ti 0.5 Cr 28.0-31.5 Cb+Ta 1.0-2.5 Mo 0.5 Other Elements Total 0.50
ENiCrFe-9	W86094	C 0.15 Mn 1.0-4.5 Fe 12.0 P 0.02 S 0.015 Si 0.75 Cu 0.50 Ni[d] 55.0 min Cr 12.0-17.5 Cb+Ta 0.5-3.0 Mo 2.5-5.5 W 1.5 Other Elements Total 0.50
ENiCrFe-10	W86095	C 0.20 Mn 1.0-3.5 Fe 12.0 P 0.02 S 0.015 Si 0.75 Cu 0.50 Ni[d] 55.0 min Cr 13.0-17.0 Cb+Ta 1.0-3.5 Mo 1.0-3.5 W 1.5-3.5 Other Elements Total 0.50
ENiMo-1	W80001	C 0.07 Mn 1.0 Fe 4.0-7.0 P 0.04 S 0.03 Si 1.0 Cu 0.50 Ni[d] Rem Co 2.5 Cr 1.0 Mo 26.0-30.0 V 0.60 W 1.0 Other Elements Total 0.50
ENiMo-3	W80004	C 0.12 Mn 1.0 Fe 4.0-7.0 P 0.04 S 0.03 Si 1.0 Cu 0.50 Ni[d] Rem Co 2.5 Cr 2.5-5.5 Mo 23.0-27.0 V 0.60 W 1.0 Other Elements Total 0.50
ENiMo-7	W80665	C 0.02 Mn 1.75 Fe 2.0 P 0.04 S 0.03 Si 0.2 Cu 0.50 Ni[d] Rem Co 1.0 Cr 1.0 Mo 26.0-30.0 W 1.0 Other Elements Total 0.50

TYPICAL WELD METAL TENSILE STRENGTHS[a]

AWS A5.14	ASME Section IX		TYPICAL WELD METAL TENSILE STRENGTHS	
Classification	**SFA-No.**	**F-No.**	**psi**	**MPa**
ERNiCrMo-8	SFA-5.14	45	85,000	590
ERNiCrMo-9	SFA-5.14	45	85,000	590
ERNiCrMo-10	SFA-5.14	44	100,000	690
ERNiCrMo-11	SFA-5.14	45	85,000	590
ERNiCrMo-13	SFA-5.14	44	110,000	760
ERNiCrMo-14	SFA-5.14	44	110,000	760
ERNiCrMo-15	SFA-5.14	---	174,000[e]	1200[e]
ERNiCrCoMo-1	SFA-5.14	43	90,000	620
ERNiCrWMo-1	SFA-5.14	44	110,000	760

a. Tensile strength in as-welded condition unless otherwise specified.
b. Age hardened condition: heat to 1475°F (802°C) for 2 hours plus 1100°F (593°C) for 16 hours, furnace cool at 25°F per hour to 900°F (482°C), then air cooled.
c. Age hardened condition: heat to 1950°F (1066°C) for 2 hours plus 1300°F (704°C) for 20 hours, then air cooled.
d. Age hardened condition: heat to 1325°F (718°C) for 8 hours, furnace cooled to 1150°F (620°C) at 100°F (56°C) per hour, held for 8 hours, then air cooled.
e. Age hardened condition: heat to 1900°F (1038°C) for 1 hours plus 1350°F (732°C) for 8 hours, then furnace cooled at 100°F (56°C) per hour to 1150°F (621°C) and held for 8 hours, then air cooled.

AWS A5.14 CLASSIFICATION SYSTEM

The system for classifying the filler metals in this specification follows the standard pattern used in other AWS filler metal specifications. The letter "ER" at the beginning of each classification designation stands for electrode and rod, indicating that the filler metal may be used either way.

Since the filler metals are classified according to their chemical composition, the chemical symbol "Ni" appears right after the "ER" as a means of identifying the filler metals as nickel-base alloys. The other symbols (Cr, Cu, Fe, and Mo) in the designations are intended to group the filler metals according to their principal alloying elements. The individual designations are made up of these symbols and a number at the end of the designation (ERNiMo-1 and ERNiMo-2, for example). These numbers separate one composition from another within a group and are not repeated within that group.

Chapter

20

TITANIUM & TITANIUM ALLOY WELDING FILLER METALS

CHEMICAL COMPOSITION REQUIREMENTS FOR TITANIUM AND TITANIUM ALLOY ELECTRODES AND RODS

d. Residual elements, total, shall not exceed 0.20 percent, with no single such element exceeding 0.05 percent. Residual elements need not be reported unless a report is specifically required by the purchaser. Residual elements are those elements (other than titanium) that are not listed in this table for the particular classification, but which are inherent in the raw material or the manufacturing practice. Residual elements can be present only in trace amounts and they cannot be elements that have been intentionally added to the product.

e. SAE/ASTM Unified Numbering System for Metals and Alloys.

SPECIFICATION CROSS INDEX[a]

AWS A5.16 Classification		ASME Section IX		Aerospace Materials	Military	ASTM/ASME
Current (1990)	**1970**	**SFA-No.**	**F-No.**	**Specification (AMS)**	**Specification (MIL)**	**Grades**
ERTi-1	ERTi-1	SFA-5.16	51	4951	MIL-R-81558	1
ERTi-2	ERTi-2	SFA-5.16	51	-	MIL-R-81558	2
ERTi-3	ERTi-3	SFA-5.16	51	-	MIL-R-81558	3
ERTi-4	ERTi-4	SFA-5.16	51	-	MIL-R-81558	4
ERTi-5	ERTi-6Al-4V	SFA-5.16	55	4954	-	5
ERTi-5ELI	ERTi-6Al-4V-1	SFA-5.16	55	4956	MIL-R-81558	-
ERTi-6	ERTi-5Al-2.5Sn	SFA-5.16	55	4953	-	6
ERTi-6ELI	ERTi-5Al-2.5Sn-1	SFA-5.16	55	-	MIL-R-81558	-
ERTi-7	ERTi-0.2Pd	SFA-5.16	52	-	-	7
ERTi-9	ERTi-3Al-2.5V	SFA-5.16	53	-	-	9
ERTi-9ELI	ERTi-3Al-2.5V-1	SFA-5.16	53	-	-	-
ERTi-12	ERTi-0.8Ni-0.3Mo	SFA-5.16	54	-	-	12
ERTi-15	ERTi-6Al-2Cb1Ta-1Mo	SFA-5.16	55	-	MIL-R-81558	-

a. Specifications are not exact duplicates. Information is supplied only for general comparison.

Chapter 21

TUNGSTEN & TUNGSTEN ALLOY WELDING FILLER METALS

AWS A5.12 CHEMICAL COMPOSITION REQUIREMENTS FOR ELECTRODES[a]

CHEMICAL COMPOSITION REQUIREMENTS FOR ELECTRODES[a]		
AWS A5.12 Classification	**UNS Number[b]**	**Composition, Weight Percent**
EWP	R07900	W min. (difference)[c] 99.5 Other oxides or elements total 0.5
EWCe-2	R07932	W min. (difference)[c] 97.3 CeO_2 1.8-2.2 Other oxides or elements total 0.5
EWLa-1	R07941	W min. (difference)[c] 98.3 La_2O_3 0.8-1.2 Other oxides or elements total 0.5
EWLa-1.5	R07942	W min. (difference)[c] 97.8 La_2O_3 1.3-1.7 Other oxides or elements total 0.5
EWLa-2	R07943	W min. (difference)[c] 97.3 La_2O_3 1.8-2.2 Other oxides or elements total 0.5
EWTh-1	R07911	W min. (difference)[c] 98.3 $ThO_2$0.8-1.2 Other oxides or elements total 0.5
EWTh-2	R07912	W min. (difference)[c] 97.3 ThO_2 1.7-2.2 Other oxides or elements total 0.5
EWZr-1	R07920	W min. (difference)[c] 99.1 ZrO_2 0.15-0.40 Other oxides or elements total 0.5
EWG[d]	---	W min. (difference)[c] 94.5 CeO_2, La_2O_3, ThO_2, ZrO_2 Not specified Other oxides or elements total 0.5

a. The electrode shall be analyzed for the specific oxides for which values are shown in this table. If the presence of other elements or oxides is indicated in the course of this work, the amount of those elements or oxides shall be determined to ensure that their total does not exceed the limit specified for "Other oxides or elements total".

b. SAE/ASTM Unified Numbering System for Metals and Alloys.

c. Tungsten content shall be determined by subtracting the total of all specified oxides and other oxides and elements from 100%.

d. Classification EWG must contain some compound or element additive and the manufacturer must identify the type and nominal content of the additive on the packaging.

Chapter 22

ZIRCONIUM & ZIRCONIUM ALLOY WELDING FILLER METALS

AWS A5.24 CHEMICAL COMPOSITION REQUIREMENTS FOR ZIRCONIUM AND ZIRCONIUM ELECTRODES AND RODS

CHEMICAL COMPOSITION REQUIREMENTS FOR ZIRCONIUM AND ZIRCONIUM ELECTRODES AND RODS				
AWS A5.24 Classification	**UNS Number[b]**	**ASME Section IX**		
		SFA-No.	**F-No.**	**Composition, Weight Percent[a]**
ERZr2	R60702	SFA-5.24	61	Zr + Hf 99.01 min Hf 4.5 Fe + Cr 0.20 O 0.016 H 0.005 N 0.025 C 0.05
ERZr3	R60704	SFA-5.24	61	Zr + Hf 97.5 min Hf 4.5 Fe + Cr 0.20 to 0.40 Sn 1.00 to 2.00 O 0.016 H 0.005 N 0.025 C 0.05
ERZr4	R60705	SFA-5.24	61	Zr + Hf 95.5 min Hf 4.5 Fe + Cr 0.20 O 0.016 H 0.005 N 0.025 C 0.05 Cb 2.0 to 3.0

a. Single values are maximum, except as noted.
b. SAE/ASTM Unified Numbering System for Metals and Alloys.
c. Analysis of the interstitial elements C, O, H and N shall be conducted on samples of filler metal taken after the filler meal has been reduced to its final diameter and all processing operations have been completed. Analysis of the other elements may be conducted on these same samples or it may have been conducted on samples taken from the ingot or the rod stock from which the filler metal is made. In case of dispute, samples from the finished filler metal shall be the referee method.7

AWS A5.24 CLASSIFICATION SYSTEM

The system of classification is similar to that used in other filler metal specifications. The letter "E" at the beginning of each designation indicates a welding electrode, and the letter "R" indicates a welding rod. Since these filler metals are used as welding electrodes in gas metal arc welding and as welding rods in gas tungsten arc welding, both letters are used.

The letters "Zr" indicate that the filler metals have a zirconium base. The digits and letters that follow provide a means for identifying the nominal composition of the filler metal.

Chapter 23

SOLID & COMPOSITE SURFACING FILLER METALS

AWS A5.13 CHEMICAL REQUIREMENTS FOR BARE SURFACING WELDING RODS AND ELECTRODES[d]

CHEMICAL COMPOSITION REQUIREMENTS FOR IRON BASE SURFACING ELECTRODES[a]

AWS A5.13 Classification	ASME Section IX		Composition, Weight Percent[b, c, d, e]										
	SFA-No.	F-No.	C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb (Cb)	Fe
EFe1	SFA-5.13	71	0.04-0.20	0.5-2.0	1.0	0.5-3.5	---	1.5	---	---	---	---	Rem
EFe2	SFA-5.13	71	0.10-0.30	0.5-2.0	1.0	1.8-3.8	1.0	1.0	0.35	---	---	---	Rem
EFe3	SFA-5.13	71	0.50-0.80	0.5-1.5	1.0	4.0-8.0	---	1.0	---	---	---	---	Rem
EFe4	SFA-5.13	71	1.0-2.0	0.5-2.0	1.0	3.0-5.0	---	---	---	---	---	---	Rem
EFe5	SFA-5.13	71	0.30-0.80	1.5-2.5	0.9	1.5-3.0	---	---	---	---	---	---	Rem
EFe6	SFA-5.13	71	0.6-1.0	0.4-1.0	1.0	3.0-5.0	---	7.0-9.5	0.5-1.5	0.5-1.5	---	---	Rem
EFe7	SFA-5.13	71	1.5-3.0	0.5-2.0	1.5	4.0-8.0	---	1.0	---	---	---	---	Rem
EFeMn-A	SFA-5.13	71	0.5-1.0	12-16	1.3	---	2.5-5.0	---	---	---	---	---	Rem
EFeMn-B	SFA-5.13	71	0.5-1.0	12-16	1.3	---	---	0.5-1.5	---	---	---	---	Rem
EFeMn-C	SFA-5.13	71	0.5-1.0	12-16	1.3	2.5-5.0	2.5-5.0	---	---	---	---	---	Rem
EFeMn-D	SFA-5.13	71	0.5-1.0	15-20	1.3	4.5-7.5	---	---	0.4-1.2	---	---	---	Rem
EFeMn-E	SFA-5.13	71	0.5-1.0	15-20	1.3	3.0-6.0	1.0	---	---	---	---	---	Rem
EFeMn-F	SFA-5.13	71	0.8-1.2	17-21	1.3	3.0-6.0	1.0	---	---	---	---	---	Rem
EFeMnCr	SFA-5.13	71	0.25-0.75	12-18	1.3	13-17	0.5-2.0	2.0	1.0	---	---	---	Rem
EFeCr-A1A	SFA-5.13	71	3.5-4.5	4.0-6.0	0.5-2.0	20-25	---	0.5	---	---	---	---	Rem
EFeCr-A2	SFA-5.13	71	2.5-3.5	0.5-1.5	0.5-1.5	7.5-9.0	---	---	---	---	1.2-1.8	---	Rem
EFeCr-A3	SFA-5.13	71	2.5-4.5	0.5-2.0	1.0-2.5	14-20	---	1.5	---	---	---	---	Rem
EFeCr-A4	SFA-5.13	71	3.5-4.5	1.5-3.5	1.5	23-29	---	1.0-3.0	---	---	---	---	Rem
EFeCr-A5	SFA-5.13	71	1.5-2.5	0.5-1.5	2.0	24-32	4.0	4.0	---	---	---	---	Rem
EFeCr-A6	SFA-5.13	71	2.5-3.5	0.5-1.5	1.0-2.5	24-30	---	0.5-2.0	---	---	---	---	Rem
EFeCr-A7	SFA-5.13	71	3.5-5.0	0.5-1.5	0.5-2.5	23-30	---	2.0-4.5	---	---	---	---	Rem
EFeCr-A8	SFA-5.13	71	2.5-4.5	0.5-1.5	1.5	30-40	---	2.0	---	---	---	---	Rem

Chapter 24

CONSUMABLE INSERTS

AWS A5.30 CHEMICAL COMPOSITION PERCENT – CARBON STEEL

CHEMICAL COMPOSITION PERCENT – CARBON STEEL			
	AWS A5.30 Classification	**UNS Number[c]**	**Composition, Weight Percent[a,b]**
Group A	INMs1	K10726	C 0.07 Mn 0.90 to 1.40 P 0.025 S 0.035 Si 0.40 to 0.70 Al 0.05[d] to 0.15 Zr 0.02[d] to 0.12 Ti 0.05[d] to 0.15
	INMs2	K01313	C 0.06 to 0.15 Mn 0.90 to 1.40 P 0.025 S 0.035 Si 0.45 to 0.70
	INMs3	K11140	C 0.07 to 0.15 Mn 1.40 to 1.85 P 0.025 S 0.035 Si 0.80 to 1.15

a. The consumable insert shall be analyzed for the specific elements for which values are shown in the table.
b. Single values are maximum
c. SAE/ASTM Unified Numbering System for Metals and Alloys. d. Al + Zr + Ti = 0.15 minimum.

CHEMICAL COMPOSITION – CHROMIUM-MOLYBDENUM STEELS			
	AWS A5.30 Classification	**UNS Number[c]**	**Composition, Weight Percent[a,b]**
Group B	IN502	S50280	C 0.10 Mn 0.40 to 0.75 P 0.025 S 0.025 Si 0.25 to 0.50 Al 0.15 Cr 4.5 to 6.0 Mo 0.45 to 0.65, Ni 0.6 Cu 0.25 Fe rem
	IN515	K20900	C 0.07-0.12 Mn 0.40 to 0.70 P 0.025 S 0.025 Si 0.40 to 0.70 Al 0.15 Cr 1.20 to 1.50 Mo 0.40 to 0.65 Ni 0.20 Cu 0.35 Fe rem Total Other Elements 0.50
	IN521	K30960	C 0.07-0.12 Mn 0.40 to 0.70 P 0.025 S 0.025 Si 0.40 to 0.70 Al 0.15 Cr 2.30 to 2.70 Mo 0.90 to 1.20 Ni 0.20 Cu 0.35 Fe rem Total Other Elements 0.50

a. The consumable insert shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last item of the table.
b. Singles values are maximum.
c. SAE/ASTM Unified Numbering System for Metals and Alloys.
rem: remainder

Chapter 25

BRAZING FILLER METALS & FLUXES

AWS A5.8 CHEMICAL COMPOSITION REQUIREMENTS FOR SILVER FILLER METALS

CHEMICAL COMPOSITION REQUIREMENTS FOR SILVER FILLER METALS		
AWS A5.8 Classification	**UNS Number[a]**	**Composition, Weight Percent**
BAg-1	P07450	Ag 44.0-46.0 Cu 14.0-16.0 Zn 14.0-18.0 Cd 23.0-25.0 Other Elements Total[b] 0.15
BAg-1a	P07500	Ag 49.0-51.0 Cu 14.5-16.5 Zn 14.5-18.5 Cd 17.0-21.0 Other Elements Total[b] 0.15
BAg-2	P07350	Ag 34.0-36.0 Cu 25.0-27.0 Zn 19.0-23.0 Cd 17.0-21.0 Other Elements Total[b] 0.15
BAg-2a	P07300	Ag 29.0-31.0 Cu 26.0-28.0 Zn 21.0-25.0 Cd 19.0-21.0 Other Elements Total[b] 0.15
BAg-3	P07501	Ag 49.0-51.0 Cu 14.5-16.5 Zn 13.5-17.5 Cd 15.0-17.0 Ni 2.5-3.5 Other Elements Total[b] 0.15
BAg-4	P07400	Ag 39.0-41.0 Cu 29.0-31.0 Zn 26.0-30.0 Ni 1.5-2.5 Other Elements Total[b] 0.15
BAg-5	P07453	Ag 44.0-46.0 Cu 29.0-31.0 Zn 23.0-27.0 Other Elements Total[b] 0.15
BAg-6	P07503	Ag 49.0-51.0 Cu 33.0-35.0 Zn 14.0-18.0 Other Elements Total[b] 0.15
BAg-7	P07563	Ag 55.0-57.0 Cu 21.0-23.0 Zn 15.0-19.0 Sn 4.5-5.5 Other Elements Total[b] 0.15
BAg-8	P07720	Ag 71.0-73.0 Cu Remainder Other Elements Total[b] 0.15
BAg-8a	P07723	Ag 71.0-73.0 Cu Remainder Li 0.25-0.50 Other Elements Total[b] 0.15
BAg-9	P07650	Ag 64.0-66.0 Cu 19.0-21.0 Zn 13.0-17.0 Other Elements Total[b] 0.15
BAg-10	P07700	Ag 69.0-71.0 Cu 19.0-21.0 Zn 8.0-12.0 Other Elements Total[b] 0.15
BAg-13	P07540	Ag 53.0-55.0 Cu Remainder Zn 4.0-6.0 Ni 0.5-1.5 Other Elements Total[b] 0.15
BAg-13a	P07560	Ag 55.0-57.0 Cu Remainder Ni 1.5-2.5 Other Elements Total[b] 0.15
BAg-18	P07600	Ag 59.0-61.0 Cu Remainder Sn 9.5-10.5 Other Elements Total[b] 0.15
BAg-19	P07925	Ag 92.0-93.0 Cu Remainder Li 0.15-0.30 Other Elements Total[b] 0.15
BAg-20	P07301	Ag 29.0-31.0 Cu 37.0-39.0 Zn 30.0-34.0 Other Elements Total[b] 0.15
BAg-21	P07630	Ag 62.0-64.0 Cu 27.5-29.5 Ni 2.0-3.0 Sn 5.0-7.0 Other Elements Total[b] 0.15
BAg-22	P07490	Ag 48.0-50.0 Cu 15.0-17.0 Zn 21.0-25.0 Ni 4.0-5.0 Mn 7.0-8.0 Other Elements Total[b] 0.15

AWS A5.31 CLASSIFICATION SYSTEM

The system for identifying the flux classifications in this specification is based on three factors: applicable base metal, applicable filler metal, and activity temperature range. The letters FB at the beginning of each classification designation stands for "Flux for Brazing or Braze Welding". The third character is a number that stands for a group of applicable base metals. The fourth character, a letter, designates a change in form and attendant composition within the broader base metal classification.

Chapter 26

WELDING SHIELDING GASES

AWS A5.32/A5.32M WELDING SHIELDING GASES

GAS TYPE, PURITY, AND DEW POINT REQUIREMENTS FOR SHIELDING GAS COMPONENTS							
			Minimum	Maximum	Dew Point Maximum Moisture at 1 Atmosphere		
Gas	AWS Classification	Product State	Purity (percent)	Moisture[a] (ppm)	°F	°C	CGA Class
Argon	SG-A	Gas	99.997	10.5	-76	-60	Type I, G-11.1 Grade C
		Liquid	99.997	10.5	-76	-60	Type II, G-11.1 Grade C
Carbon Dioxide	SG-C	Gas	99.8	32	-60	-51	G-6.2, Grade H
		Liquid	99.8	32	-60	-51	
Helium	SG-He	Gas	99.995	15	-71	-57	Type I, G-9.1 Grade L
		Liquid	99.995[b]	15	-71	-57	Type II, G-9.1 Grade L
Hydrogen	SG-H	Gas	99.95	32	-60	-51	Type I, G-5.3 Grade B
		Liquid	99.995[c]	32	-60	-51	Type II, G-5.3 Grade A
Nitrogen	SG-N	Gas	99.9	32	-60	-51	Type I, G-10.1 Grade F
		Liquid	99.998	4	-90	-68	Type II, G-10.1 Grade L
Oxygen	SG-O	Gas	99.5	50 ppm	-54	-48	Type I, G-4.3 Grade C
		Liquid	99.5	6.6 ppm	-82	-63	Type II, G-4.3 Grade B

a. Moisture specifications are guaranteed at full cylinder pressure, at which the cylinder is analyzed.
b. Including neon.
c. Including helium.

Chapter 27

LIST OF INTERNATIONAL FILLER METAL STANDARDS

AMERICAN AWS - FILLER METAL SPECIFICATIONS	
AWS	**Title**
A5.01	Filler Metal Procurement Guidelines
A5.1	Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding
A5.2	Specification for Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding
A5.3	Specification for Aluminum and Aluminum Alloy Electrodes for Shielded Metal Arc Welding
A5.4	Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding
A5.5	Specification for Low Alloy Steel Covered Arc Welding Electrodes
A5.6	Specification for Covered Copper and Copper Alloy Arc Welding Electrodes
A5.7	Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes
A5.8	Specification for Filler Metals for Brazing and Braze Welding
A5.9	Specification for Bare Stainless Steel Welding Electrodes and Rods
A5.10	Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods
A5.11	Specification for Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding
A5.12	Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting
A5.13	Specification for Solid Surfacing Welding Rods and Electrodes
A5.14	Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods
A5.15	Specification for Welding Electrodes and Rods for Cast Iron
A5.16	Specification for Titanium and Titanium Alloy Welding Electrodes and Rods
A5.17	Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
A5.18	Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding
A5.19	Specification for Magnesium Alloy Welding Electrodes and Rods
A5.20	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
A5.21	Specification for Composite Surfacing Welding Rods and Electrodes
A5.22	Specification for Flux Cored Corrosion-Resisting Chromium and Chromium-Nickel Steel Electrodes
A5.23	Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
A5.24	Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods
A5.25	Specification for Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding
A5.26	Specification for Carbon and Low Alloy Steel Electrodes for Electrogas Welding

Chapter 28

EUROPEAN DATA (EN) CARBON & LOW ALLOY STEEL FILLER METALS

EN 499 COVERED ELECTRODES FOR MANUAL METAL ARC WELDING OF NON ALLOY AND FINE GRAIN STEELS

EN 499 – SYMBOL FOR CHEMICAL COMPOSITION OF ALL-WELD METAL

Alloy Symbol	Chemical Composition[a,b,c]
No symbol	Mn 2,0
Mo	Mn 1,4 Mo 0,3-0,6
MnMo	Mn > 1,4-2,0 Mo 0,3-0,6
1Ni	Mn 1,4 Ni 0,6-1,2
2Ni	Mn 1,4 Ni 1,8-2,6
3Ni	Mn 1,4 Ni > 2,6-3,8
Mn1Ni	Mn > 1,4-2,0 Ni 0,6-1,2
1NiMo	Mn 1,4 Mo 0,3-0,6 Ni 0,6-1,2
Z	Any other agreed composition

a. If not specified Mo < 0,2, Ni < 0,3, Cr < 0,2, V < 0,05, Nb < 0,05, Cu < 0,3.
b. Single values shown in the table mean maximum values.
c. The results shall be rounded to the same number of significant figures as in the specified value using the rules according to ISO 31-0, annex B Rule A.

EN 499 – SYMBOL FOR STRENGTH AND ELONGATION OF ALL-WELD METAL

Symbol	Minimum Yield Strength[a], N/mm^2	Tensile Strength, N/mm^2	Minimum Elongation[b] ,%
35	355	440 – 570	22
38	380	470 – 600	20
42	420	500 – 640	20
46	460	530 – 680	20
50	500	560 – 720	18

a. For yield strength the lower yield (R_{eL}) shall be used when yielding occurs, otherwise the 0,2 % proof strength ($R_{po,2}$) shall be used.
b. Gauge length is equal to five times the specimen diameter.

EN 499 – SYMBOL FOR IMPACT PROPERTIES OF ALL-WELD METAL	
Symbol	**Temperature for minimum average impact energy of 47 J°C**
Z	No requirement
A	+ 20
0	0
2	- 20
3	- 30
4	- 40
5	- 50
6	- 60

EN 499 – SYMBOL FOR TYPE OF ELECTRODE COVERING

A = acid covering
C = cellulosic covering
R = rutile covering
RR = rutile thick covering
RC = rutile-cellulosic covering
RA = rutile-acid covering
RB = rutile-basic covering
B = basic covering

EN 499 – DESIGNATION SYSTEM

A covered electrode for manual metal arc welding deposits a weld metal with a minimum yield strength of 460 N/mm^2 (46) and a minimum average impact energy of 47 J at –30 ^{o}C (3) and a chemical composition of 1,1 % Mn and 0,7 % Ni (1Ni). The electrode with basic covering (B) and a metal recovery of 140 % may be used with a.c. and d.c. (5) in flat butt and flat fillet welds (4).

Hydrogen is determined according to ISO 3690 and does not exceed 5 ml/100 g deposited weld metal (H5).

The designation will be:

EN 499 – E 46 3 1Ni B 54 H5

Compulsory section:

EN 499 – E 46 3 1Ni B

where:

EN 499	=	Standard number
E	=	Covered electrode/manual metal arc welding
46	=	Strength and elongation
3	=	Impact properties
1Ni	=	Chemical composition of all-weld metal
B	=	Type of electrode covering
5	=	Recovery and type of current
4	=	Welding position
H5	=	Hydrogen content

Chapter 29

EUROPEAN DATA (EN) STAINLESS STEEL WELDING FILLER METALS

EN 1600 COVERED ELECTRODES FOR MANUAL METAL ARC WELDING OF STAINLESS AND HEAT RESISTING STEELS

EN 1600 – SYMBOL FOR CHEMICAL COMPOSITION OF ALL-WELD METAL	
Alloy Symbol	**Chemical Composition[a,b,c]**
Martensitic/Ferritic	
13	C 0,12 Si 1,0 Mn 1,5 P 0,030[d] S 0,25[d] Cr 11,0-14,0
13 4	C 0,06 Si 1,0 Mn 1,5 P 0,030[d] S 0,25[d] Cr 11,0-14,5 Ni 3,0-5,0[e] Mo 0,4-1,0[e]
17	C 0,12 Si 1,0 Mn 1,5 P 0,030[d] S 0,25[d] Cr 16,0-18,0
Austenitic	
19 9	C 0,08 Si 1,2 Mn 2,0 P 0,030[d] S 0,025[d] Cr 18,0-21,0 Ni 9,0-11.0[e]
19 9 L	C 0,04 Si 1,2 Mn 2,0 P 0,030[d] S 0,025[d] Cr 18,0-21,0 Ni 9,0-11.0[e]
19 9 Nb	C 0,08 Si 1,2 Mn 2,0 P 0,030[d] S 0,025[d] Cr 18,0-21,0 Ni 9,0-11,0[e] Other Nb[f]
19 12 2	C 0,08 Si 1,2 Mn 2,0 P 0,030[d] S 0,025[d] Cr 17,0-20,0 Ni 10,0-13,0[e] Mo 2,0-3,0[e]
19 12 3 L	C 0,04 Si 1,2 Mn 2,0 P 0,030[d] S 0,025[d] Cr 17,0-20,0 Ni 10,0-13,0[e] Mo 2,5-3,0[e]
19 12 3 Nb	C 0,08 Si 1,2 Mn 2,0 P 0,030[d] S 0,025[d] Cr 17,0-20,0 Ni 10,0-13,0[e] Mo 2,5-3,0[e] Other Nb[f]
19 13 4 N L[g]	C 0,04 Si 1,2 Mn 1,0-5,0 P 0,030[d] S 0,025[d] Cr 17,0-20,0 Ni 12,0-15,0[e] Mo 3,0-4,5[e] Other 0,20 N[e]
Austenitic-Ferritic. High Corrosion Resistance	
22 9 3 N L[h]	C 0,04 Si 1,2 Mn 2,5 P 0,030[d] S 0,025[d] Cr 21,0-24,0 Ni 7,5-10,5[e] Mo 2,5-4,0[e] Other 0,08-0,20 N[e]
25 7 2 N L[h]	C 0,04 Si 1,2 Mn 2,0 P 0,035[d] S 0,025[d] Cr 24,0-28,0 Ni 6,0-8,0[e] Mo 1,0-3,0[e] Other 0,20 N[e]
25 9 3 Cu N L[h]	C 0,04 Si 1,2 Mn 2,5 P 0,030[d] S 0,025[d] Cr 24,0-27,0 Ni 7,5-10,5[e] Mo 2,5-4,0[e] Other 0,10-0,25 N[e]; 1,5-3,5 Cu[e]
25 9 4 N L[h]	C 0,04 Si 1,2 Mn 2,5 P 0,030[d] S 0,025[d] Cr 24,0-27,0 Ni 8,0-10,5[e] Mo 2,5-4,5[e] Other 0,20-0,30 N[e]; 1,5 Cu; 1,0 M[e]
Fully Austenitic. High Corrosion Resistance	
18 15 3 L[g]	C 0,04 Si 1,2 Mn 1,0-4,0 P 0,030[d] S 0,025[d] Cr 16,5-19,5 Ni 14,0-17,0[e] Mo 2,5-3,5[e]
18 16 5 N L[f]	C 0,04 Si 1,2 Mn 1,0-4,0 P 0,035[d] S 0,025[d] Cr 17,0-20,0 Ni 15,5-19,0[e] Mo 3,5-5,0[e] Other 0,20 N[e]

EN 1600 – SYMBOL FOR TYPE OF ELECTRODE COVERING

Two symbols are used to describe the type of covering:

R - Rutile covering
B - Basic covering

EN 1600 – SYMBOL FOR WELD METAL RECOVERY AND TYPE OF CURRENT

Symbol	Weld Metal Recovery	Type of Current[a,b]
1	≤ 105	a.c. and d.c.
2	≤ 105	d.c.
3	> 105 ≤ 125	a.c. and d.c.
4	> 105 ≤ 125	d.c.
5	> 125 ≤ 160	a.c. and d.c.
6	> 125 ≤ 160	d.c.
7	> 160	a.c. and d.c.
8	> 160	d.c.

a. In order to demonstrate operability on alternating current, tests shall be carried out with a no load voltge not higher than 65 V.
b. a.c. means alternating current; d.c. means direct current.

EN 1600 – DESIGNATION SYSTEM

A covered electrode for manual metal arc welding deposits weld metal with a chemical composition 19 % Cr, 10 % Ni and 2 % Mo (19 12 2). The electrode has a rutile covering (R) and can be used with alternating current or direct current and with a metal recovery of 120 % (3) in flat butt and flat fillet welds (4).

The designation will be:

Covered electrode EN 1600 - E 19 12 2 R 3 4

Compulsory section:

Covered electrode EN 1600 - E 19 12 2 R

where:

EN 1600 = Standard number
E = Covered electrode/manual metal arc welding
19 12 2 = Chemical composition of all-weld metal
R = Type of electrode covering
3 = Recovery and type of current
4 = Welding position

Chapter 30

INTERNATIONAL FILLER METAL CROSS REFERENCES

CARBON STEEL FLUX CORED WIRES									
ISO		USA AWS		Canada CSA	Australia AS	China GB/T	Japan JIS	Russia GOST	Europe CEN
17632-A[a]	17632-B	A5.20[b]	A5.20M	W48[c]	2203.1[d]	10045[b]	Z3313[e]	26271[f]	EN 758[a]
T35 x R y	T43xT1-zy	---	---	---	TP GypW40x	---	YFW-y43xR	ЛЛ34x	T35 x R y
T3T Z R y	T43T2-zy	---	---	---	TDSGypW400	---	YFW-S43xR	---	T3T Z R y
T3T Z V N	T43T3-zN	---	---	---	TDSN pW400	---	YFW-S43xG	ЛС34x	T3T Z V N
T35 x W N	T43xT4-zN	---	---	---	TD N Pw400	---	---	---	T35 x W N
T35 x B y	T43xT5-zy	---	---	---	TP GypW40x	---	YFW-y43xB	ЛЛ34x	T35 x B y
T35 x W N	T43xT6-zN	---	---	---	TD N pW40x	---	YFW-S43xG	ЛС34x	T35 x W N
T35 x W N	T43xT7-zN	---	---	---	TP N nW40x	---	---	---	T35 x W N
T35 x Y N	T43xT8-zN	---	---	---	TP N nW40x	---	---	---	T35 x Y N
T3T Z V N	T43T10-zN	---	---	---	TDSN nW400	---	YFW-S43xG	---	T3T Z V N
T35 x W N	T43xT11-zN	---	---	---	TP N nW40x	---	---	---	T35 x W N
T35 x R y	T43xT12-zy	---	---	---	TP GypW40x	---	YFW-y43xG	ЛЛ34x	T35 x R y
T3T Z V N	T43T13-zN	---	---	---	TPSN nW400	---	YFW-S43xG	ЛС34x	T3T Z V N
T3T Z V N	T43T14-zN	---	---	---	TPSN nW400	---	---	---	T3T Z V N
T35 x M y	T43xT15-zy	---	---	---	TPGMpW40x	---	YFW-y43xM	---	T35 x M y
T42 x R y	T492T1-zy	E7zT-1y	E49zT-1y	E49zT-1y	TP GypW50x	E50xT-1, E50xT-1M	YFW-y50xR	ЛЛ39x	T42 x R y
T4T x R N	T49T2-zy	E70T-2y	E490T-2y	E492T-2y	TDSGypW500	E50xT-2, E50xT-2M	---	---	T4T x R N
T4T Z V N	T49T3-zN	E70T-3	E490T-3	E492T-3	TDSN pW500	E50xT-3	YFW-S50GG	ЛС39x	T4T Z V N
T42 x W N	T49xT4-zN	E70T-4	E490T-4	E492T-4	TD N Pw500	E50xT-4	---	---	T42 x W N
T42 x B y	T493T5-zy	E7zT-5y	E49zT-5y	E49zT-5y	TP GypW50x	E50xT-5, E50xT-5M	---	ЛЛ39x	T42 x B y
T42 x Y N	T493T6-zN	E70T-6	E490T-6	E492T-6	TD N pW50x	E50xT-6	---	ЛС39x	T42 x Y N
T42 x W N	T49xT7-zN	E7zT-7	E49zT-7	E49zT-7	TP N nW50x	E50xT-7	---	---	T42 x W N
T42 x Y N	T493T8-zN	E7zT-8	E49zT-8	E49zT-8	TP N nW50x	E50xT-8	---	---	T42 x Y N
---	---	E7zT-9y	E49zT-9y	E492T-9y	---	---	---	---	---
T4T Z V N	T49T10-zN	E70T-10	E490T-10	E492T-10	TDSN nW500	E50xT-10	YFW-S50GG	---	T4T Z V N

LOW ALLOY CREEP RESISTANT STEEL FLUX CORED WIRES (Mn-Mo & Cr-Mo)							
ISO		USA AWS		Australia AS	China GB/T	Japan JIS	Europe CEN
17634 A[a]	17634B[b]	A5.29[c]	A5.29M	2203.1[d]	17493[b]	Z 3318[e]	EN12071[a]
T Mo x y	T55 Tn-zy-2M3	E8xT1-A1	E55xT1-A1	---	E55xTn-A1	---	T Mo x y
T MoL x y	T49 Tn-zy-2M3	E7xT5-A1	E49xT5-A1	---	E50xTn-A1	YFM-x	T MoL x y
T MoV x y	---	---	---	---	---	---	T MoV x y
---	T55 Tn-zy-CM	E8xT1-B1	E55xT1-B1	W550P.B1	E55xTn-B1	YFCM-x	---
---	T55 Tn-zy-CML	E8xT1-B1L	E55xT1-B1L	---	---	---	---
T CrMo1 x y	T55 Tn-zy-1CM	E8xTn-B2	E55xTn-B2	W550P.B2	E55xTn-B2	YF1CM-x	T CrMo1 x y
T CrMo1L x y	T55 Tn-zy-1CML	E8xTn-B2L	E55xTn-B2L	W550P.B2	E55xTn-B2L	---	T CrMo1L x y
---	T55 Tn-zy-1CMH	E8xT1-B2H	E55xT1-B2H	W550P.B2C	E55xTn-B2H	---	---
T CrMo2 x y	T69 Tn-zy-2CIM	E10xTn-B3	E69xTn-B3	W550P.B3	---	YF2CM-x	T CrMo2 x y
T CrMo2L x y	T62 Tn-zy-2CIML	E9xT1-B3L	E62xT1-B3L	W550P.B3L	---	---	T CrMo2L x y
---	T55 Tn-zy-2CIMH	E10xT1-B3H	E69xT1-B3H	W550P.B3C	---	---	---
T CrMo5 x y	T55 Tn-zy-5CM	E8xT5-B6	E55xT5-B6	W550P.5Cr	---	---	T CrMo5 x y
---	T55 Tn-zy-5CML	E8xT5-B6L	E55xT5-B6L	---	---	---	---
---	---	---	---	W550P.7Cr	---	---	---
---	T55 Tn-zy-9C1M	E8xT5-B8	E55xT5-B8	W550P.9Cr	---	---	---
---	T55 Tn-zy-9C1ML	E8xT5-B8L	E55xT5-B8L	---	---	---	---
---	T69 Tn-y-9CMV	E10xT1-B9	E69xT1-B9	---	---	---	---

a. The "x" signifies core ingredients, and "y", shielding gas.
b. See Appendix 1, Flux Cored Wires and Low Alloy Steels as they apply to this table. Tn = 1, 5, or 15 (see Appendix 1, Table A1.2 for usability description).
c. The "x" designates positionality (0 = flat; 1 = all-position). Tn = T1 (rutile) or T5 (basic) with CO_2 gas shielding (no symbol), or argon + CO_2 if designated with "M".
d. Designations shown are based on weld metal classifications. These may be preceded by digits for positionality, shielding gas, and current suitability.
e. The "x" designates shielding gas, "C" = CO_2, "G" not specified.

Chapter
31

GLOSSARY OF WELDING TERMS

The terms and definitions listed in this glossary are consistent with the International Institute of Welding (IIW) terms and essentially agree with the American Welding Society (AWS) definitions and terms.

The first term listed in each group starting on the next page is English (**bold type**), the second term is French (***bold, italic type***) and the third term is Spanish (<u>***bold, italic and underlined type***</u>). Definitions for the English and French terms are provided where possible, however, Spanish term definitions are not provided at this time. The terms/definitions in the following list are arranged in alphabetical order by the English term.

These terms are also listed in Spanish and French alphabetical order following the term/definition section.

Translation of technical terms into various languages is an extremely difficult and complex undertaking and while this information was compiled with great effort and review, the publishers do not warrant its suitability and assume no liability or responsibility of any kind in connection with this information. We encourage all readers to inform *CASTI* Publishing Inc. of technical or language inaccuracies, and/or to offer suggestions for improving this glossary of terms. Your co-operation and assistance in this matter are greatly appreciated.

N

nick break test. A fracture test in which a specimen is broken from a notch cut at a predetermined position where the interior of the weld is to be examined.
essai de texture; essai de compacité. Essai consistant à rompre une éprouvette dans la soudure en y pratiquant une amorce de rupture par trait de scie. On examine les défauts apparents sur la section rompue.
<u>***ensayo de textura***</u>

nondestructive testing. Testing to detect internal, surface and concealed defects or flaws in materials using techniques that do not damage or destroy the items being tested.
essais non destructifs; END; contrôle non destructif; CND. Essai en vue de détecter dans les matériaux des défauts internes, superficiels ou cachés, en mettant en oeuvre des techniques ne provoquant ni endommagement ni destruction des biens soumis à l'essai.
<u>***ensayos no destructivos; control no destructivo CND***</u>

normalizing. Heat treatment consisting of austenitisation followed by cooling in still air.
traitement de normalisation. Traitement thermique comportant une austénitisation suivie d'un refroidissement à l'air calme.
<u>***normalización***</u>

notch sensitivity. A measure of the reduction in strength of a metal caused by the presence of stress concentration. Values can be obtained from static, impact or fatigue tests.
sensibilité à l'entaille. Une mesure de la réduction de la résistance d'un métal causée par la présence de la concentration de contrainte. Les valeurs peuvent être obtenues par des essais statiques, des essais de choc ou des essais de fatigue.
<u>***sensibilidad a la entalla***</u>

O

overhead butt weld
soudure bout à bout au plafond; soudure en bout au plafond
<u>***soldadura a tope sobre techo***</u>

overhead position welding
soudage au plafond
<u>***soldeo sobre techo***</u>

SPANISH	ENGLISH	FRENCH
abertura de la unión	groove	joint
acuerdo; acuerdo del cordón de soldadura	toe of weld	raccordement; raccordement du cordon de soudure; ligne de raccordement
anchura de la soldadura	weld width of a butt weld	largeur de la soudure
anillo soporte	backing ring	bague support; anneau support
baño de fusión	weld pool	bain de fusion
bruto de soldeo	as welded	brut de soudage
cabina de soldeo	welding booth	cabine de soudage
cara a soldar; borde	groove face	face à souder; bord à souder
cara fusible	fusion face.	face à souder par fusion
casco de soldador	welder's helmet	casque de soudeur
cavidad	cavity; void	cavité
cementación	carburisation	cémentation
certificado de cualificación del soldador	welder certification; welder certificate	certificat de qualification de soudeur; licence de soudeur; carte de soudeur
chapa apéndice de ensayo	coupon plate	appendice témoin; coupon d'essai
chispa de soldeo	welding spark	étincelle de soudage
cobresoldeo	braze welding	soudobrasage
conjunto soldado; construcción soldada	weldment	ensemble soudé; construction soudée
consumibles	welding consumables	produits consommables
cordón de metal depositado	bead on plate	cordon déposé; chenille
cordón de penetración	penetration bead	cordon de pénétration
cordón de soldadura	weld bead	cordon de soudure
cordón soporte de raíz	backing weld; support run; backing run	cordon support envers
corrosión debida al soldeo	corrosion due to welding; weld decay	corrosion due au soudage
corte de arco (sobre la pieza)	arc strike; stray flash	coup d'arc (sur la pièce)
cráter	crater	cratère
cualificación de soldadores y del procedimiento operatorio	welding procedure qualification	qualification des soudeurs et du mode opératoire

Appendix 1

WFM INDEX NUMBERS AND DESIGNATORS

Table A1.2 Designators to Define Usability of Flux Cored Wires

DESIGNATORS TO DEFINE USABILITY OF FLUX CORED WIRES						
Usability Designator	**Shielding Gas Required**	**Operating Polarity**	**Transfer of Droplet**	**Type of Core**	**Welding Position**	**Weld Type Single (S) or Multipass (M)**
T1	Yes	DCEP	Spray	Rutile	0 or 1	S and M
T2	Yes	DCEP	Spray	Rutile	0	S
T3	No	DCEP	Globular		0	S
T4	No	DCEP	Globular	Basic	0	S and M
T5	Yes	DCEP	Globular	Lime-fluoride	0 or 1	S and M
T6	No	DCEP	Spray		0	S and M
T7	No	DCEN	Small/Spray		0 or 1	S and M
T8	No	DCEN	Small/Spray		0 or 1	S and M
T10	No	DCEN	Small		0	S
T11	No	DCEN	Spray		0 or 1	S and M
T12	Yes	DCEP	Spray	Rutile	0 or 1	S and M
T13	No	DCEN	Short arc		0 or 1	S
T14	No	DCEN	Spray		0 or 1	S
T15	Yes	DCEP	Fine/Spray	Metal[a]	0 or 1	S and M
Tn	Symbol used in tables when applicable to more than one usability classification					

a. T15 usability classifications in ISO refer to metal-cored tubular wires, which in the WFM system are considered composite rather than flux cored, filler metals with the initial designator “C” as shown by Initial Alpha Designators table. AWS classifications of metal-cored filler metals are listed in tables with solid wires.

Appendix

2

HARDNESS CONVERSION NUMBERS FOR STEELS

APPROXIMATE HARDNESS CONVERSION NUMBERS FOR NONAUSTENITIC STEELS[a, b] (Continued)								
Rockwell C 150 kgf Diamond	**Vickers**	**Brinell 3000 kgf 10mm ball**	**Knoop 500 gf**	**Rockwell A 60 kgf Diamond**	**Rockwell Superficial Hardness 15 kgf Diamond**	**30 kgf Diamond**	**45 kgf Diamond**	**Approximate Tensile Strength**
HRC	**HV**	**HB**	**HK**	**HRA**	**HR15N**	**HR30N**	**HR45N**	**ksi (MPa)**
23	254	243	266	62.0	71.0	44.0	23.1	117 (810)
22	248	237	261	61.5	70.5	43.2	22.0	115 (790)
21	243	231	256	61.0	69.9	42.3	20.7	112 (770)
20	238	226	251	60.5	69.4	41.5	19.6	110 (760)

a. This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

b. 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 nonaustenitic 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.

c. Carbide ball, 10mm.

d. This Brinell hardness value is outside the recommended range for hardness testing in accordance with ASTM E 10.

Appendix
3
UNIT CONVERSIONS

METRIC CONVERSION FACTORS					
To Convert From	**To**	**Multiply By**	**To Convert From**	**To**	**Multiply By**
Angle			**Mass per unit time**		
degree	rad	1.745 329 E -02	lb/h	kg/s	1.259 979 E - 04
Area			lb/min	kg/s	7.559 873 E - 03
in.^{2}	mm^2	6.451 600 E + 02	lb/s	kg/s	4.535 924 E - 01
in.^{2}	cm^2	6.451 600 E + 00	**Mass per unit volume (includes density)**		
in.^{2}	m^2	6.451 600 E - 04	g/cm^3	kg/m^3	1.000 000 E + 03
ft^2	m^2	9.290 304 E - 02	lb/ft^3	g/cm^3	1.601 846 E - 02
Bending moment or torque			lb/ft^3	kg/m^3	1.601 846 E + 01
lbf - in.	N - m	1.129 848 E - 01	lb/in.^{3}	g/cm^3	2.767 990 E + 01
lbf - ft	N - m	1.355 818 E + 00	lb/in.^{3}	kg/m^3	2.767 990 E + 04
kgf - m	N - m	9.806 650 E + 00	**Power**		
ozf - in.	N-m	7.061 552 E - 03	Btu/s	kW	1.055 056 E + 00
Bending moment or torque per unit length			Btu/min	kW	1.758 426 E - 02
lbf - in./in.	N - m/m	4.448 222 E + 00	Btu/h	W	2.928 751 E - 01
lbf - ft/in.	N - m/m	5.337 866 E + 01	erg/s	W	1.000 000 E - 07
Corrosion rate			ft - lbf/s	W	1.355 818 E + 00
mils/yr	mm/yr	2.540 000 E - 02	ft - lbf/min	W	2.259 697 E - 02
mils/yr	µ/yr	2.540 000 E + 01	ft - lbf/h	W	3.766 161 E - 04
Current density			hp (550 ft - lbf/s)	kW	7.456 999 E - 01
A/in.^{2}	A/cm^2	1.550 003 E - 01	hp (electric)	kW	7.460 000 E - 01
A/in.^{2}	A/mm^2	1.550 003 E - 03	**Power density**		
A/ft^2	A/m^2	1.076 400 E + 01	W/in.^{2}	W/m^2	1.550 003 E + 03
Electricity and magnetism			**Pressure (fluid)**		
gauss	T	1.000 000 E - 04	atm (standard)	Pa	1.013 250 E + 05
maxwell	µWb	1.000 000 E - 02	bar	Pa	1.000 000 E + 05

METRIC CONVERSION FACTORS (Continued)					
To Convert From	**To**	**Multiply By**	**To Convert From**	**To**	**Multiply By**
Electricity and magnetism (Continued)			**Pressure (fluid) (Continued)**		
mho	S	1.000 000 E + 00	in. Hg (32 F)	Pa	3.386 380 E + 03
Oersted	A/m	7.957 700 E + 01	in. Hg (60 F)	Pa	3.376 850 E + 03
Ω - cm	Ω - m	1.000 000 E - 02	lbf/in.^{2} (psi)	Pa	6.894 757 E + 03
Ω circular - mil/ft	μΩ - m	1.662 426 E - 03	torr (mm Hg, 0 C)	Pa	1.333 220 E + 02
Energy (impact other)			**Specific heat**		
ft•lbf	J	1.355 818 E + 00	Btu/lb - F	J/kg - K	4.186 800 E + 03
Btu (thermochemical)	J	1.054 350 E + 03	cal/g - C	J/kg - K	4.186 800 E + 03
cal (thermochemical)	J	4.184 000 E + 00	**Stress (force per unit area)**		
kW - h	J	3.600 000 E + 06	tonf/in.^{2} (tsi)	MPa	1.378 951 E + 01
W - h	J	3.600 000 E + 03	kgf/mm^2	MPa	9.806 650 E + 00
Flow rate			ksi	MPa	6.894 757 E + 00
ft^3/h	L/min	4.719 475 E - 01	lbf/in.^{2} (psi)	MPa	6.894 757 E - 03
ft^3/min	L/min	2.831 000 E + 01	N/mm^2	Pa	1.000 000 E + 00
gal/h	L/min	6.309 020 E - 02	**Temperature**		
gal/min	L/min	3.785 412 E + 00	F	C	5/9 (F - 32)
Force			R	K	5/9
lbf	N	4.448 222 E + 00	**Temperature interval**		
kip (1000 lbf)	N	4.448 222 E + 03	F	C	5/9
tonf	kN	8.896 443 E + 00	**Thermal conductivity**		
kgf	N	9.806 650 E + 00	Btu - in./s - ft^2 - F	W/m - K	5.192 204 E + 02
Force per unit length			Btu/ft - h - F	W/m - K	1.730 735 E + 00
lbf/ft	N/m	1.459 390 E + 01	Btu - in./h . ft^2 - F	W/m - K	1.442 279 E - 01
lbf/in.	N/m	1.751 268 E + 02	cal/cm - s - C	W/m - K	4.184 000 E + 02

METRIC CONVERSION FACTORS (Continued)					
To Convert From	**To**	**Multiply By**	**To Convert From**	**To**	**Multiply By**
Fracture toughness			**Thermal expansion**		
ksi in.$^{1/2}$	MPa m$^{1/2}$	1.098 800 E + 00	in./in. - C	m/m - K	1.000 000 E + 00
Heat content			in./in. - F	m/m - K	1.800 000 E + 00
Btu/lb	kJ/kg	2.326 000 E + 00	**Velocity**		
cal/g	kJ/kg	4.186 800 E + 00	ft/h	m/s	8.466 667 E - 05
Heat input			ft/min	m/s	5.080 000 E - 03
J/in.	J/m	3.937 008 E + 01	ft/s	m/s	3.048 000 E - 01
kJ/in.	kJ/mm	3.937 008 E - 02	in./s	m/s	2.540 000 E - 02
Length			km/h	m/s	2.777 778 E - 01
Å	nm	1.000 000 E - 01	mph	km/h	1.609 344 E + 00
µin.	µm	2.540 000 E - 02	**Velocity of rotation**		
mil	µm	2.540 000 E + 01	rev/min (rpm)	rad/s	1.047 164 E - 01
in.	mm	2.540 000 E + 01	rev/s	rad/s	6.283 185 E + 00
in.	cm	2.540 000 E + 00	**Viscosity**		
ft	m	3.048 000 E - 01	poise	Pa - s	1.000 000 E - 01
yd	m	9.144 000 E - 01	stokes	m^2/s	1.000 000 E - 04
mile	km	1.609 300 E + 00	ft^2/s	m^2/s	9.290 304 E - 02
Mass			in.^{2}/s	mm^2/s	6.451 600 E + 02
oz	kg	2.834 952 E - 02	**Volume**		
lb	kg	4.535 924 E - 01	in.^{3}	m^3	1.638 706 E - 05
ton (short 2000 lb)	kg	9.071 847 E + 02	ft^3	m^3	2.831 685 E - 02
ton (short 2000 lb)	kg x 10^3	9.071 847 E - 01	fluid oz	m^3	2.957 353 E - 05
ton (long 2240 lb)	kg	1.016 047 E + 03	gal (U.S. liquid)	m^3	3.785 412 E - 03
kg x 10^3 = 1 metric ton					

Appendix

4

PIPE DIMENSIONS

DIMENSIONS OF WELDED AND SEAMLESS PIPE[a]

Nominal Pipe Size	Outside Diameter	Nominal Wall Thickness (in)						
		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

Appendix

5

ENGINEERING AND SCIENTIFIC WEB LINKS

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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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

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