CASTI Metals Red Book™

NonFerrous Metals

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Fourth Edition on CD-ROM™

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Subject Index

Table of Contents

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Fourth Edition

CASTI Metals Data Book Series™

Published By:

***CASTI* Publishing Inc.**
Suite 200, 10544 - 106 Street
Edmonton, Alberta, T5H 2X6, Canada
Tel: (780) 424-2552 Fax: (780) 421-1308
E-Mail: casti@casti.ca
Internet Web Site: http://www.casti.ca

ISBN 1-894038-76-2
Printed in Canada

National Library of Canada Cataloguing in Publication Data

Bringas, John E., 1953-
CASTI metals red book, nonferrous metals

(CASTI metals data book series)
Includes index.
Previous ed. has title: Metals red book.
ISBN 1-894038-76-2 (pbk.).--ISBN 1-894038-77-0 (CD-ROM)

1. Nonferrous metals--Metallurgy--Handbooks, manuals, etc. 2. Nonferrous metals--Standards--Handbooks, manuals, etc. I. Wayman, Michael L. (Michael Lash), 1943- II. Title. III. Series.
TN693.N6M48 2002 669 C2002-910850-0

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The material presented herein has been prepared for the general information of the reader and should not be used or relied upon for specific applications without first securing competent technical advice. Nor should it be used as a replacement for current complete engineering standards. In fact, it is highly recommended that current engineering standards be reviewed in detail prior to any decision-making. See the list of standards organizations, technical societies and associations in Appendix 6, many of which prepare engineering standards, to acquire the appropriate metal standards or specifications.

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First printing of Fourth Edition, January 2003
ISBN 1-894038-76-2

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Acknowledgments

CASTI Publishing Inc. has been greatly assisted by the technical reviewers of the *CASTI Metals Red Book*™ - Nonferrous Metals, namely: The Aluminum Association, Copper Development Association, Nickel Development Institute, Titanium Development Association, INCO Ltd., and Haynes International Ltd. Grammatical editing was performed by Jade DeLang Hart. These acknowledgments cannot, however, adequately express the publisher's appreciation and gratitude for their valued assistance.

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Dedication

CASTI Metals Red Book™ is dedicated to Michael, Jo-Ann, Mary-Ann and Angela-Marie, my brother and sisters, for their love and support.

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

We Would Like To Hear From You

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 Red Book*™ - Nonferrous Metals, is the second volume in the *CASTI Metals Data Book Series*™, containing over 700 pages with more than 600,000 pieces of practical metals data. Since accurate data entry of more than 600,000 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*™.

If you have any comments or suggestions we would like to hear from you:

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Tradenames & Trademarks

To make this book as useful as possible, tradenames and trademarks have been included where feasible. Many of these names are widely known, some are more obscure. A list of tradenames and trademarks with their associated companies is catalogued in Appendix 7.

Contents

SECTION I METALLURGY

SECTION II APPENDICES & INDEX

SECTION II APPENDICES & INDEX (Continued)

Chapter 1

ALUMINUM & ALUMINUM ALLOYS

Although aluminum compounds such as alum have been known since antiquity, aluminum metal was first isolated in minute quantities only during the first few decades of the 19th century. By mid-century aluminum had become more widely available but it was an expensive material. In 1884, when the six-pound ornamental pyramid of aluminum was placed on the top of the Washington Monument in Washington D.C., its cost was close to that of silver. However, in 1886 the simultaneous discovery by Hall in the U.S. and Héroult in France of an electrolytic smelting process for aluminum revolutionized its role in industry by making it economically attractive. The Hall-Héroult process, somewhat modified, remains to this day the only commercial aluminum smelting process.

Aluminum is the most abundant metal in the earth's crust, but its most common ore is bauxite, a hydrated oxide of aluminum, iron, and silicon. Alumina (aluminum oxide, Al_2O_3) is extracted from this ore by the Bayer process in which the bauxite is treated with hot sodium hydroxide. The resultant alumina is then dissolved in a bath of molten cryolite (sodium aluminum fluoride) and electrolyzed in electrolytic cells with carbon anodes and cathodes. The product is molten aluminum, which is degassed, alloyed if desired, and cast into ingots which are suitable for remelting or for mechanical processing, typically by rolling or extrusion. Aluminum is amenable to recycling, and the use of scrap in both primary and secondary production and in fabrication is an increasing trend.

Bauxite is mined in diverse parts of the world, but aluminum smelting is carried out in localities where electricity costs are low, as energy is more important than transportation in the economics of aluminum production. This is because aluminum is such a reactive metal. In alumina, aluminum and oxygen are so strongly bonded that a great deal of energy is required to separate them. When an atomically clean aluminum surface is exposed to air, it reacts immediately forming a thin oxide layer within seconds. Fortunately, this thin layer is normally adherent and protective, preventing further oxidation of the metal and endowing it with excellent corrosion resistance in most environments. Furthermore, the surface oxide layer can be controlled and even coloured by the anodization process, adding to its esthetic versatility. A less positive consequence of the reactivity of aluminum is that successful welding procedures require effective shielding from the air.

Aluminum and its alloys have face-centered cubic (fcc) crystal structures, and therefore have excellent formability properties, except when these are inhibited by the degree and type of alloying. The strength obtainable by heat treating some alloys can be greater than in many structural steels. The metal has an attractive surface appearance with good reflectivity, good electrical and thermal conductivity, and low density. This latter property, combined with the high strengths available, gives high strength-to-weight ratios which are responsible for these alloys being the primary structural materials in the aerospace industry. The stiffness (elastic modulus) of aluminum is only about one-third as high as that of steel, and this factor must be considered in component design in order to prevent unduly large deflections in service.

The transportation industry and the container and packaging industry are each responsible for more than 20% of the tonnage of aluminum produced, while the building industry provides more than 15% of the market. Consumer durables, electrical products, and the machinery and equipment industry each provide between 5% and 10% of the market.

Unalloyed (commercial purity) aluminum and some 300 commonly recognized alloys are available, in both cast and wrought forms. In most of these, the total alloy content is less than 15%. Some of the alloys are solid solutions, strengthenable by cold work, while others, both cast and wrought, are heat-treatable (i.e., strengthened by a precipitation hardening heat treatment). The alloy classification system developed by The Aluminum Association makes use of a 4 digit system for wrought aluminum and its alloys, while cast alloys are designated by 3 digits plus a period and a supplementary digit. These nomenclatures are followed by an alphanumeric temper designation which provides information on the thermal and mechanical processing. The system is described in Tables 1 and 2.

The major impurities in aluminum are iron and silicon, with common minor contaminants including zinc, gallium, titanium, and vanadium. These impurities are responsible for the presence, in all aluminum-based materials, of nonmetallic inclusions which are intermetallic compounds containing iron and silicon as well as other elements where available.

Coarse intermetallic constituents, such as particles of $FeAl_3$ (or its precursor $FeAl_6$) and $Al_{12}(Fe,Mn)_3Si$ form during solidification and, although they may be broken up by subsequent fabrication, they remain in the size range of 1-10 micrometers. Other intermetallic phases form as smaller (submicrometer) particles during the initial stages of processing; some of these (e.g. $Al_{18}Mg_3Cr_2$ and $Al_{20}Cu_2Mn_3$) can have the positive effect of retarding recrystallization and grain growth, thus contributing to grain refinement. Coarse, brittle intermetallic compounds are detrimental to the strength and ductility of the alloys, but especially to the fracture toughness and the appearance after anodizing. In casting alloys, they can also be detrimental to castability, since large insoluble particles in the liquid can dramatically reduce its fluidity. To alleviate these problems, some alloys are available in special grades with restricted levels of impurities. Because of the importance of these impurities, grades of unalloyed aluminum which are intended primarily for remelting are designated by a system using the letter P followed by the maximum contents of silicon and iron respectively in hundredths of a percent. Thus P1020 contains no more than 0.10%Si and 0.20%Fe. A letter may follow this term to designate different elemental limits for impurities other than iron and silicon.

Fabrication of wrought aluminum and its alloys can be carried out by virtually all metalworking processes, notably extrusion, forging, drawing, stamping, and machining. About 50% of wrought products are flat rolled (sheet , plate, foil) with more than 15% as extruded shapes and tubes. Combinations of rolling and extrusion are used to produce bar, rod, and wire. Most wrought alloys are available in many of these product forms. The severe deformations associated with the production of beverage cans provides a vivid illustration of the impressive fabrication properties of some aluminum-based materials. An increasing trend is to the continuous production of shapes starting from the liquid state, for example slab, strip, or bar casting with in-line hot rolling.

The Alclad alloys are composite materials in which thin layers of a cladding alloy are bonded to the surfaces of a high strength alloy to provide corrosion protection. The composition of the cladding alloy is chosen to make it corrosion resistant and also anodic to the core alloy. For example commercial purity cladding is used on aluminum-copper (2xxx) high strength alloys, while aluminum-zinc or aluminum-zinc-magnesium cladding is used on high strength aluminum-zinc-magnesium-copper alloys in the 7xxx series.

Castings are produced by sand mold, permanent mold, pressure-die, investment, and plaster casting. A variety of powder metallurgy

The alloy 7072 (UNS A97072), a binary aluminum-zinc alloy containing 1%Zn, has a high corrosion potential and finds extensive use as cladding on a wide range of Alclad alloys; it is also used for sacrificial anodes.

Cast Aluminum Alloys

Cast aluminum alloys have compositions which have been developed not only for strength, ductility, and corrosion resistance but also for castability properties such as fluidity in the liquid state. This has resulted in their having different compositions than the wrought alloys, in particular higher silicon contents. Silicon forms a simple eutectic system with aluminum, thus at a late stage of solidification there will be a highly fluid liquid available to feed the normal solidification shrinkage cavities. Thus the presence of silicon in the alloy, at levels ranging from 4% to 12%, permits production of high quality intricate castings with large variations in section thickness while keeping scrap loss minimal by reducing cracking and shrinkage porosity. Aluminum-silicon-based alloys are the most common of the aluminum casting alloys.

Casting alloys (Table 1) are available in a number of alloy systems and in both non-heat-treatable and heat-treatable grades, although here the distinctions are not as clear as in wrought alloys.

Aluminum-Copper Alloys

Aluminum-copper alloys are heat-treatable and capable of high strength, but are relatively difficult to cast, have poor weldability, and can be susceptible to corrosion. Alloy 242.0 (UNS A02420), which contains 4%Cu, 2%Ni, and 2.5%Mg, finds applications in pistons and air-cooled cylinder heads for motorcycle, diesel, and aircraft engines.

Aluminum-Copper-Silicon Alloys

Aluminum-copper-silicon alloys are extensively used, with the copper contributing to strength and the silicon to castability. A wide range of compositions is produced, ranging from high copper to high silicon, thus these alloys fall into both the 2xx.x and the 3xx.x series. These alloys are heat-treatable when the copper content is above 3-4%, especially when magnesium is present as well. Alloys in this category which have 4-5%Cu and 1-3%Si, include 208.0 (UNS A02080) which is used for pressure-tight castings such as manifolds and valve bodies, as well as 295.0 (UNS A02950) and 296.0 (UNS A02960) which are used for wheels, fittings, and housings where strength and machinability are required. Alloys which contain more silicon than copper include 308.0 (UNS A03080) and 319.0 (UNS A03190), which contain 5-6%Si and 3-5%Cu; these are used for general purpose castings and in automotive applications. Alloys with 8-12%Si and 2-4%Cu include 380.0 (UNS A03800), 383.0 (UNS A03830), and 384.0 (UNS A03840) which are die casting alloys. The 380.0 alloy in particular is very widely used in the automotive and consumer electrical industries, although it has poor weldability and brazeability. Some aluminum-silicon-copper alloys also contain small amounts of magnesium for strengthening purposes; examples include 354.0 (UNS A03540) and 355.0 (UNS A03550). Hypereutectic alloys, i.e. those with more than 12%Si, contain primary silicon particles in their microstructures which impart wear resistance, giving these alloys applications as automotive pistons and engine blocks. A popular example is 390.0 (UNS A03900), which contains 17%Si, 4.5%Cu, and 0.6%Mg.

Aluminum-Silicon Alloys

When a combination of castability and corrosion resistance is deemed more important than strength, aluminum-silicon alloys without copper are used. Examples of this type of alloy include 413.0 (UNS A04130) which has 12%Si and is used for intricate die castings which may require pressure tightness, and 443.0 (UNS A04430) with 5.2%Si which is used mainly for sand and permanent mold castings including cooking utensils and food handling equipment. These non-heat-treatable alloys have good weldability and are among the most important commercial casting alloys.

Aluminum-Silicon-Magnesium Alloys

Magnesium additions to the aluminum-silicon alloys render them heat-treatable, and hence provide increased strength. Alloys 356.0 (UNS A03560), which is very widely used for sand and permanent mold castings, and its stronger variants 357.0 (UNS A03570) and 359.0 (UNS A03590) fall into this category with 7-10%Si plus 0.3-0.6%Mg. So does the alloy 360.0 (UNS A03600), a die casting alloy for use where the corrosion resistance of 380.0 is inadequate. In some alloys, sodium or calcium additions are made to modify the Al-Si eutectic so as to provide a further increment of strength.

Aluminum-Magnesium Alloys

Aluminum-magnesium alloys are not heat-treatable, being mainly single phase solid solutions. They are used where high corrosion resistance is desired, especially in marine environments and food handling. Low impurity content is important here as well. These alloys have poorer castability than the silicon-bearing alloys but have good machinability and attractive appearance when anodized. Examples include 514.0 (UNS solution treating, annealing, and overaging can occur in the heat affected zone, so it may be necessary to re-solution treat and re-age the materials after welding to recover the strength properties; however, the ductility may not be fully recovered.

In addition to arc welding, aluminum and its alloys can in general be resistance welded and can be brazed with an appropriate flux.

Table 1 Aluminum Alloy Groups

(a) Wrought aluminum and its alloys grouped by major alloying element:

1xxx	unalloyed aluminum, 99%Al minimum
2xxx	copper
3xxx	manganese
4xxx	silicon
5xxx	magnesium
6xxx	magnesium and silicon
7xxx	zinc
8xxx	other elements

In the 1xxx series, where the aluminum content is greater than 99.00%, the last two digits give the minimum aluminum percentage. They are the same as the two digits to the right of the decimal point in the minimum aluminum percentage in the specification (e.g. 1050 contains ≥99.50%Al). The second digit is 0 for unalloyed aluminum with natural impurity limits; 1 through 9 for special limits on one or more individual elements.

In the other series, 2xxx to 7xxx, the last two digits have no special significance. The second digit indicates alloy modifications, i.e., it is assigned 0 in the original alloy developed, with 1 through 9 assigned consecutively indicating alloying modifications.

(b) Cast aluminum and its alloys grouped by major alloying element:

1xx.x	unalloyed aluminum, 99%Al minimum
2xx.x	copper
3xx.x	silicon, with added copper and/or magnesium
4xx.x	silicon
5xx.x	magnesium
7xx.x	zinc
8xx.x	tin
9xx.x	other

In the 1xx.x series, where the aluminum content is greater than 99.00%, the second and third digits give the minimum aluminum percentage. They are the same as the two digits to the right of the decimal point in the minimum aluminum percentage. Thus 150.0 contains ≥99.50%Al. The last digit indicates the product form: 1xx.0 for castings and 1xx.1 for ingot.

In the other series, 2xx.x to 7xx.x, the second and third digits have no special significance. In these series, the final digit defines the product form: xxx.0 for castings, xxx.1 and xxx.2 for ingots suitable for foundry use, where the final digits 1 and 2 refer to composition limits on iron, magnesium, and zinc in the ingots. Prefix letters are used to denote differences in impurity limits (especially iron) in castings (e.g. B443.0).

Table 2 Basic Temper Designations

F - As fabricated, with no special control over thermal or mechanical treatment and no mechanical property limits for wrought products
O - Annealed to obtain lowest strength temper (wrought products) and to improve ductility and dimensional stability (cast products). May be followed by a digit other than zero.
H - Strain hardened (wrought products only). The H is always followed by two or more digits (see below).
W - Solution heat treated. Applicable to alloys which age at room temperature over a period of months or years.
T - Heat treated to produce stable tempers other than F, O, or H. Applicable to alloys that are thermally treated, with or without supplementary strain hardening, to produce stable tempers. The T is always followed by one or more digits (see next page).

Strain Hardened Products

The first digit following the H indicates the specific sequence of basic operations as described below. The second digit indicates the degree of strain hardening on a scale from 1 through 9, where 0 corresponds to full annealing and 8 corresponds to 75% cold work following full annealing. Thus when the second digit is 2 (e.g., alloy 5005-H12) the material is said to be quarter hard, 4 - half hard, 8 - full hard. The numeral 9 is used when the UTS exceeds that of 8 by more than 10 MPa. A third digit, when used, refers to a specific variation of a 2-digit temper. There are special 3 digit designations for patterned or embossed sheet.

H1 - Strain hardened only, with no supplementary thermal treatment.

H2 - Strain hardened and partially annealed, i.e. strain hardened more than the desired final amount, then annealed to reduce the strength. The second digit refers to the strength level after the partial anneal.
H3 - Strain hardened and stabilized by a low temperature thermal treatment, for those alloys which gradually age-soften at room temperature. The second digit refers to the strength level after stabilization.

Heat Treated Products

The T is followed by a number from 1 to 10, indicating a specific sequence of basic treatments as described below. This is followed by one or more additional digits, the first of which cannot be 0, to identify a variation of one of the 10 basic tempers (e.g. alloy 2024-T3, alloy 7075-T651). In this context "naturally aged" means aged at room temperature, and "artificially aged" means aged above room temperature. Specific designations have been assigned for the cases of stress relieving by stretching, compressing, or a combination of the two. These include TX51, TX510, TX511, while TX52 refers to stress relief by compressing and TX54 by stretching and compressing.

T1 - Cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition (not cold worked).
T2 - Cooled from an elevated temperature shaping process, cold worked, and naturally aged to a substantially stable condition.
T3 - Solution treated, cold worked, and naturally aged to a substantially stable condition.
T4 - Solution treated and naturally aged to a substantially stable condition.
T5 - Cooled from an elevated temperature shaping process and artificially aged.
T6 - Solution heat treated and artificially aged.
T7 - Solution heat treated and overaged or stabilized. This applies to wrought products which have been precipitation hardened past the point of maximum strength and to cast products which are artificially aged to provide dimensional and strength stability.
T8 - Solution heat treated, cold worked, and artificially aged.
T9 - Solution heat treated, artificially aged, and cold worked.
T10 - Cooled from an elevated temperature shaping process, cold worked, and artificially aged.

SAE/AMS SPECIFICATIONS - ALUMINUM & ALUMINUM ALLOYS

AMS	Title
2201	Tolerances, Aluminum and Aluminum Alloy Bar, Rod, Wire, and Forging Stock Rolled or Cold-Finished, Superseded by ANSI H35.2 (Sep 94)
2202	Tolerances, Aluminum Alloy and Magnesium Alloy Sheet and Plate, Superseded by ANSI H35.2 (Aug 96)
2203	Tolerances, Aluminum Alloy Drawn Tubing, Superseded by ANSI H35.2 (Sep 94)
2204	Tolerances, Aluminum Alloy Standard Structural Shapes, Superseded by ANSI H35.2 (Aug 96)
2205	Tolerances, Aluminum Alloy and Magnesium Alloy Extrusions, Superseded by ANSI H35.2 (Aug 96)
2450	Sprayed Metal Finish Aluminum NONCURRENT Sep 94
2470	Anodic Treatment of Aluminum Alloys, Chromic Acid Process
2471	Anodic Treatment of Aluminum Alloys, Sulfuric Acid Process, Undyed Coating
2472	Anodic Treatment of Aluminum Alloys, Sulfuric Acid Process, Dyed Coating
2473	Chemical Film Treatment for Aluminum Alloys, General Purpose Coating
2474	Chemical Treatment for Aluminum Alloys, Low Electrical Resistance Coating
2482	Hard Coating Treatment of Aluminum Alloys Teflon-Impregnated or Codeposited
2672	Brazing, Aluminum, Torch or Furnace
2673	Brazing, Aluminum and Aluminum Alloys Molten Flux (Dip)
2811	Identification, Aluminum and Magnesium Alloy Wrought Products, Superseded by ASTM B 666 (May 98)
3412	Flux, Aluminum Brazing for Torch or Furnace Brazing
3414	Flux, Aluminum Welding
3415	Flux, Aluminum Dip Brazing 1030°F (554°C) or Lower Liquidus
4000	Aluminum Sheet and Plate, (1060-0) NONCURRENT January 1987, UNS A91060
4001	Aluminum Sheet and Plate 0.12Cu, (1100-0) Annealed, UNS A91100
4003	Aluminum Alloy, Sheet and Plate 0.12Cu, (1100-H14) Strain Hardened, UNS A91100
4004	Aluminum Alloy, Foil 2.5Mg - 0.25Cr, (5052-H191) Strain Hardened, UNS A95052
4005	Aluminum Alloy, Foil 5.0Mg - 0.12Mn - 0.12Cr, (5056-H191) Strain Hardened, NONCURRENT May 94, UNS A95056
4006	Aluminum Alloy, Sheet and Plate, 1.25Mn - 0.12Cu - (3003-0) Annealed, UNS A93003
4007	Aluminum Alloy, Foil 4.4Cu - 1.5Mg - 0.60Mn (2024-0), UNS A92024, CANCELLED (Aug 99)
4008	Aluminum Alloy, Sheet and Plate 1.25Mn - 0.12Cu (3003-H14) Strain Hardened, UNS A93003
4009	Aluminum Alloy, Foil 1.0Mg - 0.6Si - 0.30Cu - 0.20Cr (6061-0) Annealed, UNS A96061
4010	Foil 1.2Mn - 0.12Cu (3003-H18), NONCURRENT Aug 94, UNS A93003
4011	Aluminum, Foil and Light Gage Sheet, 99.45Al (1145-0) Annealed, UNS A91145

SAE/AMS SPECIFICATIONS - ALUMINUM & ALUMINUM ALLOYS (Continued)	
AMS	**Title**
4347	Aluminum Alloy Sheet, 1.0Mg - 0.8Si - 0.8Cu - 0.5Mn (6013-T4) Solution Heat Treated and Naturally Aged, UNS A96013
4348	Core, Honeycomb, Aluminum Alloy, Corrosion Inhibited, for Sandwich Construction 5052, 350 (177), UNS A95052
4349	Core, Honeycomb, Aluminum Alloy, Corrosion Inhibited, for Sandwich Construction, 5056, 350 (177), UNS A95056

ASTM SPECIFICATIONS - ALUMINUM & ALUMINUM ALLOYS	
ASTM	**Title**
Bars, Rods, Wire, and Shapes	
B 211	Aluminum and Aluminum-Alloy Bar, Rod, and Wire
B 211M	Aluminum and Aluminum-Alloy Bar, Rod, and Wire [Metric]
B 221	Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes
B 221M	Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]
B 236	Aluminum Bars for Electrical Purposes (Bus Bars)
B 236M	Aluminum Bars for Electrical Purposes (Bus Bars) [Metric]
B 308/B 308M	Aluminum-Alloy 6061-T6 Standard Structural Profiles
B 316/B 316M	Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods
B 317	Aluminum-Alloy Extruded Bar, Rod, Tube, Pipe, and Structural Profiles for Electrical Purposes (Bus Conductor)
Castings	
B 26/B 26M	Aluminum-Alloy Sand Castings
B 85	Aluminum-Alloy Die Castings
B 108	Aluminum-Alloy Permanent Mold Castings
B 618	Aluminum-Alloy Investment Castings
B 686	Aluminum Alloy Castings, High-Strength
Products for Electrical Purposes	
B 230/B 230M	Aluminum 1350-H19 Wire for Electrical Purposes
B 236	Aluminum Bars for Electrical Purposes (Bus Bars)
B 236	Aluminum Bars for Electrical Purposes (Bus Bars) [Metric]
B 314	Wire for Communication Cable, Aluminum 1350, Discontinued 1994
B 317	Aluminum-Alloy Extruded Bar, Rod, Tube, Pipe, and Structural Profiles for Electrical Purposes (Bus Conductors)

AMERICAN CROSS REFERENCED SPECIFICATIONS - ALUMINUM AND ALUMINUM ALLOYS[a]							
AA	**UNS**	**AMS/SAE**	**MIL**	**FED**	**ASTM**	**ASME**	**AWS**
1060	A91060	4000	---	---	B 209 (1060), B 210 (1060), B 211 (1060), B 221 (1060), B 234 (1060), B 241 (1060), B 345 (1060), B 361 (1060), B 404 (1060), B 483 (1060), B 548 (1060), B 736 (1060)	SB-209, SB-210, SB-221, SB-234, SB-241	---
1100	A91100	4001, 4003, 4062, 4102, 4180, QQ-A-225/1, QQ-A-250/1, AS7220 SAE AS7220 (1100), SAE J454 (1100)	MIL-W-6712	QQ-A-430, QQ-A-1876, WW-T-700/1	B 209 (1100), B 210 (1100), B 211 (1100), B 221 (1100), B 241 (1100), B 247 (1100), B 313 (1100), B 316 (1100), B 361 (1100), B 479 (1100), B 483 (1100), B 491 (1100), B 547 (1100), B 548 (1100) B 736(1100)	SB-209, SB-211, SB-241/SB-241M, SFA5.3 (E1100), SFA5.10 (ER1100)	A5.3 (E1100), A5.10 (ER1100), C2.25 (W-A1-1100)
1145	A91145	4011	---	QQ-A-1876	B 373 (1145), B 479 (1145), B 737 (1145)	---	---
1235	A91235	---	---	QQ-A-1876	B 373 (1235), B 479 (1235), B 491 (1235), B 736 (1235)	---	---
1350	A91350	---	---	---	B 230, B 231, B 232 (1350), B 233, B 236, B 314 (1350), B 324, B 400 (1350), B 401, B 524, B 778 (1350), B 779 (1350), B 901 (1350)	---	C2.25 (W-A1-1350)
2011, 2011A	A92011	QQ-A-225/3, SAE J454 (1100)	---	---	B 210 (2011), B 211 (2011)	---	---
2014, 2014A	A92014	4028, 4029, 4121, 4133, 4134, 4153, 4314, A-22771 (2014), QQ-A-200/2, QQ-A-200/4, QQ-A-225/4, SAE J454 (2024)	---	---	B 209 (2014), B 210 (2014), B 211 (2014), B 221 (2014), B 241 (2014), B 247 (2014)	SB-211	---
2017, 2017A	A92017	4118 QQ-A-225/5	---	QQ-A-430	B 211 (2017), B 316 (2017)	---	---

CHEMICAL COMPOSITIONS OF WROUGHT ALUMINUM & ALUMINUM ALLOYS	
UNS	**Chemical Composition**
A82004	Core Alloy A92004 Cladding Alloy A91070
A82014	Core Alloy A92014 Cladding Alloy A96003
A82024	Core Alloy A92024 Cladding Alloy A91230
A82219	Core Alloy A92219 Cladding Alloy A97072
A83003	Core Alloy A93003 Cladding Alloy A94343
A86061	Core Alloy A96061 Cladding Alloy A97072
A87050	Core Alloy A97050 Cladding Alloy A97072
A87075	Core Alloy A97075 Cladding Alloy A97072
A87178	Core Alloy A97178 Cladding Alloy A97072
A87475	Core Alloy A97475 Cladding Alloy A97072
A91035	Al 99.35 min Cu 0.10 max Fe 0.6 max Mg 0.05 max Mn 0.05 max Si 0.35 max Ti 0.03 max V 0.05 max Zn 0.10 max Other each 0.03 max
A91045	Al 99.45 min Cu 0.10 max Fe 0.45 max Mg 0.05 max Mn 0.05 max Si 0.30 max Ti 0.03 max V 0.05 max Zn 0.05 max Other each 0.03 max
A91050	Al 99.50 min Cu 0.05 max Fe 0.40 max Mg 0.05 max Mn 0.05 max Si 0.25 max Ti 0.03 max V 0.05 max Zn 0.05 max Other each 0.03 max
A91060	Al 99.60 min Cu 0.05 max Fe 0.35 max Mg 0.03 max Mn 0.03 max Si 0.25 max Ti 0.03 max V 0.05 max Zn 0.05 max Other each 0.03 max (Be 0.0008 max for welding electrode and filler metal only)
A91080	Al 99.80 min Cu 0.03 max Fe 0.15 max Ga 0.03 max Mg 0.02 max Mn 0.02 max Si 0.15 max Ti 0.03 max V 0.05 max Zn 0.03 max Other each 0.02 max
A91100	Al 99.00 min Cu 0.05-0.20 Mn 0.05 max Zn 0.10 max Other each 0.05 max (Be 0.0008 max for welding electrode and filler wire only), total 0.15 max, Si+Fe 0.95 max
A91145	Al 99.45 min Cu 0.05 max Mg 0.05 max Mn 0.05 max Ti 0.03 max Zn 0.05 max Other each 0.03 max, Si+Fe 0.55 max
A91188	Al 99.88 min Cu 0.005 max Fe 0.06 max Ga 0.03 max Mg 0.01 max Mn 0.01 max Si 0.06 max Ti 0.01 max V 0.05 max Zn 0.03 max Other each 0.01 max (Be 0.0008 max for welding electrode and filler wire only)
A91200	Al 99.00 min Cu 0.05 max Mn 0.05 max Ti 0.05 max Zn 0.10 max Other each 0.05 max, total 0.15 max, Fe+Si 1.0 max
A91230	Al 99.30 min Cu 0.10 max Mg 0.05 max Mn 0.05 max Ti 0.03 max V 0.05 max Zn 0.10 max Other each 0.03, Fe+Si 0.7 max
A91235	Al 99.35 min Cu 0.05 max Mg 0.05 max Mn 0.05 max Ti 0.03 max Zn 0.010 max Other each 0.03 max, Fe+Si 0.65 max
A91350	Al 99.50 min B 0.05 max Cr 0.01 max Cu 0.05 max Fe 0.40 max Ga 0.03 max Mn 0.01 max Si 0.10 max Zn 0.05 max Other each 0.03 max, total 0.10, Ti + V 0.02 max
A91435	Al 99.35 min Cu 0.02 max Fe 0.30-0.50 Mg 0.05 max Mn 0.05 max Si 0.15 max Ti 0.03 max V 0.05 max Zn 0.10 max Other each 0.03 max

CHEMICAL COMPOSITIONS OF CAST ALUMINUM & ALUMINUM ALLOYS	
UNS	**Title**
A02010	Ag 0.40-1.0 Al rem Cu 4.0-5.2 Fe 0.15 max Mg 0.15-0.55 Mn 0.20-0.50 Si 0.10 max Ti 0.15-0.35 Other each 0.05 max, total 0.10 max
A02040	Al rem Cu 4.2-5.0 Fe 0.35 max Mg 0.15-0.35 Mn 0.10 max Ni 0.05 max Si 0.20 max Sn 0.05 max Ti 0.15-0.30 Zn 0.10 max Other each 0.05 max, total 0.15 max
A02420	Al rem Cr 0.25 max Cu 3.5-4.5 Fe 1.0 max Mg 1.2-1.8 Mn 0.35 max Ni 1.7-2.3 Si 0.7 max Ti 0.25 max Zn 0.35 max Other each 0.05 max, total 0.15 max
A02950	Al rem Cu 4.0-5.0 Fe 1.0 max Mg 0.03 max Mn 0.35 max Si 0.7-1.5 Ti 0.25 max Zn 0.35 max Other each 0.05 max, total 0.15 max
A03190	Al rem Cu 3.0-4.0 Fe 1.0 max Mg 0.10 max Mn 0.50 max Ni 0.35 max Si 5.5-6.5 Ti 0.25 max Zn 1.0 max Other total 0.50 max
A03320	Al rem Cu 2.0-4.0 Fe 1.2 max Mg 0.50-1.5 Mn 0.50 max Ni 0.50 max Si 8.5-10.5 Ti 0.25 max Zn 1.0 max Other total 0.50 max
A03330	Al rem Cu 3.0-4.0 Fe 1.0 max Mg 0.05-0.50 Mn 0.50 max Ni 0.50 max Si 8.0-10.0 Ti 0.25 max Zn 1.0 max Other total 0.50 max
A03360	Al rem Cu 0.5-1.5 Fe 1.2 max Mg 0.7-1.3 Mn 0.35 max Ni 2.0-3.0 Si 11.0-13.0 Ti 0.25 max Zn 0.35 max Other each 0.05 max
A03540	Al rem Cu 1.6-2.0 Fe 0.20 max Mg 0.40-0.6 Mn 0.10 max Si 8.6-9.4 Ti 0.20 max Zn 0.10 max Other each 0.05 max, total 0.15 max
A03550	Al rem Cr 0.25 max Cu 1.0-1.5 Fe 0.6 max Mg 0.40-0.6 Mn 0.50 max Si 4.5-5.5 Ti 0.25 max Zn 0.35 max Other each 0.05 max, total 0.15 max. Note: If Fe exceeds 0.45, Mn shall not be less than 0.5 x Fe
A03560	Al rem Cu 0.25 max Fe 0.6 max Mg 0.20-0.45 Mn 0.35 max Si 6.5-7.5 Ti 0.25 max Zn 0.35 max Other each 0.05 max, total 0.15 max. Note: If Fe exceeds 0.45, Mn shall not be less than 0.5 x Fe
A03570	Al rem Cu 0.05 max Fe 0.15 max Mg 0.45-0.6 Mn 0.03 max Si 6.5-7.5 Ti 0.20 max Zn 0.05 max Other each 0.05 max, total 0.15 max
A03590	Al rem Cu 0.20 max Fe 0.20 max Mg 0.50-0.7 Mn 0.10 max Si 8.5-9.5 Ti 0.20 max Zn 0.10 max Other each 0.05 max, total 0.15 max
A03600	Al rem Cu 0.6 max Fe 2.0 max Mg 0.40-0.6 Mn 0.35 max Ni 0.50 max Si 9.0-10.0 Sn 0.15 max Zn 0.50 max Other total 0.25 max
A04130	Al rem Cu 1.0 max Fe 2.0 max Mg 0.10 max Mn 0.35 max Ni 0.50 max Si 11.0-13.0 Sn 0.15 max Zn 0.50 max Other total 0.25 max
A04430	Al rem Cr 0.25 max Cu 0.6 max Fe 0.8 max Mg 0.05 max Mn 0.50 max Si 4.5-6.0 Ti 0.25 max Zn 0.50 max Other total 0.35 max
A05120	Al rem Cr 0.25 max Cu 0.35 max Fe 0.6 max Mg 3.5-4.5 Mn 0.8 max Si 1.4-2.2 Ti 0.25 max Zn 0.35 max Other each 0.05 max, total 0.15 max
A05130	Al rem Cu 0.10 max Fe 0.40 max Mg 3.5-4.5 Mn 0.30 max Si 0.30 max Ti 0.20 max Zn 1.4-2.2 Other each 0.05 max, total 0.15 max
A05140	Al rem Cu 0.15 max Fe 0.50 max Mg 3.5-4.5 Mn 0.35 max Si 0.35 max Ti 0.25 max Zn 0.15 max Other each 0.05 max, total 0.15 max
A05180	Al rem Cu 0.25 max Fe 1.8 max Mg 7.5-8.5 Mn 0.35 max Ni 0.15 max Si 0.35 max Sn 0.15 max Zn 0.15 max Other total 0.25 max
A05200	Al rem Cu 0.25 max Fe 0.30 max Mg 9.5-10.6 Mn 0.15 max Si 0.25 max Ti 0.25 max Zn 0.15 max Other each 0.05 max, total 0.15 max
A05350	Al rem B 0.005 max Be 0.003-0.007 Cu 0.05 max Fe 0.15 max Mg 6.2-7.5 Mn 0.10-0.25 Si 0.15 max Ti 0.10-0.25 Other each 0.05 max, total 0.15 max
A07050	Al rem Cr 0.20-0.40 Cu 0.20 max Fe 0.8 max Mg 1.4-1.8 Mn 0.40-0.6 Si 0.20 max Ti 0.25 max Zn 2.7-3.3 Other each 0.05 max, total 0.15 max
A07051	Al rem Cr 0.20-0.40 Cu 0.20 max Fe 0.6 max Mg 1.5-1.8 Mn 0.40-0.6 Si 0.20 max Ti 0.25 max Zn 2.7-3.3 Other each 0.05 max, total 0.15 max

CHEMICAL COMPOSITION OF ALUMINUM ALLOYS BEARING BUSHINGS

El.	SAE 770 ISO AlSn6Cu	SAE 780	SAE 781 ISO AlSi4Cd	SAE 782 ISO AlCd3CuNi	SAE 783 ISO AlSn20Cu	SAE 784 ISO AlSi11Cu	SAE 785 ISO AlZn5Si2CuPb	SAE 786 ISO AlSn40	SAE 787	SAE 788
Al	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder
Sn	5.5.-7.0	5.5.-7.0	---	---	17.5-22.5	0.20	0.20	37-42	0.4-2.0	10.0-14.0
Cd	---	---	0.8-1.4	2.7-3.5	---	---	---	---	---	---
Si	0.7	1.0-2.0	3.5-4.5	0.30[c]	0.50[d]	10.0-12.0	1.0-2.0[e]	0.3	3.5-4.5	1.8-3.5[g]
Cu	0.7-1.3	0.7-1.3	0.05-0.15	1.0-1.5[c]	0.7-1.3	1.7-1.3	0.7-1.3	0.35-0.7	0.5-2.0[f]	0.4-1.2[g]
Ni	0.7-1.3[a]	0.20-0.7	---	0.7-1.3	0.10	0.10	0.20	0.10	---	0.10
Zn	---	---	---	---	---	---	4.5-5.5[e]	---	---	---
Pb	---	---	---	---	---	---	0.7-1.3	---	4.0-10.5[f]	1.0-2.4[g]
Mg	---	---	0.05-0.20[b]	---	---	---	---	---	---[f]	---
Mn	0.10[a]	0.10	0.10	1.2-1.6[c]	0.10[d]	0.10	0.10	0.10	---[f]	0.10
Fe	0.7	0.7	0.35	0.30[c]	0.50[d]	0.30	0.30	0.30	0.50	0.35
Cr	---	---	---	---	---	---	---	---	---	0.25
Sb	---	---	---	---	---	---	---	---	---	0.45
Sr	---	---	---	---	---	---	---	---	---	0.30
Ti	0.10[a]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total Others	0.30	0.15	0.25	0.15	0.15[d]	0.30	0.30	0.30	0.30	0.30

a. ISO AlSn6Cu has no lower limit to Ni, 0.7 max. Mn, 0.2 max. Ti, 1.0 max. Si + Fe + Mn.
b. ISO AlSi4Cd has no Mg, 0.2 max. Mn, 0.2 max. Ti.
c. ISO AlCd3CuNi has 0.7 to 1.3 Cu, 0.7 max. Si, 0.7 max. Mn, 0.7 max. Fe, 1.0 max. Si + Fe + Mn.
d. ISO AlSn20Cu has 0.7 max. Si, 0.7 max. Mn, 0.7 max. Fe, 1.0 max. Si + Fe + Mn, 0.5 max. total others.
e. A version of this alloy has 3.0 to 4.0 Zn, 2.5 to 3.5 Si.
f. A version of this alloy has 0.05 to 0.15 Cu, 0.05 to 0.15 Mg, 0.20 to 0.40 Mn.
g. A version of this alloy has 3.5 to 5.0 Si, 1.8 to 2.1 Cu and no lead.

MECHANICAL PROPERTIES OF ALUMINUM & ALUMINUM NONHEAT-TREATABLE ALLOYS - SHEET & PLATE							
ASTM B 209 Alloy/Temper	**Specified Thickness, in.**	**Tensile Strength, ksi**		**Yield Strength, ksi**		**% El min**	**Bend Dia. Factor N**
		min	**max**	**min**	**max**		
1060							
O	0.006-0.019	8.0	14.0	2.5	---	15	---
	0.020-0.050	8.0	14.0	2.5	---	22	---
	0.051-3.000	8.0	14.0	2.5	---	25	---
H12 or H22	0.017-0.050	11.0	16.0	9.0	---	6	---
	0.051-2.000	11.0	16.0	9.0	---	12	---
H14 or H24	0.009-0.019	12.0	17.0	10.0	---	1	---
	0.020-0.050	12.0	17.0	10.0	---	5	---
	0.051-1.000	12.0	17.0	10.0	---	10	---
H16 or H26	0.006-0.019	14.0	19.0	11.0	---	1	---
	0.020-0.050	14.0	19.0	11.0	---	4	---
	0.051-0.162	14.0	19.0	11.0	---	5	---
H18 or H28	0.006-0.019	16.0	---	12.0	---	1	---
	0.020-0.050	16.0	---	12.0	---	3	---
	0.051-0.128	16.0	---	12.0	---	4	---
H112	0.250-0.499	11.0	---	7.0	---	10	---
	0.500-1.000	10.0	---	5.0	---	20	---
	1.001-3.000	9.0	---	4.0	---	25	---
F	0.250-3.000	---	---	---	---	---	---
1100							
O	0.006-0.019	11.0	15.5	3.5	---	15	0
	0.020-0.031	11.0	15.5	3.5	---	20	0
	0.032-0.050	11.0	15.5	3.5	---	25	0
	0.051-0.249	11.0	15.5	3.5	---	30	0
	0.250-3.000	11.0	15.5	3.5	---	28	0
H12 or H22	0.017-0.019	14.0	19.0	11.0	---	3	0
	0.020-0.031	14.0	19.0	11.0	---	4	0

MECHANICAL PROPERTIES OF ALUMINUM & ALUMINUM HEAT-TREATABLE ALLOYS - SHEET & PLATE							
ASTM B 209 Alloy/Temper	**Specified Thickness, in.**	**Tensile Strength, ksi**		**Yield Strength, ksi**		**% El min**	**Bend Dia. Factor N**
		min	**max**	**min**	**max**		
2014							
O	0.020-0.124	---	32.0	---	16.0	16	0
	0.125-0.249	---	32.0	---	16.0	16	1
	0.250-0.499	---	32.0	---	16.0	16	2
T3	0.020-0.039	59.0	---	35.0	---	14	3
	0.040-0.124	59.0	---	36.0	---	14	3
	0.125-0.249	59.0	---	36.0	---	14	4
T4	0.020-0.124	59.0	---	35.0	---	14	3
	0.125-0.249	59.0	---	35.0	---	14	4
T42	0.020-0.124	58.0	---	34.0	---	14	3
	0.125-0.249	58.0	---	34.0	---	14	4
	0.250-0.499	58.0	---	34.0	---	14	5
	0.500-1.000	58.0	---	34.0	---	14	---
T451	0.250-1.000	58.0	---	36.0	---	14	---
	1.001-2.000	58.0	---	36.0	---	12	---
	2.001-3.000	57.0	---	36.0	---	8	---
T6, T62	0.020-0.039	64.0	---	57.0	---	6	4
	0.040-0.050	66.0	---	58.0	---	7	5
	0.051-0.124	66.0	---	58.0	---	7	6
	0.125-0.249	66.0	---	58.0	---	7	8
T62, T651	0.250-0.499	67.0	---	59.0	---	7	10
	0.500-1.000	67.0	---	59.0	---	6	---
	1.001-2.000	67.0	---	59.0	---	4	---
	2.001-2.500	65.0	---	58.0	---	2	---
	2.501-3.000	63.0	---	57.0	---	2	---
	3.001-4.000	59.0	---	55.0	---	1	---
F	0.250-1.000	---	---	---	---	---	---

WROUGHT ALUMINUM ALLOYS - TYPICAL PHYSICAL PROPERTIES[a]								
Alloy	**Average[b] Coefficient of Thermal Expansion 20 to 100°C Per °C**	**Approximate[c, d] Melting Range °C**	**Temper**	**Thermal Conductivity at 25°C W/mK**	**Electrical[e] Conductivity at 20°C (68°F) Equal Volume**	**Electrical[e] Conductivity at 20°C (68°F) Equal Mass**	**Electrical Resistivity at 20°C Ohm mm/m**	**Density 10 kg/m**
1100	23.6	640-655	0	222	59	194	0.029	2.71
2036	23.4	555-650	T4	159	41	135	0.042	2.75
2038	23.4	555-650	T4	155	40	132	0.043	2.73
3002	---	---	---	---	---	---	---	2.70
3003	23.2	640-655	H14	159	41	134	0.042	2.73
3004	23.9	630-655	All	163	42	137	0.042	2.72
5005	23.8	630-655	All	201	52	172	0.033	2.70
5052	23.8	605-650	All	138	35	116	0.050	2.78
5083	23.8	580-640	0	117	29	98	0.059	2.66
5086	23.8	585-640	All	126	31	104	0.056	2.66
5182	24.1	575-640	All	121	31	110	0.056	2.65
5252	23.8	605-650	All	138	35	116	0.050	2.67
5454	23.6	600-640	0	134	34	113	0.050	2.69
			H38	134	34	113	0.050	---
5457	23.8	630-655	All	176	46	153	0.037	2.69
6009	23.4	605-650	All	167	44	144	0.039	2.71
6010	23.2	585-650	All	151	39	128	0.044	2.71
6061	23.6	580-650	T4	155	40	132	0.043	2.70
			T6	167	43	142	0.040	---
6063	23.4	615-655	T1	193	50	165	0.034	2.70
			T5	209	55	181	0.031	2.70
			T6	201	53	175	0.032	2.70
6111	23.4	585-650	T4	154	40	131	0.043	2.71
			T6	174	45	147	0.038	2.71

TYPICAL USES OF ALUMINUM CAST ALLOYS

Alloy Designations			Type of Casting[a]	Similar Specifications	
UNS	ANSI	Former SAE		ASTM	AMS
A02010	201.0	382	S	B26	---
			PM	---	4229
A02060	206.0	---	S	---	4237
			PM	---	---
A02420	242.0	39	S	B26	---
			PM	B108	---
A02950	295.0	38	S	B26	---
A02960	296.0	380	PM	B108	---
A03190	319.0	326	S	B26	---
			PM	B108	---
A23190	B319.0	329	S	---	---
			PM	---	---
A03320	332.0	332	PM	B108	---
A03330	333.0	331	PM	B108	---
A03360	336.0	321	PM	B108	---
A03390	339.0	---	PM	---	---
A03540	354.0	---	PM	B108	---
				B686	---
A03550	355.0	322	S	B26	4210
			PM	B108	4212
				---	4214
				---	4280
				---	4281
A33550	C355.0	335	S	B26	4215
			PM	B108	---
				B686	---

TYPICAL THERMAL TREATMENTS OF ALUMINUM CAST ALLOYS

Alloy		Temper	Sand Castings						Permanent Mold Castings					
			Solution Heat Treatment[a]			Precipitation Heat Treatment			Solution Heat Treatment[a]			Precipitation Heat Treatment		
			Temperature		Hours	Temperature		Hours	Temperature		Hours	Temperature		Hours
UNS	ANSI		± 10°F	± 6°C		± 10°F	± 6°C		± 10°F	± 6°C		± 10°F	± 6°C	
A02010	201.0	T6	980[b]	527[b]	14-20	310[c]	154[c]	20	980[b]	527[b]	14-20	310[c]	154[c]	20
		T7	980[b]	527[b]	14-20	370[c]	188[c]	5	980[b]	527[b]	14-20	370[c]	188[c]	5
A02060	206.0	T4	980[b]	527[b]	14-20	---	---	---	980[b]	527[b]	14-20	---	---	---
A02420	242.0	0	---	---	---	650	343	3	---	---	---	650	343	3
		T571	---	---	---	400	204	8	---	---	---	340	171	22-26
		T61	960[e]	516	6-12	450	232	1-3	960[e]	516	4-12	400	204	3-5
		T77	960[e]	516	6	650	342	2 min.	---	---	---	---	---	---
A02950	295.0	T4	960	516	12	---	---	---	---	---	---	---	---	---
		T6	960	516	12	310	154	3-6	---	---	---	---	---	---
		T62	960	516	12	310	154	12-24	---	---	---	---	---	---
		T7	960	516	12	500	260	4-6	---	---	---	---	---	---
A02960	296.0	T4	---	---	---	---	---	---	950	510	8	---	---	---
		T6	---	---	---	---	---	---	950	510	8	310	154	3-8
		T7	---	---	---	---	---	---	950	510	8	500	260	4-6
A03190	319.0	T5	---	---	---	400	204	8	---	---	---	---	---	---
		T6	940	504	6-12	310	154	2-5	940	504	4-12	310	154	2-5
		T61	---	---	---	---	---	---	940	504	4-12	310	154	8-12
A23190	B319.0	T5	---	---	---	400	204	8	---	---	---	---	---	---
		T6	940	504	6-12	310	154	2-5	940	504	4-12	310	154	2-5
A03320	332.0	T5	---	---	---	---	---	---	---	---	---	400	204	7-9
A03330	333.0	T5	---	---	---	---	---	---	---	---	---	400	204	7-9
		T6	---	---	---	---	---	---	940	504	6-12	310	154	2-5
		T7	---	---	---	---	---	---	940	504	6-12	500	260	4-6

INTERNATIONAL SPECIFICATION DESIGNATIONS & TITLES OF ALUMINUM AND ALUMINUM ALLOYS	
Specification	**Title**
ISO 209: Part 1	Wrought aluminium and aluminium alloys - chemical composition and forms of products - Chemical composition
ISO 209: Part 2	Wrought aluminium and aluminium alloys - chemical composition and forms of products - Forms of products
ISO 2107	Aluminium, magnesium and their alloys – Temper designations
ISO 2378	Aluminium alloy chill castings - Reference test bar
ISO 2379	Aluminium alloy sand castings - Reference test bar
ISO 2437	Recommended practice for the X-ray inspection of fusion welded butt joints for aluminium and its alloys and magnesium and its alloys 5 to 50 mm thick
ISO 3522	Cast aluminium alloys - Chemical composition and mechanical properties
ISO 3777	Radiographic inspection of resistance spot welds for aluminium and its alloys - Recommended practice – Withdrawn 1998
ISO 5193	Wrought aluminium and aluminium alloys - Drawn round bars - Tolerances on shape and dimensions (Symmetric plus and minus tolerances on diameter)
ISO 6279	Plain bearings - Aluminium alloy for solid bearings
ISO 6361: Part 1	Wrought aluminium and aluminium alloy sheets, strips and plates - Technical conditions for inspection and delivery
ISO 6361: Part 2	Wrought aluminium and aluminium alloy sheets, strips and plates - Mechanical properties
ISO 6361: Part 3	Wrought aluminium and aluminium alloy sheets, strips and plates - Strips - Tolerances on shape and dimensions
ISO 6361: Part 4	Wrought aluminium and aluminium alloy sheets, strips and plates - Sheets and Plates - Tolerances on form and dimensions
ISO 6362: Part 1	Wrought aluminium and aluminium alloy extruded rods/bars, tubes and profiles - Technical conditions for inspection and delivery
ISO 6362: Part 2	Wrought aluminium and aluminium alloy extruded rods/bars, tubes and profiles - Mechanical properties
ISO 6362: Part 3	Wrought aluminium and aluminium alloy extruded rods/bars, tubes and profiles - Extruded rectangular bars - Tolerances on shape and dimensions
ISO 6362: Part 4	Wrought aluminium and aluminium alloy extruded rods/bars, tubes and profiles - Extruded profiles - Tolerances on shape and dimensions
ISO 6362: Part 5	Wrought aluminium and aluminium alloy extruded rods/bars, tubes and profiles - Extruded round, square and hexagonal bars - Tolerances on shape and dimensions
ISO 6363: Part 1	Wrought aluminium and aluminium alloy cold-drawn rods/bars and tubes - Technical conditions for inspection and delivery
ISO 6363: Part 2	Wrought aluminium and aluminium alloy cold-drawn rods/bars and tubes - Mechanical properties
ISO 6363: Part 4	Wrought aluminium and aluminium alloy cold-drawn rods/bars and tubes - Drawn rectangular bars - Tolerances on form and dimensions
ISO 6363: Part 5	Wrought aluminium and aluminium alloy cold-drawn rods/bars and tubes - Drawn square and hexagonal bars - Tolerances on form and dimensions

EN 1706 – CHEMICAL COMPOSITION OF ALUMINUM & ALUMINIUM ALLOYS - CASTINGS

Designation[a]		
Number	**Symbol**	**Chemical Composition**
21000	Al Cu4MgTi	Al rem Si 0.20 Fe 0.35 Cu 4.2-5.0 Mn 0.10 Mg 0.15-0.35 Ni 0.05 Zn 0.10 Pb 0.05 Sn 0.05 Ti 0.15-0.30
21100	Al Cu4Ti	Al rem Si 0.18 Fe 0.19 Cu 4.2-5.2 Mn 0.55 Zn 0.07 Ti 0.15-0.30
41000	Al Si2MgTi	Al rem Si 1.6-2.4 Fe 0.60 Cu 0.10 Mn 0.30-0.50 Mg 0.45-0.65 Ni 0.05 Zn 0.10 Pb 0.05 Sn 0.05 Ti 0.05-0.20
42000	Al Si7Mg	Al rem Si 6.5-7.5 Fe 0.55 Cu 0.20 Mn 0.35 Mg 0.20-0.65 Ni 0.15 Zn 0.15 Pb 0.15 Sn 0.05 Ti 0.05-0.25
42100	Al Si7Mg0.3	Al rem Si 6.5-7.5 Fe 0.19 Cu 0.05 Mn 0.10 Mg 0.25-0.45 Zn 0.07 Ti 0.08-0.25
42200	Al Si7Mg0.6	Al rem Si 6.5-7.5 Fe 0.19 Cu 0.05 Mn 0.10 Mg 0.45-0.70 Zn 0.07 Ti 0.08-0.25
43000	Al Si10Mg(a)	Al rem Si 9.0-11.0 Fe 0.55 Cu 0.05 Mn 0.45 Mg 0.25-0.45 Ni 0.05 Zn 0.10 Pb 0.05 Sn 0.05 Ti 0.15
43100	Al Si10Mg(b)	Al rem Si 9.0-11.1 Fe 0.55 Cu 0.10 Mn 0.45 Mg 0.25-0.45 Ni 0.05 Zn 0.10 Pb 0.05 Sn 0.05 Ti 0.15
43200	Al Si10Mg(Cu)	Al rem Si 9.0-11.2 Fe 0.65 Cu 0.35 Mn 0.55 Mg 0.20-0.45 Ni 0.15 Zn 0.35 Pb 0.10 Ti 0.20
43300	Al Si9Mg	Al rem Si 9.0-11.3 Fe 0.19 Cu 0.05 Mn 0.10 Mg 0.25-0.45 Zn 0.07 Ti 0.15
43400	Al Si10Mg(Fe)	Al rem Si 9.0-11.4 Fe 1.0 Cu 0.10 Mn 0.55 Mg 0.20-0.45 Ni 0.15 Zn 0.15 Pb 0.15 Sn 0.05 Ti 0.20
44000	Al Si11	Al rem Si 10.0-11.8 Fe 0.19 Cu 0.05 Mn 0.10 Mg 0.45 Zn 0.07 Ti 0.15
44100	Al Si12(b)	Al rem Si 10.5-13.5 Fe 0.65 Cu 0.15 Mn 0.55 Mg 0.10 Ni 0.10 Zn 0.15 Pb 0.10 Ti 0.20
44200	Al Si12(a)	Al rem Si 10.5-13.5 Fe 0.55 Cu 0.05 Mn 0.35 Zn 0.10 Ti 0.15
44300	Al Si12(Fe)	Al rem Si 10.5-13.5 Fe 1.0 Cu 0.10 Mn 0.55 Zn 0.15 Ti 0.15
44400	Al Si9Mg	Al rem Si 8.0-11.0 Fe 0.65 Cu 0.10 Mn 0.50 Mg 0.10 Ni 0.05 Zn 0.15 Pb 0.05 Sn 0.05 Ti 0.15
45000	Al Si6Cu4	Al rem Si 5.0-7.0 Fe 1.0 Cu 3.0-5.0 Mn 0.20-0.65 Mg 0.55 Cr 0.15 Ni 0.45 Zn 2.0 Pb 0.30 Sn 0.15 Ti 0.25
45100	Al Si5Cu3Mg	Al rem Si 4.5-6.0 Fe 0.60 Cu 2.6-3.6 Mn 0.55 Mg 0.15-0.45 Ni 0.10 Zn 0.20 Pb 0.10 Sn 0.05 Ti 0.25
45200	Al Si5Cu3Mn	Al rem Si 4.5-6.0 Fe 0.8 Cu 2.5-4.0 Mn 0.20-0.55 Mg 0.40 Ni 0.30 Zn 0.55 Pb 0.20 Sn 0.10 Ti 0.20
45300	Al Si5Cu1Mg	Al rem Si 4.5-5.5 Fe 0.65 Cu 1.0-1.5 Mn 0.55 Mg 0.35-0.65 Ni 0.25 Zn 0.15 Pb 0.15 Sn 0.05 Ti 0.05-0.25
45400	Al Si5Cu3	Al rem Si 4.5-6.0 Fe 0.60 Cu 2.6-3.6 Mn 0.55 Mg 0.05 Ni 0.10 Zn 0.20 Pb 0.10 Sn 0.05 Ti 0.25
46100	Al Si11Cu2(Fe)	Al rem Si 10.0-12.0 Fe 1.1 Cu 1.5-2.5 Mn 0.55 Mg 0.30 Ni 0.45 Zn 1.7 Pb 0.25 Sn 0.25 Ti 0.25
46200	Al Si8Cu3	Al rem Si 7.5-9.5 Fe 0.8 Cu 2.0-3.5 Mn 0.15-0.65 Mg 0.05-0.55 Cr 0.15 Ni 0.35 Zn 1.2 Pb 0.25 Sn 0.15 Ti 0.25
46300	Al Si7Cu3Mg	Al rem Si 6.5-8.0 Fe 0.8 Cu 3.0-4.0 Mn 0.20-0.65 Mg 0.30-0.60 Ni 0.30 Zn 0.65 Pb 0.15 Sn 0.10 Ti 0.25
46000	Al Si9Cu3(Fe)	Al rem Si 8.0-11.0 Fe 1.3 Cu 2.0-4.0 Mn 0.55 Mg 0.05-0.55 Cr 0.15 Ni 0.55 Zn 1.2 Pb 0.35 Sn 0.25 Ti 0.25
46400	Al Si9Cu1Mg	Al rem Si 8.3-9.7 Fe 0.8 Cu 0.8-1.3 Mn 0.15-0.55 Mg 0.25-0.65 Ni 0.20 Zn 0.8 Pb 0.10 Sn 0.10 Ti 0.10-0.20
46500	Al Si9Cu3(Fe)(Zn)	Al rem Si 8.0-11.0 Fe 1.3 Cu 2.0-4.0 Mn 0.55 Mg 0.05-0.55 Ni 0.55 Zn 3.0 Pb 0.35 Sn 0.25 Ti 0.25
46600	Al Si7Cu2	Al rem Si 6.0-8.0 Fe 0.8 Cu 1.5-2.5 Mn 0.15-0.65 Mg 0.35 Ni 0.35 Zn 1.0 Pb 0.25 Sn 0.15 Ti 0.25

INTERNATIONAL CROSS REFERENCES – ALUMINUM & ALUMINUM CAST ALLOYS						
USA AA	**UK BS**	**GERMANY DIN**	**FRANCE NF**	**INTERNATIONAL ISO**	**JAPAN JIS**	**RUSSIA GOST**
A242	4L35	---	A-U4NT	Al Cu4Ni2Mg2	---	AL1
---	---	AlCu4Ti	---	Al Cu4Ti	---	AL19
204	---	AlCu4TiMg	A-U5GT	Al Cu4MgTi	AC1B	---
295	L154	---	---	---	AC1A	AL7
203	---	---	A-U5NKZr	---	---	---
---	---	---	A-U8S	---	---	---
222	LM12	---	---	---	---	---
355	LM16	3.2134	---	AlSi5Cu1Mg	AC4D	AL5
363	---	---	A-S5U3G	AlSi5Cu3	AC2A	AK5M2
---	LM4	---	A-S5U3	---	---	AL6
319	LM21	AlSi6Cu4	A-S5UZ	AlSi6Cu4	AC2B	AK5M
---	LM27	---	---	---	---	AK7M2
320	---	---	A-S7U3G	---	---	---
380	LM24	AlSi9Cu3	A-S9U3	AlSi8Cu3Fe	AC4B	AK8M3
---	---	---	A-S9U3Z	---	---	---
383	LM2	---	---	---	---	---
---	---	VDS-Nr260	A-S12UNG	---	AC8A	---
---	---	---	---	---	---	---
---	---	---	---	---	---	AK12M2N
390	LM30	---	---	---	---	---
---	LM28	---	---	---	---	---
393	LM29	---	---	---	---	AK21M2N2
A443	---	---	---	Al Si5	---	---
B443	---	---	---	Al Si5Fe	---	---
A444	---	---	---	---	---	AK7
---	---	---	A-S9	---	---	---

INTERNATIONAL CROSS REFERENCES – ALUMINUM & ALUMINUM WROUGHT ALLOYS						
USA AA	**UK BS**	**GERMANY DIN**	**FRANCE NF**	**INTERNATIONAL ISO**	**JAPAN JIS**	**RUSSIA GOST**
1050	---	---	---	---	A 1050	---
1050A	1B	A199.5	A5	Al 99.5	---	---
1060	---	---	---	Al 99.6	A 1060	A6
1065	---	---	---	---	---	---
1070	---	---	---	---	A 1070	A7
1070A	---	A199.7	A7	Al 99.7	---	---
1080	---	---	---	---	A 1080	---
1080A	A8	A199.8	A8	Al 99.8(A)	---	---
1085	---	---	---	---	A 1085	---
1090	---	---	---	---	A 1N90	---
1098	---	A199.98R	---	---	---	---
1100	A45	---	A45	Al 99.0 Cu	A 1100; A 1N00	---
1185	---	---	---	---	A 1185	A85
1199	---	---	---	---	---	A99
1200	A4	A199	A4	Al 99.0	A 1200	A0
1230	---	---	---	Al 99.3	A 1N30	---
1250	---	---	---	---	---	---
1350	---	---	---	E-Al 99.5	---	A5E
1350A	---	E-A1	---	---	---	---
1370	---	---	---	E-Al 99.7	---	---
2001	---	---	A-U6MT	---	---	---
2007	---	AlCuMgPb	---	---	---	---
2011	FC1	AlCuBiPb	A-U5PbBi	Al Cu6BiPb	A 2011	---
2011A	H15	---	---	---	---	---
2014	---	AlCuSiMn	A-U4SG	Al Cu4SiMg	A 2014	1110
2014A	---	---	---	Al Cu4SiMg(A)	---	---
2017	---	---	---	Al Cu4MgSi	A 2017	---

Chapter 2

COPPER & COPPER ALLOYS

Copper is one of the first metals used by humanity. Initially, the naturally occurring native copper was exploited but since at least 5000 BC copper has been produced as a smelted product. It was likely the first metal to be smelted from its ore as well as the first metal used in alloyed form. The copper-tin alloy bronze has been used since at least 3500 BC and the copper-zinc alloy brass since before Roman times. Copper and its alloys remain to this day among the most important engineering materials as a result of a combination of properties which include resistance to corrosion, outstanding electrical and thermal conductivity, attractive appearance, strength, ductility, and ease of fabrication and joining.

Copper is produced by the smelting of sulphide minerals. Since copper ores are generally low-grade, with copper contents well below 1%, they are first subjected to beneficiation to produce a concentrate. This concentrate is smelted, usually via pyrometallurgical processes, to impure "blister copper." Blister copper is fire refined to tough pitch copper, which contains at least 99.5%Cu with a significant content of copper oxide. Tough pitch copper is normally cast into anodes and refined electrolytically to produce electrolytic copper (≥99.95%Cu), also known as cathode copper, which is remelted and cast into shapes for further fabrication. Alloying can be carried out as desired during this final remelting. Some copper is extracted by hydrometallurgical methods, producing a copper-bearing aqueous solution from which refined copper is extracted by electrowinning. Processing of copper-bearing scrap is very common, with more than half of refined copper produced coming from recycled scrap.

About half of the copper consumption is processed in wire mills, for production of electrical conductors (wire and cable). Another 40% goes to brass mills where both unalloyed and alloyed copper products are produced. The unalloyed copper and high-copper alloys are typically produced as tube for plumbing and air conditioning, as well as bus bar and roofing sheet. The main copper alloy products are free-cutting brass rod and brass strip, with other products including plate, sheet, tube, bar, forgings, extrusions and mechanical wire. Minor amounts of copper are consumed in foundries, as powder metallurgy products and in other metallurgical and chemical industries.

The major markets for copper and copper alloy products are, in decreasing order of importance, the building industry, electrical and electronic products, industrial machinery and equipment, transportation, and consumer and general products. Both cast and wrought products are used.

Pure copper has a face-centered cubic (fcc) crystal structure, and is a very soft material, with a ductility so high that it can be subjected to very large changes in shape in a single reduction pass. It can be strengthened by solid solution strengthening and by cold working, with reasonably high strength levels being achieved in some alloys. Formability decreases with increasing cold work. Many copper-based materials are solid solutions, with single phase (face-centered cubic) microstructures. In a few alloys, a dispersion of particles of an intermetallic phase can form, providing a grain refining and strengthening effect which results in improved formability for a given strength level. In UNS C63800 and C68800, for example, these intermetallic particles result from the presence of cobalt.

Most copper-based alloys are not strengthened by heat treatment but there are some important exceptions. Precipitation hardening can give very high strengths to the beryllium-coppers (e.g., UNS C17000, C17200, C17300, C17500, and C17510), the zirconium-coppers (e.g. UNS C15000 and C15100), the chromium-coppers (e.g., UNS C18200, 18400, and 18500), some copper-nickel-phosphorus alloys (e.g., UNS C19000 and C19100) and the copper-nickel-silicon alloys UNS C64700 and C70250. A few other alloys, including UNS C71900 (copper-nickel-chromium) can be hardened by spinodal decomposition. Certain aluminum bronzes, notably those containing more than 9%Al, can be hardened by quenching from above a critical temperature to form a martensitic microstructure. Control of the quenching rate or tempering after the quench gives more control over mechanical properties, as is the case in ferrous martensites. Some alloys have additions of lead, sulphur, or tellurium to improve machinability, but these generally have detrimental effects on hot workability (lead in high-zinc brass is an exception as discussed below). Other alloying additions are made to deoxidize the copper; phosphorus in tin bronzes and silicon in chromium-coppers are examples.

Corrosion Resistance

Copper and its alloys are relatively resistant to general corrosion in most environments, but can be susceptible to stress corrosion cracking (e.g., brass in ammonia, amines, mercury compounds or cyanide). Some copper-based alloys in some environments suffer from hydrogen embrittlement by the steam reaction (e.g., tough pitch copper in reducing atmospheres). Brasses containing more than 15%Zn are also susceptible to dezincification, in which zinc is selectively removed by corrosion from the surface of the material, leaving a porous layer of copper and corrosion products.

Weldability

Copper and its alloys are most frequently welded using GTAW (gas tungsten arc welding), or its pulsed variant, especially for thin sections, since high localized heat input is important in materials with high thermal conductivity. In thicker sections, GMAW (gas metal arc welding) is preferred. The weldability varies among the different alloys for a variety of reasons, including the occurrence of hot cracking in the leaded (free-machining) alloys and unsound welds in alloys containing copper oxide. Tin and zinc both reduce the weldability of copper alloys. The presence in the alloy of residual phosphorus is beneficial to weldability, since it combines with absorbed oxygen, thereby preventing the formation of copper oxide in the weld. Resistance welding is also widely used, particularly in alloys with low thermal conductivity. Most copper alloys can be brazed satisfactorily. Oxygen-bearing coppers can be subject to gassing and embrittlement, particularly in oxyacetylene welding.

Nomenclature

Copper and its alloys were formerly given designations according to the Copper Development Association (CDA) system of three digits. This CDA system was used as the basis for the Unified Numbering System (UNS) designations, shown in Table 1. For copper and its alloys, the UNS system has come into common usage by all specification writing organizations.

The traditional system of temper designations referred to the amount of reduction in cold work, stated in Brown & Sharpe (B&S) gage numbers for rolled sheet and drawn wire. The current system defined in ASTM B 601 is more comprehensive; this assigns an alphanumeric code to each of the standard descriptive temper designations. Here cold worked tempers are defined by the letter H and 2 digits where the digits refer either to the amount of cold work or to the specific product. Other letter designations, which are followed by digits used for many purposes, include: HR (cold worked and stress relieved), M (as manufactured), O and OS (annealed), TB (solution treated), TD (solution treated and cold worked), TF (solution treated and precipitation hardened), TM (mill hardened), TQ (quench hardened), and WH (welded and drawn).

Table 1 UNS Designations For Copper & Copper Alloys

UNS Designations - Wrought Alloys	
C10100-C15760	Coppers (>99%Cu)
C16200-C19600	High-copper alloys (>96%Cu)
C21000-C28000	Brasses (Cu-Zn)
C31200-C38500	Leaded brasses (Cu-Zn-Pb)
C40400-C48600	Tin brasses (Cu-Zn-Sn-Pb)
C50100-C52400	Phosphor bronzes (Cu-Sn-P)
C53400-C54400	Leaded phosphor bronzes (Cu-Sn-Pb-P)
C55180-C55284	Copper-phosphorus and copper-silver-phosphorus alloys (Cu-P-Ag)
C60800-C64210	Aluminum bronzes and aluminum-silicon bronzes (Cu-Al-Ni-Fe-Si-Sn)
C64700-C66100	Silicon bronzes (Cu-Si-Sn)
C66400-C69900	Other copper-zinc alloys
C70100-C72950	Copper-nickels (Cu-Ni-Fe)
C73500-C79800	Nickel silvers (Cu-Ni-Zn)
UNS Designations - Cast Alloys	
C80100-C81200	Coppers (>99%Cu)
C81400-C82800	High-copper alloys (>94%Cu)
C83300-C84800	Red and leaded red brasses (Cu-Zn-Sn-Pb, 75-89%Cu)
C85200-C85800	Yellow and leaded yellow brasses (Cu-Zn-Sn-Pb, 57-74%Cu)
C86100-C86800	Manganese bronzes and leaded manganese bronzes (Cu-Zn-Mn-Fe-Pb)
C87300-C87800	Silicon bronzes, silicon brasses (Cu-Zn-Si)
C90200-C94500	Tin bronzes and leaded tin bronzes (Cu-Sn-Zn-Pb)
C94700-C94900	Nickel-tin bronzes (Cu-Ni-Sn-Zn-Pb)
C95200-C95900	Aluminum bronzes (Cu-Al-Fe-Ni)
C96200-C96800	Copper-nickels (Cu-Ni-Fe)
C97300-C97800	Nickel silvers (Cu-Ni-Zn-Pb-Sn)
C98200-C98800	Leaded coppers (Cu-Pb)
C99300-C99750	Miscellaneous alloys

Copper and its alloys are discussed in this chapter in order of the UNS system general categories, i.e., wrought alloys first, beginning with coppers and high-copper alloys and moving through brasses, bronzes, copper-nickels and nickel silvers, followed by cast alloys in a similar order. It is important to note that although the terms brass and bronze can be clearly defined as copper-zinc and copper-tin alloys respectively, the common names are not always consistent with these definitions. In particular, the name "bronze" is applied to many different copper-based alloys. Hence, for example, Cu-10%Zn is called "commercial bronze" despite the fact that it is clearly a brass and is so categorized in the CDA and UNS designation systems.

Wrought Alloys - Coppers (UNS C10100-C15760)

Unalloyed copper is widely used, mainly because of its high electrical conductivity, but also to take advantage of its attractive appearance, its corrosion resistance, ease of fabrication, and reasonable strength. These "coppers" are classified according to their oxygen and impurity contents since these have strong effects on electrical conductivity. Oxygen is normally present as copper oxide particles, often in the copper-copper oxide eutectic which forms interdendritically during ingot casting. Oxygen also forms a fine dispersion of blowholes which prevent pipe cavities from forming during ingot solidification. These are welded together during hot working.

The electrical conductivity, which is reported as %IACS (International Annealed Copper Standard), is affected by both oxygen and impurity atoms. Impurity atoms in solid solution degrade the conductivity, but if they can react with oxygen to form oxides they have a less detrimental effect. On the other hand, oxygen in the form of copper oxide can create problems when the material is heated above 400°C (752°F) in atmospheres containing hydrogen. The hydrogen atoms diffuse into the copper and reduce copper oxide particles to create steam under high pressure which can cause rupture along grain boundaries. This "steam embrittlement" creates problems during annealing, brazing, or welding in a reducing atmosphere.

In general, coppers have good resistance to corrosion by non-oxidizing acids unless the acids are aerated. Coppers also resist caustic solutions, saline solutions, and natural and process waters, including ground water. They are not used in oxidizing environments such as nitric acid, ammonia, ferric chloride, acid chromate solutions, mercury salts, perchlorates, or persulphates.

The machinability of these coppers is poor because of their high ductility, but some compositions have been developed specifically to counteract this deficiency. UNS C14500 and C14700 contain small additions of tellurium and sulphur, respectively, to make them free-machining for use in screw machine products requiring some combination of conductivity, corrosion resistance, colour, etc., for example electrical and plumbing components and fittings.

High-Copper Alloys (UNS C16200-C19600)

These materials, sometimes referred to as dilute copper alloys, contain more than 96%Cu generally with more than 0.7% impurities and additions, including beryllium, cadmium, chromium, and iron. Many of the alloys in this classification are heat-treatable by precipitation hardening. The first stage of this process involves solution treating at temperatures above 750°C (1382°F) to take the alloying elements into solid solution, then quenching to create a supersaturated solid solution. This is then given an aging treatment at 260-500°C (500-932°F) to allow a fine dispersion of strengthening particles to precipitate from solution. The coarseness of the dispersion of particles determines the strength and ductility. If aging is carried out too long or at too high a temperature, the particles become too coarse, the strength falls below the maximum possible (the "peak aged" condition), and the alloy is said to be "overaged." The particles which precipitate from solution are generally intermetallic phases or non-equilibrium transition phases which are their precursors. For example, in the beryllium-copper system the precipitating intermetallic phase is (Cu,Co)Be, a mixed copper-cobalt beryllide.

The most important of the high-copper alloys are beryllium-copper alloys, which can be precipitation hardened to very high strength levels. There are two commercially important groups of beryllium-copper alloys, with different beryllium contents as well as additions of cobalt or nickel. One group, the "red" alloys, which includes alloys UNS C17500 and C17510, contains approximately 0.2-0.7%Be with additions of nickel or cobalt totaling 1.4-2.7%. These alloys maintain a moderate electrical conductivity (50%IACS) and yield strengths as high as 895 MPa (130 ksi) and find applications as fasteners and connectors, springs, switch parts, and spot welding tips. The higher alloyed "gold" alloys, such as UNS C17000 and C17200, contain 1.4-2.7%Be, which gives them their shiny lustrous colour, plus about 0.25%Co. These are even stronger than the "red" alloys, with yield strength as high as 1380 MPa (200 ksi). For enhanced machinability, lead additions can be made (UNS C17300) but electrical conductivity is as low as 20%IACS. These alloys are used for applications requiring high strength combined with good formability, for example in bellows, valves, pumps, rolling mill parts, and nonsparking predicts that this phase is unstable below 350°C (662°F). The hardness of the δ phase contributes to wear resistance of the alloys and improves their suitability for use as bearing materials.

If phosphorus is present in excess of that required for deoxidation, it occurs as the hard intermetallic compound Cu3P, which can have a strengthening effect. Most of the phosphor bronzes contain about 0.2%P, which is sufficient for purposes of deoxidation, while tin contents range up to above 10%. Most alloys are produced as flat products, bar, rod, wire, and tubing. Common alloys include UNS C50500 (1.3%Sn), which is used in such applications as electrical hardware, and UNS C51000 (5%Sn) and C51100 (4%Sn) which are used for architectural, electrical, fasteners, and industrial components. For more severe service conditions, higher tin alloys are employed, including UNS C52100 (8%Sn) and C52400 (10%Sn). Examples of specific applications include bridge bearing and expansion plates and fittings, Bourdon tubes, fasteners, chemical hardware, and textile machinery components.

In addition to these lead-free alloys, there is a free-machining phosphor bronze, UNS C54400, which contains 4% of each of tin, lead, and zinc. This is used for bearings, bushings, gears, and screw machine products.

Aluminum Bronzes (UNS C60800-C64210)

These materials have good strength properties, with good resistance to wear and corrosion; the latter property is due to the formation of a protective surface film of aluminum oxide. This gives them resistance to non-oxidizing mineral acids as long as dissolved oxygen or oxidizing agents are not present in quantity. As well, they are suitable for service in alkalis, neutral salts, non-oxidizing acid salts, and many organic acids. They have good resistance to corrosion by water, including sea water, although resistance is less in softened water. They are susceptible to stress corrosion cracking in moist ammonia and mercury compounds.

The commercial alloys in this system contain 5-13%Al with minor amounts of nickel, iron, silicon, and cobalt. In these alloys, a range of microstructures can be obtained depending on composition and heat treatment. Alloys containing 5-8%Al are solid solution alloys similar to the α-brasses. Aluminum is a highly effective solid solution strengthening agent, comparable to tin and much more effective than zinc; hence, these alloys have good strength (increasing with aluminum content) as well as good toughness, cold workability, and corrosion resistance. Examples include UNS C60800 (5%Al) which is used in the form of seamless tubing for heat exchangers and condensers, and UNS C61000 (8%Al) which is produced as rod and wire for bolts, shafts and

UNS C63800 (3%Al, 2%Si, 0.4%Co) is a high strength aluminum bronze in which the presence of cobalt is responsible for strengthening by a dispersion of intermetallic particles. This alloy also has excellent resistance to crevice corrosion and to high temperature oxidation and is used for springs, switch parts, contacts, glass sealing, and porcelain enamelling.

Silicon Bronzes (UNS C64700-C66100)

These alloys contain 1-3%Si, with small additions of manganese and iron to improve properties. They are not heat treatable but can be cold worked to high strength levels. Their combination of corrosion resistance with high strength and toughness compares favourably to that of low-carbon steels.

Low-silicon bronze UNS C65100 (1.5%Si), available in bar, rod, wire, and shapes as well as tubular and flat products, is used for aircraft hydraulic pressure lines, heat exchanger tubes, and marine and industrial hardware and fasteners. The high-silicon bronze UNS C65500 (3%Si) is used for similar applications as well as for chemical process equipment and marine propeller shafts.

Copper-Nickels (UNS C70100-C72950)

Nickel has complete solid solubility in copper so that a continuous range of solid solution copper-nickel alloys is possible, all with the fcc crystal structure. The cupronickel alloys containing 10-30%Ni have moderate strength provided by the nickel which also improves the oxidation and corrosion resistance of copper. These alloys have good hot and cold formability and are produced as flat products, pipe, rod, tube, and forgings. The common alloys are UNS C70600 (10%NI), C71000 (20%Ni), and C71500 (30%Ni). These find applications as plates and tubes for evaporators, condensers, and heat exchangers as well as for saltwater piping. The alloy UNS C71900 (30%Ni, 3%Cr) is similar to UNS C71500 but the chromium content permits it to undergo spinodal decomposition during slow cooling. This produces a two-phase microstructure, giving higher strength for a given amount of cold work. The tin-bearing copper-nickel UNS C72500 (10%Ni, 2.5%Sn) has excellent hot and cold formability in a wide range of forming processes, as well as excellent resistance to sea water. It is used for relay and switch springs, connectors, sensing bellows, and as a brazing alloy.

Nickel Silvers (UNS C73500-C79800)

Although these alloys are referred to as German silvers or nickel silvers, they contain no silver; they are copper-nickel-zinc alloys containing zinc in the range 17-27% along with 8-18%Ni. The use of the name silver arises from their colour, which ranges from soft ivory to silvery white as the nickel content is increased. Most of these alloys are single phase solid solutions, and have medium strengths with good cold workability. Corrosion resistance is excellent, but some are subject to dezincification and they can be susceptible to stress corrosion cracking as well.

Commercial alloys include UNS C74500 (25%Zn, 10%Ni), C75200 (17%Zn, 18%Ni), C75400 (20%Zn, 15%Ni), C75700 (23%Zn, 12%Ni), and C77000 (27%Zn, 18%Ni). Specific applications include hardware, fasteners, optical and camera parts, etching stock, and hollowware. They are particularly appropriate for articles which require a smooth surface for plating. The alloy UNS C78200 (25%Zn, 8%Ni) also contains 2%Pb to provide free-machining properties, making it suitable for use as key blanks and watch parts.

Cast Alloys

The cast copper alloys are generally comparable to the wrought alloys, however the ranges of allowable impurity and alloying elements are often larger in castings, as no consideration need be given to their effects on cold or hot workability. On the other hand, consideration must be given to castability, which is related to solidification shrinkage characteristics and the temperature range over which freezing occurs. Foundry alloys are conveniently classified as high-shrinkage or low-shrinkage alloys. Among the common high-shrinkage alloys are the manganese bronzes, aluminum bronzes, and silicon bronzes; the red brasses are low-shrinkage alloys. High-shrinkage alloys can produce high grade castings, but careful design is necessary to avoid internal shrinkage porosity and cracks.

Pure copper is extremely difficult to cast, with the potential for surface cracks and internal cavities. Small additions of alloying elements improve the casting characteristics, but for property improvement, larger amounts of alloying elements are necessary. In particular, for higher strength cast alloys, it is necessary to select aluminum bronzes, manganese bronzes, silicon bronzes, or some nickel silvers.

Sand casting is appropriate for all copper alloys. Permanent mold casting and die casting are applicable to tin bronzes, silicon bronzes, aluminum bronzes, and manganese bronzes, as well as to yellow brasses.

Investment casting is also applicable to many of these alloys, while plaster casting is most suitable for low-lead alloys. Most casting alloys are readily machinable, especially those containing lead particles in a copper-based solid solution. The most difficult alloys to machine are the high strength manganese bronzes and aluminum bronzes with high iron or nickel content.

Coppers (UNS C80100-C81200) and High Copper Alloys (UNS C81400-82800)

The high purity copper casting alloys, such as UNS C81100 (99.7%Cu), are soft and low in strength, but can be used in applications requiring electrical and thermal conductivity along with resistance to corrosion and oxidation. However, many high copper alloys are available which give better strength while retaining good conductivity. These are typically heat-treatable alloys containing more than 96%Cu with small amounts of chromium or beryllium and various combinations of silicon, cobalt, and nickel. Examples include the precipitation-hardenable chromium coppers UNS C81400 (0.8%Cu, 0.06%Be) and C81500 (1%Cr), used as electrical and/or thermal conductors which are also structural members. The heat-treatable low-beryllium casting coppers, containing about 0.5%Be, in which the silver content provides improved surface conductivity, includes UNS C82000 (2.5%Co, 0.5%Be) which is used for circuit breaker and switch gear parts and continuous casting molds, and UNS C82200 (1.5%Ni, 0.5%Be) whose uses include brake drums and clutch rings. In addition, these three low beryllium alloys find applications as components of welding equipment, such as electrodes, holders, tips, etc.

The high-strength precipitation-hardenable high-beryllium alloys often include cobalt for grain size control and silicon for improved castability. These alloys include UNS C82500 (2%Be, 0.5%Co, 0.25%Si) which is especially suited for investment casting and finds applications as safety (non-sparking) tools, machine components, and structural parts. Several modifications to this alloy are available, including UNS C82400 (1.7%Be, 0.3%Co), a lower cost, high toughness alloy which is used in marine applications, UNS C82800 (2%Be, 0.5%Co, 0.25%Si) which is a highly castable alloy used for molds for forming of plastics as well as for precision cast parts for the communications, textile, aerospace, and business machine industries, and beryllium-copper 21C (2%Be, 1%Co) which is desirable for thin section castings because of the grain-refining effect of the cobalt.

marine fittings. The heat-treatable alloys include UNS C95400/C95410 (11%Al, 4%Fe) and C95500 (11%Al, 4%Fe, 4%Ni), which are used for valve guides and seats, bushings, gears, and impellers. Alloy UNS C95800 (9%Al, 4%Fe, 4%Ni, 1%Mn) has higher resistance to cavitation and sea water fouling and so is especially suited for marine applications such as propeller blades and hubs.

Copper-Nickels (UNS C96200-C96800), Nickel Silvers (UNS C97300-97800) and Miscellaneous Alloys (UNS C99300-99750)

The common cast copper nickels are the solid solution alloys UNS C96200 (10%Ni) and C96400 (30%Ni) which are used for their sea water corrosion resistance as centrifugal and sand castings for valves, pump components, etc. A heat-treatable beryllium cupronickel, UNS C96600 (30%Ni, 0.5%Be), has about twice the strength of C96400 while maintaining sea water corrosion resistance for applications as pressure housings, pump and valve bodies, and line fittings for marine service. For improved castability, a higher-beryllium cupronickel 72C (30%Ni, 1.2%Be) is also available with applications in the plastic tooling industry. Leaded nickel silver alloys are used for investment, centrifugal, permanent mold, and sand castings for hardware fittings, valves, statuary, and ornamental castings. Alloys include UNS C97300 (12%Ni, 20%Zn, 10%Pb, 2%Sn), C97600 (20%Ni, 8%Zn, 4%Pb, 4%Sn), and C97800 (25%Ni, 2%Zn, 1.5%Pb, 5%Sn).

Alloys developed for resistance to dezincification and/or dealuminification under corrosion conditions are UNS C99400 (2%Ni, 2%Fe, 1%Al, 1%Si, 3%Zn) and the higher strength equivalent alloy UNS C99500 (4%Ni, 4%Fe, 1%Al, 1%Si, 1%Zn). Uses include valves, wheels, gears, and electrical parts for mining equipment and the outboard marine industry.

SAE/AMS SPECIFICATIONS - COPPER & COPPER ALLOYS	
AMS	**Title**
4500	Copper, Sheet, Strip, and Plate, Soft Annealed, UNS C11000
4501	Copper Sheet, Strip, and Plate, Oxygen-Free, Light Cold Rolled, UNS C10200
4505	Copper Alloy (Brass), Sheet, Strip, and Plate, 70Cu - 30Zn, Annealed (O61), UNS C26000
4507	Copper Alloy (Brass), Sheet, Strip, and Plate, 70Cu - 30Zn, Half Hard (HO2), UNS C26000
4508	Copper-Zinc Alloy Laminated Sheet 70Cu - 30Zn, Surface Bonded, UNS C26000
4510	Phosphor Bronze, Sheet, Strip, and Plate, 94.5Cu - 4.0Sn - 0.19P, Spring Temper (H08), UNS C51000
4511	Copper-Beryllium Alloy Castings, 97Cu - 2.1Be - 0.52(Co + Ni) - 0.28Si, Solution and Precipitation Heat Treated (TF00), UNS C82500
4520	Leaded Phosphor Bronze, Strip, 88.5Cu - 4.0Sn - 4.0Pb - 3.0Zn - 0.26P, Cold Rolled, Half Hard (HO2), UNS C54400
4533	Copper-Beryllium Alloy Bars and Rods 98Cu - 1.9Be Solution and Precipitation Heat Treated (TF00, formerly AT), UNS C17200
4534	Copper-Beryllium Alloy, Bars and Rods, 98Cu - 1.9Be, Solution Heat Treated, Cold Worked, and Precipitation Heat Treated (TH04, formerly HT), UNS C17200
4535	Copper-Beryllium Alloy, Mechanical Tubing, 98Cu - 1.9Be, Solution and Precipitation Heat Treated (TF00, formerly AT), UNS C17200
4553	Brass, Seamless, Tubing 85Cu - 15Zn, Annealed, UNS C23000
4554	Brass Tubing Seamless 66.5Cu - 33Zn - 0.45Pb, Annealed, UNS C33000
4555	Leaded Brass, Seamless Tubing 66.5Cu - 32.5Zn - 0.48Pb Light Annealed (O50), UNS C33000
4558	Brass, Seamless, Tubing 66.5Cu - 31.5Zn - 1.6Pb Drawn Temper (H58), UNS C33200
4590	Extrusions, Nickel-Aluminum Bronze, Martensitic 78.5Cu - 10.5Al - 5.1Ni - 4.8Fe, Solution Heat Treated and Tempered (TQ50), UNS C63020
4602	Copper Bars, Rods, and Shapes, Oxygen-Free, Hard Temper, UNS C10200
4610	Brass, Free-Cutting Bars and Rods 61.5Cu - 35Zn - 3.1Pb - Half Hard (H02), UNS C36000
4611	Brass, Naval, Bars and Rods 60.5Cu - 38.7Zn - 0.8Sn, Half Hard (H02), UNS C46400
4612	Brass, Naval, Bars and Rods 60.5Cu - 38.5Zn - 0.75Sn, Hard Temper (H04), UNS C46400
4614	Brass Forgings, Free Cutting, 60Cu - 2.0Pb - 37.5Zn, As Forged (M10), UNS C37700
4616	Silicon Bronze Bars, Rods, Forgings, and Tubing, 92Cu - 3.2Si - 2.8Zn - 1.5Fe, Stress Relieved, UNS C65620
4625	Phosphor Bronze Bars, Rods and Tubing, 95Cu - 5Sn, Hard Temper, UNS C51000
4633	Bronze, Aluminum Silicon, Rods, Bars, and Forgings, 90Cu - 7.0Al - 1.8Si, Drawn and Stress Relieved (HR50), UNS C64200
4634	Aluminum Bronze Bars, Rods, and Forgings, 90.5Cu - 7.5Al - 1.9Si, Stress Relieved, UNS C64200
4635	Aluminum Bronze Bars, Rods, and Forgings, 87Cu - 9Al - 3Fe, Stress Relieved, UNS C62300

ASTM SPECIFICATIONS AND PRODUCT FORMS FOR COPPER & COPPER ALLOYS

UNS	Electrical Conductors	Fasteners	Refinery Products	Plate, Sheet, Strip, Rolled Bar	Rod, Bar, Shapes, Die Forgings	Wire	Pipe & Tube
C10100	B 1, B 2, B 3, B 8, B 33, B 48, B 49, B 173, B 174, B187, B 188, B 189, B 246, B 272, B 286, B 298, B 355, B 470, B 496, F 68	---	---	B 152, B 432	---	---	B 75, B 111 (OFE), B 359, B 447, B 640, B 698 (OFE)
C10200	B 1, B 2, B 3, B 8, B 33, B 48, B 49, B 68, B 172, B 173, B 174, B 187, B 188, B 189, B 226, B 246, B 272, B 286, B 298, B 355, B 372, B 470, B 496, B 566, B 738	---	---	B 152, B 432	---	---	B 42, B 75, B 111, B 359, B 395, B 447, B 640, B 687, B 698 (OF), B 743
C10300	B 68, B 187, B 188, B 372	---	B 379	B 152, B 432	---	---	B 42, B 75, B 111, B 302, B 359, B 395, B 447, B 640, B 687, B 698 (OFXLP), B 743
C10400	B 1, B 2, B 3, B 49, B 187, 188, B 189, B 246, B 298, B 355	---	---	B 152	---	---	---
C10500	B 1, B 2, B 3, B 49, B 187, B 188, B 189, B 246, B 272, B 298, B 355	---	---	B 152	---	---	---
C10700	B 1, B 2, B 3, B 49, B 187, B 188, B 189, B 246, B 272, B 298, B 355	---	---	B 152	---	---	---
C10800	B 68, B 187	---	B 379	B 152, B 432	---	---	B 42, B 75, B 111, B 302, B 359, B 360, B 395, B 447, B 543, B 687, B 698 (OFLP), B 743

ASTM SPECIFICATIONS – CAST COPPER & COPPER ALLOYS	
UNS	**Ingots & Castings**
C81400	B 30, B 770
C82000	B 30 (10C), B 770
C82200	B 30 (3C, 14C), B 770
C82400	B 30 (165C, 165CT), B 770
C82500	B 30 (20C, 20CT), B 770
C82510	B 30 (21C), B 770
C82600	B 30 (245C, 245CT), B 770
C82800	B 30 (275C, 275CT), B 770
C83450	B 30, B 584, B 763
C83600	B 30 (4A), B 62, B 271, B 505, B 584
C83800	B 30, B 271, B 505, B 584, B 763
C84200	B 30, B 505
C84400	B 30, B 271, B 505, B 584, B 763
C84800	B 30, B 271, B 505, B 584, B 763
C85200	B 30, B 271, B 584, B 763
C85400	B 30, B 271, B 584, B 763
C85700	B 30, B 176, B 271, B 584, B 763
C85800	B 30, B 176
C86200	B 30, B 271, B 505, B 584, B 763
C86300	B 22, B 30, B 271, B 505, B 584, B 763
C86400	B 30, B 271, B 505, B 584 B 763
C86500	B 30, B 176, B 271, B 505, B 584, B 763
C86700	B 30, B 271, B 584, B 763
C87300	B 30, B 271, B 584, B 763
C87400	B 30, B 271, B 584, B 763
C87500	B 30, B 271, B 584, B 763, B 806
C87600	B 30, B 584, B 763

CHEMICAL COMPOSITION OF COPPER & COPPER ALLOYS	
UNS	**Chemical Composition**
C10100	Cu 99.99 min Ag 0.0025 max As 0.0005 max Bi 0.0001 max Cd 0.0001 max Fe 0.0010 max Hg 0.0001 max Mn 0.0005 max Ni 0.0010 max O_2 0.0005 max P 0.0003 max Pb 0.0005 max S 0.0018 max Sb 0.0004 max Se 0.0010 max Sn 0.0002 max Te 0.0002 max Zn 0.0001 max Other total As, Bi, Mn, Sb, Se, Sn, and Te 0.0040 max
C10200	Cu (incl Ag) 99.95 min O_2 0.0010 max
C10300	Cu (incl Ag) 99.95 min P 0.001-0.005
C10400	Cu (incl Ag) 99.95 min Ag 0.027 min O_2 0.0010 max
C10500	Cu (incl Ag) 99.95 min Ag 0.034 min O_2 0.0010 max
C10700	Cu (incl Ag) 99.95 min Ag 0.085 min O_2 0.0010 max
C10800	Cu (incl Ag+P) 99.95 min P 0.005-0.012
C11000	Cu (incl Ag) 99.90 min
C11010	Cu (incl Ag) 99.90 min Other Unspecified oxygen and trace elements
C11020	Cu (incl Ag) 99.90 min Other Unspecified oxygen and trace elements
C11030	Cu (incl Ag) 99.90 min Other Unspecified oxygen and trace elements
C11040	Cu 99.90 min Ag 0.0025 max As 0.0005 max Bi 0.00010 max Fe 0.0010 max Ni 0.0010 max O_2 0.010-0.065 Pb 0.0005 max S 0.0015 max Sb 0.0004 max Se 0.0002 max Sn 0.0005 max Te 0.0002 max Other Bi+Se+Te 0.0003 max total, Total all (except Cu+O_2) 0.0065 max
C11100	Cu (incl Ag) 99.90 min Note: Small amounts of Cd or other elements may be added to improve the resistance to softening at elevated temperatures
C11300	Cu (incl Ag) 99.90 min Ag 0.027 min Note: Oxygen and trace elements may vary depending on the process
C11400	Cu (incl Ag) 99.90 min Ag 0.034 min Note: Oxygen and trace elements may vary depending on the process
C11500	Cu (incl Ag) 99.90 min Ag 0.054 min Note: Oxygen and trace elements may vary depending on the process
C11600	Cu (incl Ag) 99.90 min Ag 0.085 min Note: Oxygen and trace elements may vary depending on the process
C12000	Cu (incl Ag) 99.90 min P 0.004-0.012
C12100	Cu (incl Ag) 99.90 min Ag 0.014 min P 0.005-0.012
C12200	Cu (incl Ag) 99.90 min P 0.015-0.040
C12300	Cu (incl Ag) 99.90 min P 0.015-0.040
C12900	Cu (incl Ag) 99.88 min Ag 0.054 min As 0.012 max Bi 0.003 max Ni 0.050 max Pb 0.004 max Sb 0.003 max Te 0.025 max Other Se included in Te
C14180	Cu (incl Ag) 99.90 min Al 0.01 max P 0.075 max Pb 0.02 max

CHEMICAL COMPOSITION OF BEARING BUSHING ALLOYS – COPPER-BASED ALLOYS – STEEL BACKED						
	SAE 48 ISO CuPb30	**SAE 49 ISO CuPb24Sn**	**SAE 485 ---**	**SAE 792[g] ISO CuPb10Sn10**	**SAE 793 ---**	**SAE 794[g] ISO CuPb24Sn4**
Cu	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder
Pb	26.0-33.0	21.0-27.0[b]	36.0-58.0	9.0-11.0	7.0-9.0	21.0-25.0[e]
Sn	0.50[a]	0.6-2.0[c]	1.0-8.0	9.0-11.0	3.5-4.5	3.0-4.0[e]
Fe	0.7	0.7	0.5	0.7	0.7	0.7
Ni	0.50	0.50	---	0.50	0.50	0.50
P	0.10	0.10	---	0.10	0.10	0.10
Sb	0.50	0.50	---	0.50	0.50	0.50
Zn	0.50	0.50	---	0.50[d]	0.50[f]	0.50[f]
Total Others	0.50	0.50	1.0	0.50	0.50	0.50

a. A version of this alloy has 1.3 maximum Sn.
b. ISO CuPb24Sn has 19.0 to 27.0 Pb.
c. A version of this alloy has 2.8 maximum Sn.
d. A version of this alloy has 0.8 maximum Zn.
e. ISO CuPb24Sn4 has 19.0 to 27.0 Pb and 3.0 to 4.5 Sn.
f. A version of this alloy has 3.0 maximum Zn.
g. SAE 792 now covers both cast and sintered versions of CuPb10Sn and SAE 794 covers both cast and sintered versions of CuPb24Sn4. The SAE 797 and SAE 799 designations for the sintered versions have been eliminated.

MECHANICAL PROPERTIES OF COPPER ALLOYS -
PLATE & SHEET FOR PRESSURE VESSELS, CONDENSERS & HEAT EXCHANGERS

ASTM B 171 Copper Alloy UNS No.	Thickness, in.	Tensile Strength ksi	Yield Strength[a] ksi	Yield Strength[b] ksi	% El
C36500	2 and under	50	20	20	35
	over 2 to 3.5, incl	45	15	15	35
	over 3.5 to 5, incl	40	12	12	35
C44300, C44400, and C44500	4 and under	45	15	15	35
C46400 and C46500	3 and under	50	20	20	35
	over 3 to 5, incl	50	18	18	35
C61300	2 and under	75	37	36	30
	over 2 to 3, incl	70	30	28	35
	over 3 to 5, incl	65	28	26	35
C61400	2 and under	70	30	28	35
	over 2 to 5, incl	65	28	26	35
C63000 and C63200	2 and under	90	36	34	10
	over 2 to 3.5, incl	85	33	31	10
	over 3.5 to 5, incl	80	30	28	10
C70600 and C70620	2.5 and under	40	15	15	30
	over 2.5 to 5, incl	40	15	15	30
C71500 and C71520	2.5 and under	50	20	20	30
	over 2.5 to 5, incl	45	18	18	30
C72200	2.5 and under	42	16	16	35

a. Yield Strength is determined as the stress producing an elongation of 0.5% under load, that is, 0.01 in. in a gage length of 2 in.
b. Yield strength at 0.2% offset, minimum.
All values are minimum, unless otherwise noted.

MECHANICAL PROPERTIES OF COPPER ALLOYS -
U-BEND SEAMLESS COPPER & COPPER ALLOY HEAT EXCHANGER & CONDENSER TUBES

ASTM B 395	Temper Designation		Tensile Strength	Yield Strength	% El
Copper or Copper Alloy UNS No.	**Standard**	**Former**	**ksi, min**	**ksi, min**	**min**
C10200, C10300, C10800, C12000, C12200, C14200	H55	light drawn	36	30	---
C19200	H55	light drawn	40	35	---
	O61	annealed	38	12	---
C23000	O61	annealed	40	12	---
C44300, C44400, C44500	O61	annealed	45	15	---
C60800	O61	annealed	50	19	---
C68700	O61	annealed	50	18	---
C70400	O61	annealed	38	12	---
	H55	light drawn	40	30	---
C70600	O61	annealed	40	15	---
	H55	light drawn	45	35	---
C71000	O61	annealed	45	16	---
C71500:	O61	annealed	52	18	---
For wall thicknesses up to 0.048 in., inclusive	HR50	drawn, stress-relieved	72	50	12
For wall thicknesses over 0.048 in.	HR50	drawn, stress-relieved	72	50	15
C72200	O61	annealed	45	16	---
	H55	light drawn	50	45	---

All values are minimum, unless otherwise noted.

ASTM F 468M – MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOY BOLTS, HEX CAP SCREWS, AND STUDS FOR GENERAL USE								
				Full-Size Tests[b]		Machined Specimen Tests		
Alloy	**Marking**	**Nominal Thread Diameter**	**Hardness[a]**	**Tensile Strength, MPa**	**Yield Strength, min, MPa**	**Tensile Strength, min, MPa**	**Yield Strength min, MPa[c]**	**Elongation in 4*D*, min, %[d]**
Cu 110	F 468MA	all	65–90 HRF	205–345	70	205	70	15
Cu 270	F 468MB	all	55–80 HRF	410–620	345	380	345	35
Cu 462	F 468MC	all	65–90 HRB	345–550	170	345	170	20
Cu 464	F 468MD	all	55–75 HRB	345–550	105	345	105	25
Cu 510	F 468ME	---	60–95 HRB	410–620	240	380	205	15
Cu 613	F 468MF	M16 to M12	70–95 HRB	550–760	345	550	345	30
		M14 to M36	70–95 HRB	520–720	310	520	310	30
Cu 614	F 468MG	all	70–95 HRB	520–760	240	520	240	30
Cu 630	F 468MH	all	85–100 HRB	690–900	345	690	345	5
Cu 642	F 468MJ	all	75–95 HRB	520–760	240	520	240	10
Cu 651	F 468MK	M6 to M20	75–95 HRB	480–690	380	480	365	8
		M24 to M36	70–95 HRB	380–620	275	370	260	8
Cu 655	F 468ML	all	60–80 HRB	345–550	140	345	105	20
Cu 661	F 468MM	all	75–95 HRB	480–690	240	480	240	15
Cu 675	F 468MN	all	60–90 HRB	380–590	170	380	170	20
Cu 710	F 468MP	all	50–85 HRB	310–520	105	310	105	40
Cu 715	F 468MR	all	60–95 HRB	380–590	140	380	140	45

a. Where both tension and hardness tests are performed, the tension tests shall take precedence for acceptance purposes.
b. The yield and tensile strength values for full-size products shall be computed by dividing the yield and maximum tensile load by the stress area for the product diameter and thread pitch as given in table on tensile stress areas.
c. Yield strength is the stress at which an offset of 0.2 % gage length occurs.
d. Elongation is determined using a gage length of 4 diameters of test specimen in accordance with Test Methods E 8.

TYPICAL PHYSICAL PROPERTIES OF WROUGHT COPPER ALLOYS

Copper or Copper Alloy UNS No.	Melting Point °C		Density g/cm^3 at 20°C	Coefficient of Thermal Expansion /°C x 10^{-5}			Thermal Conductivity W/m·K	Electrical Resistivity nΩ·m	Specific Heat J/kg·K	Modulus Gpa	
	Liquidus	Solidus		20–100°C	20–200°C	20–300°C				Elastic	Rigid
C10200	1083	---	8.94	1.70	1.73	1.77	391	17.1	385	117	44
C11000	1083	1065	8.91	1.70	1.73	1.77	391	17.1	385	117	44
C11100	1083	1065	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11300	1082	---	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11400	1082	---	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11500	1082	---	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11600	1082	---	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C12000	1083	---	8.94	1.70	1.73	1.77	386	17.6	385	117	44
C12200	1083	---	8.94	1.70	1.73	1.77	339	20.3	385	117	44
C14500	1075	1051[a]	8.94	1.71	1.74	1.78	355	18.6	385	117	44
C14700	1076	1067	8.94	1.70	1.73	1.77	374	18.1	385	117	44
C15000	1080	980	8.89	1.63	1.80	2.01	367[c]	18.6[c]	385	117	44
C16200	1076	1030	8.89	1.70	1.73	1.77	360	19.2	385	117	44
C17000	980	865	8.26	1.67	1.70	1.78	118	76.8	420	131	50
C17200	980	865	8.26	1.67	1.70	1.78	118	76.8	420	131	50
C17500	1075	1070	8.75	---	1.76	---	234	37.9	420	124	47
C17600	1054	1010	8.75	---	---	---	---	31.6	---	124	47
C18400	1075	1070	8.89	1.76	---	---	324[c]	21.6[c]	385	131	50
C18700	1080	953[b]	8.94	---	---	1.76	377	17.9	385	117	44
C19200	1084	---	8.87	1.62	---	---	216	34.5	385	117	44
C21000	1065	1050	8.86	---	---	1.81	234	30.8	377	117	44
C22000	1045	1020	8.80	---	---	1.84	189	39.2	377	117	44
C23000	1025	990	8.75	---	---	1.87	159	46.6	377	117	44
C24000	1000	965	8.67	---	---	1.91	140	53.9	377	110	41

ASME P-No. - BASE METAL COPPER & COPPER ALLOYS				
ASME Specification	**Tensile Strength, ksi[a]**	**UNS No.**	**Nominal Composition**	**Product Form**
P No. 31				
SB-42	30	C10200	99.95Cu-P	Seamless Pipe
	30	C12000	99.9Cu-P	Seamless Pipe
	30	C12200	99.9Cu-P	Seamless Pipe
SB-75	30	C10200	99.95Cu-P	Seamless Tube
	30	C12000	99.9Cu-P	Seamless Tube
	30	C12200	99.9Cu-P	Seamless Tube
SB-111	38	C19200	99.7Cu-Fe-P	Seamless Tube
	30	C10200	99.95Cu-P	Seamless Tube
	30	C12000	99.9Cu-P	Seamless Tube
	30	C12200	99.9Cu-P	Seamless Tube
	30	C14200	99.4Cu-As-P	Seamless Tube
SB-152	30	C10200	99.95Cu-P	Sheet, Strip, Plate, Bar
	30	C10400	99.95Cu+Ag	Sheet, Strip, Plate, Bar
	30	C10500	99.95Cu+Ag	Sheet, Strip, Plate, Bar
	30	C10700	99.95Cu+Ag	Sheet, Strip, Plate, Bar
	30	C11000	99.90Cu	Sheet, Strip, Plate, Bar
	30	C12200	99.9Cu-P	Sheet, Strip, Plate, Bar
	30	C12300	99.9Cu-P	Sheet, Strip, Plate, Bar
	30	C12500	99.88	Sheet, Strip, Plate, Bar
	30	C14200	99.4Cu-As-P	Sheet, Strip, Plate, Bar
SB-187	30	C10200	99.95Cu-P	Rod, Bar
	30	C11000	99.9Cu	Rod, Bar
SB-359	30	C10200	99.95Cu-P	Seamless Tube
	30	C12000	99.9Cu-P	Seamless Tube

EN 1652 – CHEMICAL COMPOSITION OF COPPER ALLOYS - PLATE, SHEET, STRIP & CIRCLES FOR GENERAL PURPOSES			
Material Designation		**Chemical Composition**	**Density[a] g/cm^3 approx.**
Symbol	**Number**		
CuBe2	CW101C	Cu rem min Be 1,8-2,1 Co 0,3 max Fe 0,2 max Ni 0,3 max Other total 0,5 max	8,3
CuCo1Ni1Be	CW103C	Cu rem min Be 0,4-0,7 Co 0,8-1,3 Fe 0,2 max Ni 0,8-1,3 Other total 0,5 max	8,8
CuCo2Be	CW104C	Cu rem min Be 0,4-0,7 Co 2,0-2,8 Fe 0,2 max Ni 0,3 max Other total 0,5 max	8,8
CuNi2Be	CW110C	Cu rem min Be 0,2-0,6 Co 0,3 max Fe 0,2 max Ni 1,4-2,2 Other total 0,5 max	8,8
CuNi2Si	CW111C	Cu rem min Fe 0,2 max Mn 0,1 max Ni 1,6-2,5 Pb 0,02 max Si 0,4-0,8 Other total 0,3 max	8,8
CuZn0,5	CW119C	Cu rem min P 0,02 max Zn 0,1-1,0 Other total 0,1 max	8,9
CuAl8Fe3	CW303G	Cu rem min Al 6,5-8,5 Fe 1,5-3,5 Mn 1,0 max Ni 1,0 max Pb 0,05 max Si 0,2 max Sn 0,1 max Zn 0,5 max Other total 0,2 max	7,7
CuNi25	CW350H	Cu rem min C 0,05 max Co 0,1 max Fe 0,3 max Mn 0,5 max Ni 24,0-26,0 Pb 0,02 max Sn 0,03 max Zn 0,5 max Other total 0,1 max	8,9
CuNi9Sn2	CW351H	Cu rem min Fe 0,3 max Mn 0,3 max Ni 8,5-10,5 Pb 0,03 max Sn 1,8-2,8 Zn 0,1 max Other total 0,1 max	8,9
CuNi10Fe1Mn	CW352H	Cu rem min C 0,05 max Co 0,1 max[b] Fe 1,0-2,0 Mn 0,5-1,0 Ni 9,0-11,0 P 0,02 max Pb 0,02 max S 0,05 max Sn 0,03 max Zn 0,5 max Other total 0,2 max	8,9
CuNi30Mn1Fe	CW354H	Cu rem min C 0,05 max Co 0,1 max[b] Fe 0,4-1,0 Mn 0,5-1,5 Ni 30,0-32,0 P 0,02 max Pb 0,02 max S 0,05 max Sn 0,05 max Zn 0,5 max Other total 0,2 max	8,9
CuNi10Zn27	CW401J	Cu 61,0-64,0 Fe 0,3 max Mn 0,5 max Ni 9,0-11,0 Pb 0,05 max Zn rem min Other total 0,2 max	8,6
CuNi12Zn24	CW403J	Cu 63,0-66,0 Fe 0,3 max Mn 0,5 max Ni 11,0-13,0 Pb 0,03 max Sn 0,03 max Zn rem min Other total 0,2 max	8,7
CuNi12Zn25Pb1	CW404J	Cu 60,0-63,0 Fe 0,3 max Mn 0,5 max Ni 11,0-13,0 Pb 0,5-1,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,7
CuNi18Zn20	CW409J	Cu 60,0-63,0 Fe 0,3 max Mn 0,5 max Ni 17,0-19,0 Pb 0,03 max Sn 0,03 max Zn rem min Other total 0,2 max	8,7
CuNi18Zn27	CW410J	Cu 53,0-56,0 Fe 0,3 max Mn 0,5 max Ni 17,0-19,0 Pb 0,03 max Sn 0,03 max Zn rem min Other total 0,2 max	8,7
CuSn4	CW450K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 3,5-4,5 Zn 0,2 max	8,9
CuSn5	CW451K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 4,5-5,5 Zn 0,2 max Other total 0,2 min	8,9
CuSn6	CW452K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 5,5-7,0 Zn 0,2 max Other total 0,2 min	8,8
CuSn8	CW453K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 7,5-8,5 Zn 0,2 max Other total 0,2 min	8,8

EN 12166 – CHEMICAL COMPOSITION OF COPPER-NICKEL-ZINC ALLOYS			
Material Designation		**Chemical Composition**	**Density[a] g/cm^3 approx.**
Symbol	**Number**		
CuNi7Zn39Pb3Mn2	CW400J	Cu 47,0-50,0 Fe 0,3 max Mn 1,5-0,3 Ni 6,0-8,0 Pb 2,3-3,3 Sn 0,2 max Zn rem min Other total 0,2 max	8,5
CuNi10Zn27	CW401J	Cu 61,0-64,0 Fe 0,3 max Mn 0,5 max Ni 9,0-11,0 Pb 0,05 max Zn rem min Other total 0,2 max	8,6
CuNi10Zn42Pb2	CW402J	Cu 45,0-48,0 Fe 0,3 max Mn 0,5 max Ni 9,0-11,0 Pb 1,0-2,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,4
CuNi12Zn24	CW403J	Cu 63,0-66,0 Fe 0,3 max Mn 0,5 max Ni 11,0-13,0 Pb 0,03 max Sn 0,03 max Zn rem min Other total 0,2 max	8,7
CuNi12Zn30Pb1	CW406J	Cu 56,0-58,0 Fe 0,3 max Mn 0,5 max Ni 11,0-13,0 Pb 0,5-1,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,6
CuNi18Zn19Pb1	CW408J	Cu 59,5-62,5 Fe 0,3 max Mn 0,7 max Ni 17,0-19,0 Pb 0,5-1,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,7
CuNi18Zn20	CW409J	Cu 60,0-63,0 Fe 0,3 max Mn 0,5 max Ni 17,0-19,0 Pb 0,03 max Sn 0,03 max Zn rem min Other total 0,2 max	8,7

a. For information only

EN 12166 – CHEMICAL COMPOSITION OF COPPER-TIN ALLOYS

Material Designation			Density[a] g/cm³ approx.
Symbol	Number	Chemical Composition	
CuSn4	CW450K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 3,5-4,5 Zn 0,2 max Other total 0,2 max	8,9
CuSn5	CW451K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 4,5-5,5 Zn 0,2 max Other total 0,2 max	8,9
CuSn6	CW452K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 5,5-7,0 Zn 0,2 max Other total 0,2 max	8,8
CuSn8	CW453K	Cu rem min Fe 0,1 max Ni 0,2 max P 0,01-0,4 Pb 0,02 max Sn 7,5-8,5 Zn 0,2 max Other total 0,2 max	8,8

a. For information only

EN 12166 – CHEMICAL COMPOSITION OF COPPER-ZINC ALLOYS

Material Designation			Density[a] g/cm³ approx.
Symbol	Number	Chemical Composition	
CuZn10	CW501L	Cu 89,0-91,0 Al 0,02 max Fe 0,05 max Ni 0,3 max Pb 0,05 max Sn 0,01 max Zn rem min Other total 0,1 max	8,8
CuZn15	CW502L	Cu 84,0-86,0 Al 0,02 max Fe 0,05 max Ni 0,3 max Pb 0,05 max Sn 0,01 max Zn rem min Other total 0,1 max	8,8
CuZn20	CW503L	Cu 79,0-81,0 Al 0,02 max Fe 0,05 max Ni 0,3 max Pb 0,05 max Sn 0,01 max Zn rem min Other total 0,1 max	8,7
CuZn30	CW505L	Cu 69,0-71,0 Al 0,02 max Fe 0,05 max Ni 0,3 max Pb 0,05 max Sn 0,01 max Zn rem min Other total 0,1 max	8,5

EN 12166 – CHEMICAL COMPOSITION OF COPPER-ZINC ALLOYS (Continued)			
Material Designation			**Density[a] g/cm³ approx.**
Symbol	**Number**	**Chemical Composition**	
CuZn36	CW507L	Cu 63,5-65,5 Al 0,02 max Fe 0,05 max Ni 0,3 max Pb 0,05 max Sn 0,01 max Zn rem min Other total 0,1 max	8,4
CuZn37	CW508L	Cu 62,0-64,0 Al 0,05 max Fe 0,1 max Ni 0,3 max Pb 0,01 max Sn 0,01 max Zn rem min Other total 0,1 max	8,4

a. For information only

EN 12166 – CHEMICAL COMPOSITION OF COPPER-ZINC-LEAD ALLOYS			
Material Designation			**Density[a] g/cm³ approx.**
Symbol	**Number**	**Chemical Composition**	
CuZn35Pb1	CW600N	Cu 62,5-64,0 Al 0,05 max Fe 0,1 max Ni 0,3 max Pb 0,8-1,6 Sn 0,1 max Zn rem min Other total 0,1 max	8,5
CuZn35Pb2	CW601N	Cu 62,0-63,5 Al 0,05 max Fe 0,1 max Ni 0,3 max Pb 1,6-2,5 Sn 0,1 max Zn rem min Other total 0,1 max	8,5
CuZn36Pb3	CW603N	Cu 60,0-62,0 Al 0,05 max Fe 0,3 max Ni 0,3 max Pb 2,5-3,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,5
CuZn37Pb2	CW606N	Cu 61,0-62,0 Al 0,05 max Fe 0,2 max Ni 0,3 max Pb 1,6-2,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,4
CuZn38Pb2	CW608N	Cu 60,0-61,0 Al 0,05 max Fe 0,2 max Ni 0,3 max Pb 1,6-2,5 Sn 0,2 max Zn rem min Other total 0,2 max	8,4
CuZn38Pb4	CW609N	Cu 57,0-59,0 Al 0,05 max Fe 0,3 max Ni 0,3 max Pb 3,5-4,2 Sn 0,3 max Zn rem min Other total 0,2 max	8,4

EN 12166 – MECHANICAL PROPERTIES OF COPPER											
Material Designations			Nominal Diameter[a] mm			Tensile Strength R_m N/mm^2	0,2% Proof Strength $R_{p0,2}$ N/mm^2 Approx.	Elongation			Hardness HV
Symbol	Number	Condition	From	Over	≤			A_{100mm} % min	$A_{11,3}$ % min	A % min	
Cu-DHP	CW024A	M	All			As manufactured					
		R200	1,5	---	20,0	200-270	(60)	33	37	40	---
		H040	1,5	---	20,0	---	---	---	---	---	40-70
		R270	1,0	---	8,0	270 min	(250)	10	12	---	---
		H065	1,0	---	8,0	---	---	---	---	---	65-90
		R250	---	8,0	20,0	250 min	(230)	---	---	15	---
		H065	---	8,0	20,0	---	---	---	---	---	65-90
		R330	1,0	---	8,0	330 min	(290)	(4)	7	---	---
		H090	1,0	---	8,0	---	---	---	---	---	90-105
		R300	---	8,0	15,0	300 min	(250)	---	---	10	---
		H090	---	8,0	15,0	---	---	---	---	---	90-105
		R400	1,0	---	8,0	400 min	(380)	---	---	---	---
		H105	1,0	---	8,0	---	---	---	---	---	105 min
		R350	---	8,0	12,0	350 min	(320)	---	---	---	---
		H105	---	8,0	12,0	---	---	---	---	---	105 min

a. Or equivalent cross-sectional area for polygonal wire.

NOTE 1: Figures in parentheses are not requirements of this standard, but are given for information only.

NOTE 2: 1 N/mm^2 is equivalent to 1 MPa.

Chapter 3

NICKEL & NICKEL ALLOYS

Metallic nickel was first isolated by the Swedish scientist A.F. Cronstedt in 1751, and since then it has become one of the most useful metals. Among the attractive properties of nickel and its alloys are excellent ductility and formability, good resistance to oxidation and corrosion and good high temperature strength. In addition it is ferromagnetic up to its Curie temperature of 358°C (676°F). Its relatively high cost, however, has restricted its use to specialized applications, generally involving severe service conditions.

Commercially important nickel ores include sulphides, oxides, and silicates. In all of these ores the nickel content is low, generally less than 3%, and the mineralogy and extraction processes are often complex. Many different smelting processes are used for the production of nickel including pyrometallurgical, hydrometallurgical, and vapour phase metallurgical processes. The vapour phase process involves the formation and decomposition of nickel carbonyl, and the metallic nickel produced is often referred to as carbonyl nickel.

More than half of the world's nickel production is used as an alloying addition in stainless steel, where its presence stabilizes the austenitic structure, giving improved formability and toughness, and resistance to corrosion and oxidation in particular environments. Approximately one-sixth of the nickel produced is used in nickel-based alloys. Nickel is also used as a plating material and as an alloy addition to carbon steel and copper-based alloys.

One of the many interesting aspects of nickel use is that unlike many other alloy systems, such as those based on aluminium or titanium which normally contain less than 15% total alloy content, useful nickel alloys have a wide range of nickel content. In some cases alloys with as little as 30% nickel are considered to be nickel-based alloys. Some of these alloys have been developed by experimentation with alloy additions to nickel, while others have been developed by increasing the nickel content of iron-based alloys, notably stainless steel.

Uses of commercial purity nickel are relatively restricted; however, an enormous range of nickel alloys is available, the most important being nickel-copper alloys, and nickel-chromium (and nickel-iron-chromium) alloys, many of which contain other alloying elements such as titanium, aluminum and molybdenum. The common presence of cobalt in nickel ores, and the similar behaviour of nickel and cobalt during extraction processes, has led to the specification of combined nickel plus cobalt in some alloy compositions rather than simply nickel.

Pure nickel has a face-centered cubic (fcc) crystal structure at all temperatures, and this is also true of most nickel alloys, but alloying elements have different influences on the microstructure and properties. Some produce solid solution hardening. Some form carbide or nitride particles within the nickel-based solid solution matrix. Some form brittle intermetallic phases which are detrimental to properties, and some form precipitates which provide useful precipitation hardening. Most alloying elements can contribute to several of these effects. Perhaps the most important is the precipitation of particles of the ordered fcc γ' *(gamma prime)* phase, which is generally of the form $Ni_3(Ti,Al)$. This is referred to as *gamma prime* to differentiate it from the fcc matrix phase which is conventionally termed *gamma*. Precipitation hardening by this phase contributes strength at intermediate temperatures because the γ' particles are very stable and have low energy interfaces with the matrix solid solution. Most of the nickel-based alloys which are strengthened by γ' belong to the category of "superalloys". These are alloys designed specifically for jet aircraft engine and gas turbine applications requiring high temperature strength and creep resistance as well as resistance to corrosion, oxidation, and carburization. The nickel alloy groups will be discussed in the following sections.

Commercial Purity Nickel And Low Alloy Nickels

The highest purity nickels commercially available are Nickel 270 (UNS N02270) and Nickel 290 (UNS N02290), which contain at least 99.95% Ni. This material finds applications in the electronics industry. The standard commercial purity nickels are Nickel 200 (UNS N02200) and Nickel 201 (UNS N02201); both of these contain 99.5% combined Ni + Co, but Nickel 201 has a lower maximum carbon content, 0.02%, to avoid the formation of graphite, which embrittles the material during extended use at temperatures above about 300°C (572°F). In addition to coinage and electronic industry uses, these materials find applications in chemical processing, especially for the handling of hot concentrated caustic soda and dry chlorine. A comparable material, Nickel 205 (UNS N02205), has controlled low levels of magnesium for improved electronic characteristics. All of the above materials are solid solutions and are strengthened only by work hardening. However, two low-alloy nickels have alloy additions which provide higher strengths by precipitation hardening, making them useful for springs and other applications where both corrosion resistance and strength are required. These are Permanickel 300 (UNS N03300), which has titanium added, and Duranickel 301 (UNS N03301) which has both aluminum and titanium additions.

Nickel Copper Alloys

Nickel and copper form a complete range of solid solutions at all compositions, although some commercial nickel-copper alloys contain other alloying elements to encourage precipitation hardening. Nickel-copper alloys have excellent fabrication properties and a range of electrical properties, magnetic properties, and colour across the range of compositions. Many applications of these alloys are based on their corrosion resistance in reducing environments and in sea water, for example in the chemical and hydrocarbon processing industries and in marine engineering. Both castings and wrought products are available including pipe, shafts, tools, pumps, valves and fasteners. The most important alloys in this category are Monel 400 (UNS N04400 - 66%Ni+Co, 32%Cu), Monel R-405 (UNS N04405) which is similar but has added sulphur to make it free machining, and Monel K-500 (UNS N05500 which again has 66% Ni+Co with 30% Cu but in addition contains aluminum and titanium to provide precipitation hardening by the formation of $Ni_3(Ti,Al)$. Especially high strength is obtained when the latter alloy is cold worked before the precipitation hardening; it finds uses where a higher strength is required in a corrosion resistant application, for example for tools and springs.

Solid Solution Nickel-Chromium and Nickel-Chromium-Iron Alloys

A wide range of nickel-bearing alloys contain chromium in the approximate range of 15% to 23%, with varying amounts of iron and other elements such as molybdenum. At one extreme are the common austenitic stainless steels, having nickel contents which can be less than 10%. As the nickel content is raised and the iron content falls, the cost increases, but so does the maximum useful operating temperature, typically from around 1000°C (1832°F) to around 1200°C (2192°F), depending in part on reactions with the operating environments.

SAE/AMS SPECIFICATIONS - NICKEL & NICKEL ALLOYS	
AMS	**Title**
2261	Tolerances, Nickel, Nickel Alloy, and Cobalt Alloy Bars, Rods, and Wire
2262	Tolerances, Nickel, Nickel Alloy, and Cobalt Alloy Sheet, Strip, and Plate
2263	Tolerances, Nickel, Nickel Alloy, and Cobalt Alloy Tubing
2268	Chemical Check Analysis Limits, Cast Nickel and Nickel Alloys, Superseded by AMS 2269 (May 95)
2269	Chemical Check Analysis Limits, Nickel, Nickel Alloys, and Cobalt Alloys
2280	Trace Element Control, Nickel Alloy Castings
2316	Metallographic Evaluation of Grain Size in Wrought Nickel And Heat Resistant Alloys, Superseded by ASTM E 1181 for duplex grain size evaluation, ASTM E 112 for uniform grain size evaluation (Oct 91)
2399	Electroless Nickel-Boron Plating NONCURRENT, Mar 94
2403	Plating, Nickel, General Purpose
2404	Plating, Electroless Nickel
2405	Electroless Nickel Plating Low Phosphorus NONCURRENT, Dec 00
2410	Plating, Silver, Nickel Strike, High Bake
2416	Plating, Nickel-Cadmium Diffused
2417	Plating, Zinc-Nickel Alloy
2423	Plating, Nickel Hard Deposit
2424	Plating, Nickel, Low Stressed Deposit
2433	Plating, Nickel-Thallium-Boron or Nickel-Boron Electroless Deposition
2675	Nickel Alloy Brazing
4544	Nickel-Copper Alloy, Corrosion Resistant Sheet, Strip, and Plate 67Ni - 30Cu Annealed, UNS N04400
4574	Nickel-Copper Alloy Tubing, Seamless, Corrosion Resistant, 67Ni - 31Cu Annealed, UNS N04400
4575	Nickel-Copper Alloy Tubing, Brazed, Corrosion Resistant, 67Ni - 31Cu Annealed, UNS N04400
4674	Nickel-Copper Alloy, Corrosion Resistant Bars and Forgings, Free-Machining, 67Ni - 30Cu - 0.04S, UNS N04405
4675	Alloy Bars and Forgings, Corrosion Resistant, 67Ni - 30Cr, UNS N04400
4676	Nickel-Copper Alloy, Corrosion Resistant, Bars and Forgings, 66.5Ni-3.0Al-0.62Ti-28Cu, Hot-Finished, Precipitation Hardenable, UNS N05500
4677	Nickel-Copper Alloy Bars and Forgings, Corrosion Resistant 66.5Ni - 2.9Al - 30Cu Annealed, UNS N05502
4730	Nickel-Copper Alloy, Wire, Corrosion Resistant 67Ni - 31Cu Annealed (400), UNS N04400

ASTM SPECIFICATIONS AND PRODUCT FORMS FOR NICKEL AND NICKEL ALLOYS

UNS	Castings	Electrical Conductors	Fasteners	Fittings	Forgings	Pipe & Tube	Plate, Sheet, & Strip	Rod, Bar, & Wire
N02100	A 494 (CZ-100)	---	---	---	---	---	---	---
N02200	---	---	---	B 366	B 564	B 161, B 163, B 725, B 730	B 162	B 160
N02201	---	---	---	B 366	---	B 161, B 163, B 725, B 730	B 162	B 160
N02205	---	F 1, F 3	---	---	---	---	---	---
N02211	---	F 290	---	---	---	---	---	---
N02233	---	F 1, F 3, F 4	---	---	---	---	---	---
N02253	---	F1 (Grade 3) F3 (Grade 3)	---	---	---	---	---	---
N02270	---	F 1, F 3	---	---	---	---	---	---
N03300	---	F 290	---	---	---	---	---	---
N04020	A 494 (M-35-2)	---	---	---	---	---	---	---
N04400	---	F 96	F 467 (400) F 468 (400)	B 366	B 564	B 163, B 165, B 725, B 730	B 127	B 164
N04404	---	F 96	---	---	---	---	---	---
N04405	---	---	F 467 (405) F 468 (405)	---	---	---	---	B 164
N05500	---	---	F 467 (500) F 468 (500)	---	B 865	---	---	B 865
N06002	---	---	---	B 366	---	B 619, B 622, B 626	B 435	B 572
N06003	---	---	---	---	---	---	---	B 344
N06004	---	---	---	---	---	---	---	B 344
N06006	A 297 (HX)	---	---	---	---	---	---	---
N06007	---	---	---	B 366	---	B 619, B 622, B 626	B 582	B 581
N06022	---	---	---	B 366, B 462	B 564	B 619, B 622, B 626	B 575	B 574, B 472

AMERICAN CROSS REFERENCED SPECIFICATIONS - NICKEL & NICKEL ALLOYS

UNS	SAE/AMS	MILITARY	ASTM	ASME	AWS
N02016	---	---	---	---	---
N02061	---	E-21562 (EN61, RN61), I-23413 (MIL-61)	---	SFA-5.14 (ERNi-1), SFA-5.30 (IN61)	A5.14 (ERNi-1), A5.30 (IN61)
N02100	---	---	A 494 (CZ-100)	---	---
N02200	---	---	B 160, B 161, B 162, B 163, B 366, B 564, B 725, B 730	SB-160, SB-161, SB-162, SB-163	C2.25 (W-Ni-2)
N02205	5555	---	F 1, F 3	---	---
N02211	---	---	F 290	---	---
N02215	---	---	---	SFA-5.15 (ERNi-CI)	A5.15 (ERNi-CI)
N02216	---	---	---	SFA-5.15 (ERNiFeMn-CI)	A5.15 (ERNiFeMn-CI)
N02220	---	---	---	---	---
N02225	---	---	---	---	---
N02230	---	---	---	---	---
N02233	---	---	F 1, F 3, F 4	---	---
N02253	---	---	F1 (Grade 3), F3 (Grade 3)	---	---
N02270	---	---	F 1, F 3	---	---
N02290	---	---	---	---	---
N03220	---	---	---	---	---
N03260	5865, 5890	---	---	---	---
N03300	---	---	F 290	---	---
N03301	---	---	---	---	---
N03360	---	---	---	---	---
N04019	4892, 4893	V-17647	---	---	---
N04020	---	---	A 494 (M-35-2)	---	---
N04060	---	E-21562 (EN60, RN60), I-23413 (MIL-60)	---	SFA-5.14 (ERNiCu-7), SFA-5.30 (IN60)	A5.14 (ERNiCu-7), A5.30 (IN60)

CHEMICAL COMPOSITION OF NICKEL & NICKEL ALLOYS	
UNS	**Chemical Composition**
N02016	Ni rem Al 1.75-2.25 C 0.15 max Fe 0.50 max Mn 2.0-3.0 Si 1.6 max
N02061	Ni 93.0 min Al 1.5 max C 0.15 max Cu 0.25 max Fe 1.0 max Mn 1.0 max P 0.03 max S 0.015 max Si 0.75 max Ti 2.0-3.5
N02100	Ni rem C 1.00 max Cu 1.25 max Fe 3.00 max Mn 1.50 max Si 2.00 max
N02200	Ni 99.0 min C 0.15 max Cu 0.25 max Fe 0.40 max Mn 0.35 max S 0.010 max Si 0.35 max
N02201	Ni 99.0 min C 0.02 max Cu 0.25 max Fe 0.40 max Mn 0.35 max S 0.010 max Si 0.35 max
N02205	Ni 99.0 min C 0.15 max Cu 0.15 max Fe 0.20 max Mg 0.01-0.08 Mn 0.35 max S 0.008 max Si 0.15 max Ti 0.01-0.05
N02211	Ni 93.7 min C 0.20 max Cu 0.25 max Fe 0.75 max Mn 4.25-5.25 S 0.015 max Si 0.15 max
N02215	Ni rem C 1.0 max Cu 4.0 max Fe 4.0 max Mn 2.5 max S 0.03 max Si 0.75 max Other 1.0 max total
N02216	Ni 35.0-45.0 Al 1.0 max C 0.50 max Cu 2.5 max Fe rem Mn 10.0-14.0 S 0.03 max Si 1.0 max Other 1.0 max total
N02220	Ni 99.00 min C 0.15 max Cu 0.10 max Fe 0.10 max Mg 0.01-0.08 Mn 0.20 max S 0.008 max Si 0.01-0.05 Ti 0.01-0-05
N02225	Ni 99.00 min C 0.15 max Cu 0.10 max Fe 0.10 max Mg 0.01-0.08 Mn 0.20 max S 0.008 max Si 0.15-0.25 Ti 0.01-0-05
N02230	Ni 99.00 min C 0.15 max Cu 0.10 max Fe 0.10 max Mg 0.04-0.08 Mn 0.15 max S 0.008 max Si 0.010-0.035 Ti 0.005 max
N02233	Ni 99.00 min C 0.15 max Cu 0.10 max Fe 0.10 max Mg 0.01-0.10 Mn 0.30 max S 0.008 max Si 0.10 max Ti 0.005 max
N02270	Ni 99.97 min C 0.02 max Co 0.001 max Cr 0.001 max Cu 0.001 max Fe 0.005 max Mg 0.001 max Mn 0.001 max S 0.001 max Si 0.001 max Ti 0.001 max
N02290	Ni rem Al 0.001 max C 0.006 max Cr 0.001 max Cu 0.02 max Fe 0.015 max Mg 0.001 max Mn 0.001 max N 0.001 max O 0.025 max S 0.0008 max Si 0.001 max
N03220	Ni rem Be 1.80-2.30 C 0.30-0.50
N03260	Ni rem C 0.02 max Co 0.20 max Cr 0.05 max Cu 0.15 max Fe 0.05 max S 0.0025 max Ti 0.05 max Other ThO_2 1.80-2.60
N03300	Ni 97.0 min C 0.40 max Cu 0.25 max Fe 0.60 max Mg 0.20-0.50 Mn 0.50 max S 0.01 max Si 0.35 max Ti 0.20-0.60
N03301	Ni 93.0 min Al 4.00-4.75 C 0.30 max Cu 0.25 max Fe 0.60 max Mn 0.50 max S 0.01 max Si 1.00 max Ti 0.25-1.00
N03360	Ni rem Be 1.85-2.05 Ti 0.4-0.6
N04019	Ni 60.0 min C 0.25 max Cu 27.0-31.0 Fe 2.50 max Mn 1.50 max S 0.015 max Si 3.50-4.50 max
N04020	Ni rem Al 0.50 max C 0.35 max Cu 26.0-33.0 Fe 2.50 max Mn 1.5 max Si 2.0 max
N04060	Ni 62.0-69.0 Al 1.25 max C 0.15 max Cu rem Fe 2.5 max Mn 4.0 max P 0.02 max S 0.015 max Si 1.25 max Ti 1.5-3.0
N04400	Ni 63.00-70.00 C 0.3 max Cu rem Fe 2.50 max Mn 2.00 max S 0.024 max Si 0.50 max
N04401	Ni 40.0-45.0 C 0.10 max Co 0.25 max Cu rem Fe 0.75 max Mn 2.25 max S 0.015 max Si 0.25 max

CHEMICAL COMPOSITION OF NICKEL & NICKEL ALLOYS (Continued)	
UNS	**Chemical Composition**
N99645	Ni rem B 2.00-4.00 C 0.40-0.80 Co 1.25 max Cr 10.0-16.0 Fe 3.00-5.00 Se 0.005 max Si 3.00-5.00
N99646	Ni rem B 2.50-4.50 C 0.50-1.00 Co 1.00 max Cr 12.0-18.0 Fe 3.50-5.50 Se 0.005 max Si 3.50-5.50
N99650	Ni rem Al 0.05 max B 0.03 max C 0.10 Co 0.10 max Cr 18.5-19.5 P 0.02 max S 0.02 max Se 0.005 max Si 9.75-10.50 Ti 0.05 max Zr 0.05 max Other 0.50 max
N99651	Ni rem Al 0.05 max B 1.0-1.5 C 0.10 max Co 0.10 max Cr 18.5-19.5 Fe 0.5 max P 0.02 max S 0.02 max Se 0.005 max Si 7.0-7.5 Ti 0.05 max Zr 0.05 max
N99700	Ni rem Al 0.05 max C 0.01 max Co 0.10 max P 10.0- 12.0 S 0.02 max Se 0.005 max Ti 0.05 max Zr 0.05 max Other 0.50 max
N99710	Ni rem Al 0.05 max B 0.01 max C 0.08 max Co 0.10 max Cr 13.0-15.0 Fe 0.2 max Mn 0.04 max P 9.7-10.5 S 0.02 max Se 0.005 max Si 0.10 max Ti 0.05 max Zr 0.05 max Other 0.50 max
N99800	Ni rem Al 0.05 max C 0.10 max Co 0.10 max Cu 4.0-5.0 Mn 21.5-24.5 P 0.02 max S 0.02 max Se 0.005 max Si 6.0-8.0 Ti 0.05 max Zr 0.05 max Other 0.50 max

rem – remainder; Nom -Nominal

ASTM A 494 - CHEMICAL COMPOSITION OF NICKEL & NICKEL ALLOY CASTINGS		
Grade	**UNS**	**Chemical Composition**
CZ-100	N02100	Ni 95.00 min C 1.00 max Cu 1.25 max Fe 3.00 max Mn 1.50 max Si 2.00 max P 0.03 max S 0.03 max
M-35-1	N24135	Ni rem C 0.35 max Cb 0.5 max Cu 26.0-33.0 Fe 3.50 max Mn 1.50 max P 0.03 max S 0.03 max Si 1.25 max
M-35-2	N04020	Ni rem C 0.35 max Cb 0.5 max Cu 26.0-33.0 Fe 3.50 max Mn 1.50 max P 0.03 max S 0.03 max Si 2.00 max
M-30H	N24030	Ni rem C 0.30 max Cu 27.0-33.0 Fe 3.50 max Mn 1.50 max P 0.03 max S 0.03 max Si 2.7-3.7
M-25S[a]	N24025	Ni rem C 0.25 max Cu 27.0-33.0 Fe 3.50 max Mn 1.50 max P 0.03 max S 0.03 max Si 3.5-4.5
M-30C	N24130	Ni rem C 0.30 max Cb 1.0-3.0 Cu 26.0-33.0 Fe 3.50 max Mn 1.50 max P 0.03 max S 0.03 max Si 1.0-2.0
N-12MV[a]	N30012	Ni rem C 0.12 max Cr 1.00 max Fe 4.0-6.0 Mn 1.00 max Mo 26.0-30.0 P 0.040 max S 0.030 max Si 1.00 max V 0.20-0.60
N-7M[a]	N30007	Ni rem C 0.07 max Cr 1.0 max Fe 3.00 max Mn 1.00 max Mo 30.0-33.0 P 0.040 max S 0.030 max Si 1.00 max
CY-40[a]	N06040	Ni rem C 0.40 max Cr 14.0-17.0 Fe 11.0 max Mn 1.50 max Si 3.00 max P 0.03 max S 0.03 max

ASTM A 494 - CHEMICAL COMPOSITION OF NICKEL & NICKEL ALLOY CASTINGS (Continued)		
Grade	**UNS**	**Chemical Composition**
CW-12MW[a]	N30002	Ni rem C 0.12 max Cr 15.5-17.5 Fe 4.5-7.5 Mn 1.00 max Mo 16.0-18.0 P 0.040 max S 0.030 max Si 1.00 max V 0.20-0.40 W 3.75-5.25
CW-6M[a]	N30107	Ni rem C 0.07 max Cr 17.0-20.0 Fe 3.0 max Mn 1.00 max Mo 17.0-20.0 P 0.040 max S 0.030 max Si 1.00 max
CW-2M[a]	N26455	Ni rem C 0.02 max Cr 15.0-17.5 Fe 2.0 max Mn 1.00 max Mo 15.0-17.5 P 0.03 max S 0.03 max Si 0.80 max W 1.0 max
CW-6MC	N26625	Ni rem C 0.06 max Cb 3.15-4.50 Cr 20.0-23.0 Fe 5.0 max Mn 1.00 max Mo 8.0-10.0 P 0.015 max S 0.015 max Si 1.00 max
CY5SnBiM	N26055	Ni rem Bi 3.0-5.0 C 0.05 max Cr 11.0-14.0 Fe 2.0 max Mn 1.5 max Mo 2.0-3.5 P 0.03 max S 0.03 max Si 0.5 max Sn 3.0-5.0
CX2MW[a]	N26022	Ni rem C 0.02 max Cr 20.0-22.5 Fe 2.0-6.0 Mn 1.00 max Mo 12.5-14.5 P 0.025 max S 0.025 max Si 0.80 max V 0.35 max W 2.5-3.5
CU5MCuC	N28820	Ni 38.0-44.0 C 0.050 max Cb 0.60-1.20 Cr 19.5-23.5 Cu 1.50-3.50 Fe rem Mn 1.00 max Mo 2.5-3.5 P 0.030 max S 0.030 max Si 1.0 max

a. See ASTM A 494 for details regarding class designations and heat treat requirements. rem – remainder; Nom - Nominal

ASTM F 467 - CHEMICAL COMPOSITION OF NICKEL AND NICKEL ALLOYS NUTS FOR GENERAL USE[f]														
UNS Designation Number	**Alloy**	**General Name**	**C**	**Cr**	**Cu[a]**	**Fe**	**Mn**	**Ni[a]**	**P**	**Si**	**Co**	**Mo**	**S**	**V**
N10001	335	Ni-Mo	0.05	1.0	---	4.0–6.0	1.0	bal.	0.025	1.00	2.50	26.0–30.0	0.030	0.2–0.4
N10276[c]	276	Ni-Mo-Cr	0.02	14.5–16.5	---	4.0–7.0	1.00	bal.	0.040	0.08	2.50	15.0–17.0	0.030	0.35
N04400	400	Ni-Cu Class A	0.3	---	bal.	2.5	2.0	63.0–70.0	---	0.5	b	---	0.024	---
N04405	405	Ni-Cu Class B	0.3	---	bal.	2.5	2.0	63.0–70.0	---	0.5	b	---	0.025–0.060	---
N05500[d]	500	Ni-Cu-Al	0.25	---	bal.	2.0	1.5	63.0–70.0	---	0.5	b	---	0.01	---
N06686[e]	686	Ni-Cr-Mo-W	0.010	19.0-23.0	---	5.0	0.75	Bal.	0.04	0.08	---	15.0-17.0	0.02	---

a. Elements shown as balance shall be arithmetically computed by deducting the sum of the other named elements from 100. b. Cobalt is to be counted as Nickel. c. Tungsten 3.0 to 4.5. d. Aluminum 2.30 to 3.15 and titanium 0.35 to 0.85. e. Titanium 0.02-0.25 and tungsten 3.0-4.4. f. Same nickel and nickel alloys for bolts, hex cap screws, and studs for general use (ASTM F 468M).

Single values are maximum unless otherwise specified.

MECHANICAL PROPERTIES OF NICKEL & NICKEL ALLOYS - TUBING & PIPING									
ASTM Spec.	**UNS**	**Condition[a]**	**Size, in (mm)**	**Tensile Strength**		**Yield Strength**		**% El**	**Hardness HRB max**
				ksi	**MPa**	**Ksi**	**MPa**		
B 161 SP, ST	N02200	Annealed	≤ 5 (127)	55	380	15	105	35	---
			> 5 (127)	55	380	12	80	40	---
		Stress Relieved	all sizes	65	450	40	275	15	---
	N02201	Annealed	≤ 5 (127)	50	345	12	80	35	---
			> 5 (127)	50	345	10	70	40	---
		Stress Relieved	all sizes	60	415	30	205	15	---
B 163 ST	N02200	Annealed	---	55	379	15	103	40	---
		Stress relieved	---	65	448	40	276	15	65
	N02201	Annealed	---	50	345	12	83	40	---
		Stress relieved	---	60	414	30	207	15	62
	N04400	Annealed	---	70	483	28	193	35	---
		Stress relieved	---	85	586	55	379	15	75
	N06600	Annealed	---	80	552	35	241	30	---
	N06601	Annealed	---	80	552	30	207	30	---
	N06690	Annealed	---	85	586	35	241	30	---
	N06045	Annealed	---	90	620	35	240	35	---
	N06025	Annealed	---	98	680	39	270	30	---
	N06603	Annealed	---	94	650	43	300	25	---
	N06686	Solution annealed	---	100	690	45	310	45	---
	N08120	Annealed	---	90	620	40	276	30	---
	N08800	Annealed	---	75	517	30	207	30	---
	N08801	Annealed	---	65	448	25	172	30	---
	N08800	Cold-worked	---	83	572	47	324	30	---
	N08810	Annealed	---	65	448	25	172	30	---
	N08811	Annealed	---	65	448	25	172	30	---

MECHANICAL PROPERTIES OF NICKEL & NICKEL ALLOYS – PLATE, SHEET & STRIP									
ASTM Spec.	**UNS**	**Form**	**Condition[a]**	**Tensile Strength**		**Yield Strength**		**% El**	**Hardness HRB max**
				ksi	**MPa**	**ksi**	**MPa**		
B 127	N04400	Hot-Rolled Plate	Annealed	70	485	28	195	35	---
			As-rolled	75	515	40	275	25	---
		Hot-Rolled Sheet	Annealed	70	485	28	195	35	---
		Cold-Rolled Sheet	Annealed	70-85	485-585	28	195	35	---
			Quarter-hard	---	---	---	---	---	73-83
			Half-hard	---	---	---	---	---	82-90
			Hard	100	690	90	620	2	---
		Cold-Rolled Strip	Annealed	70-85	485-585	28	195	35	---
			Skin-hard	---	---	---	---	---	68-73
			Quarter-hard	---	---	---	---	---	73-83
			Half-hard	---	---	---	---	---	82-90
			Three-quarter-hard	---	---	---	---	---	89-94
			Hard	100	690	90	620	2	---
			Spring temper	---	---	---	---	---	98 min
B 162	N02200	Hot-Rolled Plate	Annealed	55	380	15	100	40	---
			As-rolled	55	380	20	135	30	---
		Hot-Rolled Sheet	Annealed	55	380	15	100	40[b]	---
		Cold-Rolled Sheet	Annealed	55	380	15	100	40[b]	---
			Quarter-hard	---	---	---	---	---	70-80
			Half-hard	---	---	---	---	---	79-86
			Hard	90	620	70	480	2	---
		Cold-Rolled Strip	Annealed	55	380	15	100	40[b]	---
			Skin-hard	---	---	---	---	---	64-70
			Quarter-hard	---	---	---	---	---	70-80
			Half-hard	---	---	---	---	---	79-86

MECHANICAL PROPERTIES OF NICKEL ALLOYS - FLANGES, FORGED FITTINGS & VALVE PARTS									
ASTM Spec.	Form	UNS	Condition[a]	Tensile Strength		Yield Strength		% El	% RA
				ksi	MPa	ksi	MPa		
B 462	Fl, FFt, V	N08020	Stabilized-annealed	80	551	35	241	30.0	50.0
		N08024	Annealed	80	551	35	241	30.0	50.0
		N08026	Solution-annealed	80	551	35	241	30.0	50.0
		N08367	Solution-annealed	95	655	45	310	30.0	50.0
		R20033	Solution-annealed	109	750	55	380	40.0	---
		N06030	see standard	85	586	35	241	30	---
		N06022	see standard	100	690	45	310	45	---
		N06200	see standard	100	690	41	283	45	---
		N10276	see standard	100	690	41	283	40	---
		N10665	see standard	110	760	51	350	40	---
		N10675	see standard	110	760	51	350	40	---

a. See specific ASTM Standard for specific details of heat treat condition.
Fl - flange, FFt - forged fitting, V - valve. Single values are minimum specified.

MECHANICAL PROPERTIES OF NICKEL ALLOYS - FORGINGS								
ASTM Spec.	**UNS**	**Condition**	**Section Thickness max, in. (mm)**	**Tensile Strength**		**Yield Strength**		**% El**
				ksi	**MPa**	**ksi**	**MPa**	
B 564	N02200	Annealed	---	55	380	15	105	40
	N04400	Annealed	---	70	483	25	172	35
	N06600	Annealed	---	80	552	35	241	30
	N06690	Annealed	---	85	586	35	241	30
	N06058	---	---	110	760	52	360	40
	N06059	---	---	100	690	45	310	45
	N06200	---	---	100	690	41	283	45
	N08120	---	---	90	621	40	276	30
	N08800	---	---	75	517	30	207	30
	N08810	---	---	65	448	25	172	30
	N08811	---	---	65	448	25	172	30
	N06625	---	≤ 4 (102)	120	827	60	414	30
		---	> 4 - 10 (102 - 254)[a]	110	758	50	345	25
	N06110	---	≤ 4 (102)	95	655	45	310	60
		---	> 4 - 10 (102 - 254)[a]	90	621	40	276	50
	N08825	---	---	85	586	35	241	30
	N10276	---	---	100	690	41	283	40
	N06022	---	---	100	690	45	310	45
	N08367	---	---	95	655	45	310	30
	N08031	---	---	94	650	40	276	40
	N06230	Annealed	---	110	758	45	310	40
	N06617	---	---	95	655	35	241	35
	N10665	Annealed	---	110	760	51	350	40
	N10675	Annealed	---	110	760	51	350	40

MECHANICAL PROPERTIES OF NICKEL & NICKEL ALLOYS - RODS & BARS

ASTM Spec.	UNS	Condition	Thickness or Diameter, in (mm)	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	% El
B 160	N02200	CW (as worked)	Rounds, ≤ 1 (25.4)	80	550	60	415	10
			Rounds, > 1-4 (25.4-101.6) incl.	75	515	50	345	15
			Squares, hexagons, rectangles, all sizes	65	450	40	275	25
		Hot-worked	All sections, all sizes	60	415	15	105	35
			Rings and disks	---	---	---	---	---
		Annealed	Rods and bars, all sizes	55	380	15	105	40[a]
			Rings and disks	---	---	---	---	---
		Forging quality	All sizes	NR	NR	NR	NR	NR
	N02201	Hot-worked	All sections, all sizes	50	345	10	70	40
		Annealed	All products, all sizes	50	345	10	70	40
B 164	N04400	CW (as worked)	Rounds under ½ (12.7)	110	760	85	585	8
			Squares, hexagons, and rectangles < ½ (12.7)	85	585	55	380	10
		CW (stress-relieved)	Rounds under ½ (12.7)	84	580	50	345	10
			Rounds ½-3½ (12.7-88.9), incl.	87	600	60	415	20
			Rounds > 3½-4 (88.9-101.6), incl.	84	580	55	380	20
			Squares, hexagons, and rectangles ≤ 2 (50.8)	84	580	50	345	20
			Squares, hexagons, and rectangles > 2-3⅛ (50.8-79.4), incl.	80	552	50	345	20
		HW (as worked or stress-relieved)	Rounds, squares, and rectangles up to 12 (305) incl. and hexagons ≤ 2⅛ (54)	80	552	40	276	30

MECHANICAL PROPERTIES OF NICKEL ALLOYS - WIRES[a]								
ASTM Spec.	UNS	Condition	Size, in (mm)	Tensile Strength		Yield Strength		% El
				ksi	MPa	ksi	MPa	
B 164	N04400	Annealed	All sizes	70-85	483-586	---	---	---
		No. 0 temper	< ½ (12.7)	80-95	552-655	---	---	---
		No. 1 temper	< ½ (12.7)	90-110	621-758	---	---	---
		Regular temper	< ½ (12.7)	110-140	758-965	---	---	---
		Regular temper	≥ ½ (12.7)	90-130	621-896	---	---	---
		Spring temper	≤ 0.028 (0.71), incl.	165	1138	---	---	---
			> 0.028-0.057 (0.71-1.45), incl.	160	1103	---	---	---
			> 0.057-0.114 (1.45-2.90), incl.	150	1034	---	---	---
	N04400	Spring temper	> 0.114-0.312 (2.90-7.92), incl.	140	965	---	---	---
			> 0.312-0.375 (7.92-9.53), incl.	135	931	---	---	---
			> 0.375-0.500 (9.53-12.7), incl.	130	896	---	---	---
			> 0.500-0.563 (12.7-14.3), incl.	120	827	---	---	---
	N04405	Annealed	All sizes	70-85	483-586	---	---	---
		No. 0 temper	< ½ (12.7)	80-95	552-655	---	---	---
		No. 1 temper	< ½ (12.7)	90-110	621-758	---	---	---

MECHANICAL PROPERTIES OF NICKEL & NICKEL ALLOYS - CASTINGS									
ASTM Spec.	**Grade**	**UNS**	**Condition**	**Tensile Strength**		**Yield Strength**		**% El**	**Hardness HB**
				ksi	**MPa**	**ksi**	**MPa**		
A 494	CZ-100	N02100	a	50	345	18	125	10.0	---
	M-35-1	N24135	a	65	450	25	170	25.0	---
	M-35-2	N04020	a	65	450	30	205	25.0	---
	M-30H	N24030	a	100	690	60	415	10.0	---
	M-25S[a,b]	N24025	a	---	---	---	---	---	300 min[d]
	M-30C	N24130	a	65	450	32.5	225	25.0	---
	N-12MV[a]	N30012	a	76	525	40	275	6.0	---
	N-7M[a]	N30007	a	76	525	40	275	20.0	---
	CY-40[a,c]	N06040	a	70	485	28	195	30.0	---
	CW-12MW[a]	N30002	a	72	495	40	275	4.0	---
	CW-6M[a]	N30107	a	72	495	40	275	25.0	---
	CW-2M[a]	N26455	a	72	495	40	275	20.0	---
	CW-6MC	N26625	a	70	485	40	275	25.0	---
	CY5SnBiM	N26055	a	---	---	---	---	---	---
	CX2MW[a]	N26022	a	80	550	45	280	30.0	---
	CU5MCuC[a]	N28820	a	75	520	35	240	20.0	---

a. See ASTM A 494 for details regarding class designation and heat treat requirements.
b. M-25S class 1 - as cast; class 2 and class 3 see ASTM A 494 for more details.
c. CY-40 class 1 - as cast; CY-40 class 2 - solution-annealed, see ASTM A 494 for more details.
d. For information only, see ASTM A 494 for more details.

ASME P-No. - BASE METAL NICKEL & NICKEL ALLOYS				
ASME Spec.	**UTS ksi[c]**	**UNS**	**Nominal Composition**	**Product Form**
P No. 41				
SB-160	55	N02200	99.0Ni	Rod, Bar
	50	N02201	99.0Ni-Low C	Rod, Bar
SB-161	55	N02200	99.0Ni	Smls. Pipe & Tube
	50	N02201	99.0Ni-Low C	Smls. Pipe & Tube
SB-162	55	N02200	99.0Ni	Plate, Sheet, Strip
	50	N02201	99.0Ni-Low C	Plate, Sheet, Strip
SB-163	55	N02200	99.0Ni	Smls. Tube
	50	N02201	99.0Ni-Low C	Smls. Tube
SB-366	55	N02200	99Ni	Fittings
	50	N02201	99Ni-Low C	Fittings
P No. 42				
SB-127	70	N04400	67Ni-30Cu	Plate, Sheet, Strip
	75	N04400	67Ni-30Cu	Plate, Sheet, Strip
SB-163	70	N04400	67Ni-30Cu	Smls. Tube
	85	N04400	67Ni-30Cu	Smls. Tube
SB-164	70	N04400	67Ni-30Cu	Rod, Bar, Wire
	70	N04405	67Ni-30Cu	Rod, Bar, Wire
SB-165	70	N04400	67Ni-30Cu	Smls. Pipe & Tube
SB-366	70	N04400	67Ni-30Cu	Fittings
SB-564	70	N04400	67Ni-30Cu	Forging
P No. 43				
SB-163	80	N06600	72Ni-15Cr-8Fe	Smls. Tube
	85	N06690	58Ni-29Cr-9Fe	Smls. Tube

ASME F No. – WELDING FILLER METAL NICKEL & NICKEL ALLOYS					
F No.	**ASME Spec. No.**	**AWS Classification**	**F No.**	**ASME Spec. No.**	**AWS Classification**
41	SFA-5.11	ENi-1	44	SFA-5.11	ENiMo-1
	SFA-5.14	ERNi-1			ENiMo-3
	SFA-5.30	IN 61			ENiMo-7
42	SFA-5.11	ENiCu-7			ENiMo-8
	SFA-5.14	ERNiCu-7			ENiMo-9
		ERNiCu-8			ENiMo-10
	SFA-5.30	IN 60			ENiCrMo-4
43	SFA-5.11	ENiCrFe-1			ENiCrMo-5
		ENiCrFe-2			ENiCrMo-7
		ENiCrFe-3			ENiCrMo-10
		ENiCrFe-4			ENiCrMo-13
		ENiCrFe-7			ENiCrMo-14
		ENiCrFe-9		SFA-5.14	ERNiMo-1
		ENiCrFe-10			ERNiMo-2
		ENiCrCoMo-1			ERNiMo-3
		ENiCrMo-2			ERNiMo-7 (B-2 alloy)
		ENiCrMo-3			ERNiMo-8
		ENiCrMo-6			ERNiMo-9
		ENiCrMo-12			ERNiMo-10
	SFA-5.14	ERNiCr-3			ERNiCrMo-4
		ERNiCr-4			ERNiCrMo-7 (Alloy C-4)
		ERNiCr-6			ERNiCrMo-10
		ERNiCrFe-5			ERNiCrWMo-1
		ERNiCrFe-6			ERNiCrMo-13
		ERNiCrFe-7			ERNiCrMo-14

COMMON NAMES & CROSS REFERENCED SPECIFICATIONS - NICKEL & NICKEL ALLOYS - WELD FILLER METALS				
Common Name	**UNS**	**ASME**	**AWS**	**MIL-SPEC**
75Ni-20Cr[a]	W86003	---	---	---
904L Electrode	W88904	SFA-5.4 (E385)	A5.4 (E385)	---
Avesta P12R	W86032	---	A5.11 (ENiCrMo-12)	---
Carpenter 20Cb-3	W88021	SFA-5.4 (E320)	A5.4 (E320)	---
Carpenter 20Cb3L.R.	W88022	SFA-5.4 (E320LR)	A5.4 (E320LR)	---
		SFA-5.9 (EC320LR)	A5.9 (EC320LR)	---
Cast Iron Electrode ENi-CI	W82001	---	A5.15 (ENi-CI)	---
Cast Iron Electrode ENi-CI-A	W82003	SFA-5.15 (ENi-CI-A)	A5.15 (ENi-CI-A)	---
Cast Iron Electrode ENiCu-A	W84001	---	A5.15 (ENiCu-A)	---
Cast Iron Electrode ENiCu-B	W84002	---	A5.15 (ENiCu-B)	---
Cast Iron Electrode ENiFe-CI	W82002	SFA-5.15 (ENiFe-CI)	A5.15 (ENiFe-CI)	---
Cast Iron Electrode ENiFe-CI-A	W82004	SFA-5.15 (ENiFe-CI-A)	A5.15 (ENiFe-CI-A)	---
Cast Iron Electrode ENiFeMn-CI	W82006	SFA-5.15 (ENiFeMn-CI)	A5.15 (ENiFeMn-CI)	---
Cast Iron Flux Cored Wire[a]	W82032	SFA-5.15 (ENiFeT3-CI)	A5.15 (ENiFeT3-CI)	---
E383 Electrode	W88028	SFA-5.4 (E383)	A5.4 (E383)	---
E330 Electrode	W88331	SFA-5.4 (E330)	A5.4 (E330)	E-22200/2 (MIL-330)
E330H high carbon	W88335	SFA-5.4 (E330H)	A5.4 (E330H)	---
Hard Surfacing Electrode	W83002	SFA-5.13 (ENiCrFeCo)	A5.13 (ENiCrFeCo)	---
Hard Surfacing Electrode[a]	W89604	---	A5.13 (ENiCr-A)	---
Hard Surfacing Electrode[a]	W89605	---	A5.13 (ENiCr-B)	---
Hard Surfacing Electrode	W89606	---	A5.13 (ENiCr-C)	---
Hastelloy B	W80001	SFA-5.11 (ENiMo-1)	A5.11 (ENiMo-1)	E-22200/3 (MIL-3N1B)
Hastelloy B-2	W80665	SFA-5.11 (ENiMo-7)	A5.11 (ENiMo-7)	---
Hastelloy C	W80002	SFA-5.11 (ENiCrMo-5)	A5.11 (ENiCrMo-5)	E-22200/3 (MIL-3N1C)
		SFA-5.13 (ENiCrMo-5A)	A5.13 (ENiCrMo-5A)	

NICKEL ALLOYS - AVERAGE PHYSICAL CONSTANTS[a]												
Alloy	Density at 20°C g/cm³ (lb/in.³)	Melting Range, Sol/Liq °C (°F)	Thermal Conductivity 0-100°C (32-212°F) W/m·K (Btu/hr/ft.²/F/in.)	Coefficient of Linear Thermal Expansion °C⁻¹ x 10⁻⁶ (°F⁻¹ x 10⁻⁶)		Specific Heat 0-100°C (32-212°F) J/kg K (Btu/lb·°F)	Electrical Resistivity at R.T. Ω·mm²/m (Ohm circular-mil/ft.)	Temperature Coefficient of Electrical Resistance		Magnetic Properties		Max. Operating T in Air (Sulfur Free) °C (°F)
				0-100°C (32-212°F)	0-1000°C (32-1832°F)			20-100°C Per °C	20-1000°C Per °C	Condition[m] at R.T.	Curie T. °C (°F)	
---[b]	X 27.68	---	X 0.1441	X 1.8	X 1.8	X 4186.8	X 0.16624	---	---	---	---	---
Nickel UNS N02200	8.88 (0.321)	1435-1446 (2615-2635)	60.52 (420)	13.0 (7.2)	---	544 (0.13)	9.5 (57)	0.00432	---	F	360 (680)	1038 (1900)
Age Hardenable Nickel	8.75 (0.316)	1435-1446 (2615-2635)	60.52 (420)	13.0 (7.2)	---	544 (0.13)	15.7 (94.5)	0.0036	---	F	290-299 (555-570)	---
High Purity Nickel UNS N02270	8.88 (0.321)	1455 (2650)	79 (548)	13.3 (7.4)	---	460 (0.11)	7.5 (45)	---	---	F	353 (667)	---
Nickel-Beryllium 2Be97Ni0.5Ti	8.36 (0.302)	1220-1370 (2240-2500)	32 (220)	14.5 (8.0)[c]	---	473 (0.113)	23.8 (143)	---	---	F	---	---
Nickel-Manganese 95Ni4Mn1Si	8.40 (0.3035)	1416-1445 (2550-2600)	28.5 (198)	13.2 (7.33)	16.0 (8.89)	---	22 (130)	---	0.00135	Strongly M	---	---
Nickel-Manganese Aluminum-Silicon 95Ni2Mn2Al1Si	8.60 (0.3107)	1380-1410 (2525-2575)	29.7 (206)	12.0 (6.66)	---	523 (0.125)	29-32 (177-191)	0.00188	---	Strongly M	---	1260 (2300)

INTERNATIONAL SPECIFICATION DESIGNATIONS & TITLES OF NICKEL & NICKEL ALLOYS	
Specification	**Title**
ISO 6207	Seamless nickel and nickel alloy tube
ISO 6208	Nickel and nickel alloy plate, sheet and strip
ISO 6372: Part 1	Nickel and nickel alloys - Terms and definitions - Materials
ISO 6372: Part 2	Nickel and nickel alloys - Terms and definitions - Refinery products
ISO 6372: Part 3	Nickel and nickel alloys - Terms and definitions – Wrought products and castings
ISO 9400	Nickel-based alloys - Determination of resistance to intergranular corrosion
ISO 9722	Nickel and nickel alloys - Composition and forms of wrought products
ISO 9723	Nickel and nickel alloy bars
ISO 9724	Nickel and nickel alloy wire and drawing stock
ISO 9725	Nickel and nickel alloy forgings
ISO 12725	Nickel and nickel alloy castings
EN ISO 6871-2	Dental base metal casting alloys – Part 2: Nickel-based alloys
EN 9400	Nickel-based alloys – Determination of resistance to intergranular corrosion
BS 375	Refined nickel
BS 558, 564	Nickel anodes, anode nickel and nickel salts for electroplating
BS 2857	Nickel-iron transformer and choke laminations
BS 2901: Part 5	Filler rods and wires for gas-shielded arc welding part 5: specification for nickel and nickel alloys
BS 3071	Nickel-copper alloy castings
BS 3072	Nickel and nickel alloys: sheet and plate
BS 3073	Nickel and nickel alloys: strip
BS 3074	Nickel and nickel alloys: seamless tube
BS 3075	Nickel and nickel alloys: wire
BS 3076	Nickel and nickel alloys: bar
BS 3146: Part 2	Investment castings in metal. Part 2: Corrosion and heat resisting steels, nickel and cobalt base alloys
BS 3382: Parts 3, 4	Electroplated coatings on threaded components. Parts 3: Nickel or nickel plus chromium on steel components. Part 4: Nickel or nickel plus chromium on copper and copper alloy (including brass) components.

BS 3072 - MECHANICAL PROPERTIES OF NICKEL & NICKEL ALLOYS - SHEET AND PLATE									
Alloy	**Condition**	**Over (mm)**	**Up to and including (mm)**	**0.2% Proof Stress N/mm^2, min.**	**1.0% Proof Stress N/mm^2, min.**	**Tensile Strength, min.**	**%El**	**HV max.**	**ASTM Grain Size**
NA 11	Cold Rolled & Annealed	0.25	0.5	---	---	380	30	110	6 or finer
		0.5	1.5	105	130	380	35	---	---
		1.5	4.0	105	130	380	40	---	---
	Hot Rolled	All		130	---	380	30	---	---
	Hot Rolled & Annealed	All		105	130	380	40	---	---
NA 12	Cold Rolled & Annealed	0.25	0.5	---	---	350	30	110	6 or finer
		0.5	1.5	85	110	350	35	---	---
		1.5	4.0	85	110	350	40	---	---
	Hot Rolled	All		85	---	350	30	---	---
	Hot Rolled & Annealed	All		85	110	350	40	---	---
NA 13	Cold Rolled & Annealed	0.25	0.5	---	---	480	35	140	6 or finer
		0.5	4	195	220	480	35	---	---
	Hot Rolled	All		275	---	510	25	---	---
	Hot Rolled & Annealed	All		195	220	480	35	---	---
NA 14	Cold Rolled & Annealed	0.25	0.5	---	---	550	30	170	6 or finer
		0.5	4.0	240	265	550	30	---	---
	Hot Rolled	All		240	---	580	30	---	---
	Hot Rolled & Annealed	All		240	265	550	30	---	---
NA 15	Cold Rolled & Annealed	0.25	0.5	---	---	520	30	170	6 or finer
		0.5	4.0	205	235	520	30	---	---
	Hot Rolled	All		240	---	550	25	---	---

INTERNATIONAL CROSS REFERENCES - NICKEL & NICKEL ALLOYS[a]

Common Name	USA UNS	Product Form	USA ASTM/AWS	UNITED KINGDOM		GERMANY	
				BS	Alloy	DIN	W. Nr.
Nickel 200	N02200	Plate, Sheet	B 162	3072	NA11	17750 Ni99.0	2.4066
		Strip	B 162	3073	NA11	17750 Ni99.0	2.4066
		Rod	B 160	3075	NA11	17152 Ni99.0	2.4066
		Bar	B 160	3076	NA11	17152 Ni99.0	2.4066
		Seamless Pipe	B 161	---	---	17751 Ni99.0	2.4066
		Seamless Tube	B 161	3074	NA11	17751 Ni99.0	2.4066
		Welded Pipe	B 725	---	---	---	---
		Welded Tube	B 730	---	---	---	---
		Fittings	B 366	---	---	---	---
Nickel 201	N02201	Plate, Sheet	B 162	3072	NA12	17750 LCNi99.0	2.4068
		Strip	B 162	3073	NA12	17750 LCNi99.0	2.4068
		Bar	B 160	3076	NA12	17152 LCNi99.0	2.4068
		Rod	B 160	3075	NA12	17152 LCNi99.0	2.4068
		Seamless Pipe	B 161	---	---	17751 LCNi99.0	2.4068
		Seamless Tube	B 161	3074	NA12	17751 LCNi99.0	2.4068
		Welded Pipe	B 725	---	---	---	---
		Welded Tube	B 730	---	---	---	---
		Fittings	B 366	---	---	---	---
Alloy 20Cb-3	N08020	Plate	B 463	---	---	NiCr20CuMo	2.4660
		Fittings	B 366	---	---	NiCr20CuMo	2.4660
		Welded Pipe	B 464	---	---	NiCr20CuMo	2.4660
		Welded Tube	B 468	---	---	NiCr20CuMo	2.4660
Alloy 400 (Monel 400)	N04400	Plate, Sheet	B 127	3072	NA13	17750 NiCu30Fe	2.4360
		Strip	B 127	3073	NA13	17750 NiCu30Fe	2.4360
		Rod	B 164	3075	NA13	17752 NiCu30Fe	2.4360

Chapter 4

TITANIUM & TITANIUM ALLOYS

Metallic titanium was first isolated in impure form in 1887 and with higher purity in 1910; however, it was not until the 1950s that it began to come into use as a structural material. This was initially stimulated by aircraft applications. Although the aerospace industry still provides the major market, titanium and titanium alloys are finding increasingly widespread use in other industries due to their many desirable properties. Notable among these is their low densities, which fall between those of aluminum and iron and give very attractive strength to weight ratios. In addition, titanium and titanium alloys readily form stable protective surface layers which give them excellent corrosion resistance in many environments, including oxidizing acids and chlorides, and good elevated temperature properties up to about 550°C (1022°F) in some cases.

Titanium metal is abundant in the earth's crust and is extracted commercially from the ore minerals rutile (titanium dioxide) and ilmenite (iron-titanium oxide). The commercial extraction process involves treatment of the ore with chlorine gas to produce titanium tetrachloride, which is purified and reduced to a metallic titanium sponge by reaction with magnesium or sodium. The sponge, blended with alloying elements (and reclaimed scrap) as desired, is then vacuum melted. Several meltings may be necessary to achieve a homogeneous ingot which is ready for processing into useful shapes, typically by forging followed by rolling. For many applications the cost of titanium alloys can be justified on the basis of desirable properties.

Pure titanium, like iron, is allotropic. At ambient temperature it has a hexagonal close packed (hcp) crystal structure which is stable during heating up to 883°C (1621°F) where it transforms to the body centered cubic (bcc) crystal structure. It remains bcc at higher temperatures until it melts at 1668°C (3034°F). On cooling, the transformation from bcc to hcp in pure titanium cannot be suppressed by rapid cooling, the transformation occurring by a martensitic type reaction. This is not, however, the case with titanium alloys, in which the transformation can be suppressed or modified. Thus the microstructures of titanium alloys frequently contain particles of the bcc phase at ambient temperatures.

Different alloying elements have different effects. Some stabilize the hcp "alpha" structure by allowing it to exist at temperatures above 883°C (1621°F) while others stabilize the bcc "beta" structure by allowing it to remain stable below this temperature. Particular combinations of alloy composition and heat treatment can thus be used to obtain a wide range of possible microstructures, and hence a wide range of useful combinations of properties. The most important of the alpha stabilizers are aluminium, tin, and oxygen, while the important beta stabilizers include molybdenum, vanadium, manganese, chromium, and iron.

The spectrum of titanium-based materials can be divided into four classes depending their constituent phases; this in turn depends on their relative contents of alpha-stabilizing and beta-stabilizing alloying elements. The four basic classes are: (1) unalloyed or commercially pure titanium; (2) alpha and near-alpha alloys; (3) alpha-plus-beta alloys; and, (4) beta alloys. These four classes will be considered further in the sections that follow.

Unalloyed (Commercial Purity) Titanium

Unalloyed titanium typically contains between 99% and 99.5% titanium with the balance being made up of iron and the interstitial impurity elements hydrogen, nitrogen, carbon and, most importantly, oxygen. Titanium has a strong affinity for the interstitial elements, so much so that commercial purity titanium is sometimes referred to as an alpha phase titanium-oxygen alloy. The properties of titanium and its alloys are quite sensitive to the amounts of these elements present. For example, an oxygen content of only 0.1% is sufficient to raise the hardness of pure titanium by a factor of about three. At the same time the ductility and impact toughness are adversely affected, with excessive quantities causing embrittlement. Maximum contents of iron and the four interstitial impurity elements are therefore specified. For example, there are four ASTM grades of unalloyed titanium (grades 1 to 4, corresponding to UNS R50250, R50400, R50500 and R50700), differing primarily in their specified maximum oxygen contents (between about 0.1 and 0.4%). Unalloyed titanium also has a specified maximum hydrogen content, typically about 0.01%, because the presence of small amounts of hydrogen can lead to the precipitation of embrittling hydride particles, even at ambient temperature. Small amounts of iron cause the formation of microscopic particles of beta phase which act to strengthen the material. Typically a maximum of 0.2 to 0.5% is specified. Nitrogen and carbon also cause strengthening. The ASTM standards deal with the adverse effects

AMERICAN CROSS REFERENCED SPECIFICATIONS - TITANIUM & TITANIUM ALLOYS					
UNS	**SAE/AMS**	**MILITARY**	**ASTM**	**ASME**	**AWS**
R50100	---	---	---	SFA5.16 (ERTi-1)	A5.16 (ERTi-1)
R50120	---	---	---	SFA5.16 (ERTi-2)	A5.16 (ERTi-2), C2.25 (W-Ti)
R50125	4951	---	---	SFA5.16 (ERTi-3)	A5.16 (ERTi-3)
R50130	---	---	---	---	A5.16 (ERTi-4)
R50250	AMS-T-81915	T-81556	B 265 grade 1, B 338 grade 1, B 348 grade 1, B 381 grade F-1, B 861(1), B 862 (1), B 863 (1), F 67 grade 1, F 467 (1), F 468 (1), F 1341	---	---
R50400	4902, 4941, 4942, AMS-T-9046, SAE J467(A40)	T-81556	B 265 grade 2, B 337 grade 2, B 338 grade 2, B 348 grade 2, B 367 grade C-2, B 381 grade F-2, B 861(2), B 862 (2), B 863 (2), F 67 grade 2, F 467 (2), F 468 (2), F 1341	---	---
R50550	4900, AMS-T9046, SAE J467(A55)	T-81556	B 265 grade 3, B 338 grade 3, B 348 grade 3, B 367 grade C-3, B 381 grade F-3, B 861(3), B 862 (3), B 863 (3), F 67 grade 3, F 467, F 468, F 1341	---	---
R50700	4901, 4921, AMS-T9046, SAE J467(A70)	T-81556	B 265 grade 4, B 348 grade 4, B 381 grade F-4, F 67 grade 4, F 467 alloy Ti 4, F 468 alloy Ti 4, F 1341, F 1580	---	---
R52250	---	---	B 265 grade 11, B 338 grade 11, B 348 grade 11, B 381 grade F-11, B 861(11), B 862 (11), B 863 (11)	---	---
R52400	---	---	B 265 grade 7, B 338 grade 7, B 348 grade 7, B 381 grade F-7, B 861(7), B 862 (7), B 863 (7), F 467 alloy Ti 7, F 468 alloy Ti 7	---	---
R52401	---	---	B 265 grades 7, 11, B 338 grades 7, 11, B 348 grades 7, 11, B 367 grades Ti-Pd7B, Ti-Pd8A, B 381 grades 7, 11	---	A5.16 (ERTi-7)
R52402	---	---	B 265 grade 16, B 338 grade 16, B 348 grade 16, B 381 grade 16, B 861(16), B 862 (16), B 863 (16)	---	---
R52550	---	---	B 367 grade C-2, C-3	---	---

CHEMICAL COMPOSITION OF ALLOYED TITANIUM

UNS	ASTM Spec.	Gr	C	Fe	H	N	O	Other[c]
R56400	B265, B348, B367[a],B381[b],F467	5	0.10	0.40	0.015	0.05	0.20	5.5-6.75 Al, 3.5-4.5 V
R54520	B265, B348, B367[a], B381[b]	6	0.10	0.50	0.020	0.05	0.20	4.0-6.0 Al, 2.0-3.0 Sn
R52400	B265, B337 B338, B348, B381[b], F467, F468	7	0.10	0.30	0.015	0.03	0.25	0.12-0.25 Pd,
R56320	B265, B337, B338, B348, B381[b]	9	0.05	0.25	0.013	0.02	0.12	2.5-3.5Al, 2.0-3.0 V
R52250	B265, B337, B338, B348, B381[b]	11	0.10	0.20	0.015	0.03	0.18	0.12-0.25 Pd
R53400	B265, B337, B338, B348, B381[b]	12	0.08	0.30	0.015	0.03	0.25	0.2-0.4 Mo, 0.6-0.9 Ni
R53413	B265, B337, B338, B348, B381[b]	13	0.10	0.20	0.015[d]	0.03	0.10	0.04-0.06 Ru, 0.40-0.60 Ni
R53414	B265, B337, B338, B348, B381[b]	14	0.10[e]	0.30	0.015[d]	0.03	0.15	0.04-0.06 Ru, 0.40-0.60 Ni
R53415	B265, B337, B338, B348, B381[b]	15	0.10	0.30	0.015[d]	0.03	0.25	0.04-0.06 Ru, 0.40-0.60 Ni
R52402	B265, B337, B338, B348, B381[b]	16	0.10	0.30	0.010[d]	0.03	0.25	0.04-0.08 Pd
R52252	B265, B337, B338, B348, B381[b]	17	0.10	0.20	0.015[d]	0.03	0.18	0.04-0.08 Pd
R56322	B265, B337, B338, B348, B381[b]	18	0.10	0.25	0.015[d]	0.02	0.15	0.04-0.08 Pd, 2.5-3.5 Al, 2.0-3.0 V
---	B265	19	0.05	0.30	0.02	0.03	0.12	3.0-4.0 Al, 5.5-6.5 Cr, 3.5-4.5 Mo, 7.5-8.5 V, 3.5-4.5 Zr
R58645	B265, B337, B348, B381[b]	20	0.05	0.30	0.02	0.03	0.14	3.0-4.0 Al, 5.5-6.5 Cr, 3.5-4.5 Mo, 0.04-0.08 Pd 7.5-8.5 V, 3.5-4.5 Zr
R58210	B265, B337, B338, B348, 363, B381[b]	21	0.05	0.20-0.40	0.015	0.03	0.11-0.15	2.5-3.5 Al, 2.2-3.2 Cb, 14.0-16.0 Mo, 0.15-0.25 Si
---	B265	23	0.08	0.25	0.0125	0.03	0.13	5.5-6.5 Al, 3.5-4.5V,
R56405	B265, B337, B338, B348, 363, B381[b]	24	0.10	0.40	0.015	0.05	0.20	5.5-6.75 Al, 0.04-0.08 Pd, 3.5-4.5 V
R56403	B348	25	0.10	0.40	0.0125	0.05	0.20	5.5-6.75 Al, 0.3-0.8 Ni, 0.04-0.08 Pd, 3.5-4.5 V
---	B265	26	0.08	0.30	0.015	0.03	0.25	0.08-0.14 Ru
---	B265	27	0.08	0.20	0.015	0.03	0.18	0.08-0.14 Ru

ASTM F 468M – MECHANICAL PROPERTIES OF TITANIUM ALLOYS BOLTS, HEX CAP SCREWS, AND STUDS FOR GENERAL USE[e]

Alloy	Marking	Nominal Thread Diameter	Hardness[a]	Full-Size Tests[b]		Machined Specimen Tests		Elongation in 4*D*, min, %[d]
				Tensile Strength, MPa	Yield Strength, min, MPa	Tensile Strength, min, MPa	Yield Strength min, MPa[c]	
Ti 1	F 468MAT	all	140–160 HV	240–480	170	240	170	24
Ti 2	F 468MBT	all	160–180 HV	345–580	275	345	275	20
Ti 4	F 468MCT	all	200–220 HV	550–785	483	550	483	15
Ti 5 Class A[f]	F 468MDT	all	30–39 HRC	895–1125	828	895	828	10
Ti 5 Class B[f]	F 468MHT	all	30–39 HRC	895–1125	828	895	828	10
Ti 7	F 468MET	all	160–180 HV	345–580	275	345	275	20
Ti 19	F 468MFT	all	24–38 HRC	793–1025	759	793	759	15
Ti 23	F 468MGT	all	25–36 HRC	828–1125	759	828	759	10
Ti-5-1-1-1	F 468MHT	all	24–38 HRC	725–1035	620	690	585	10

a. Where both tension and hardness tests are performed, the tension tests shall take precedence for acceptance purposes. For Ti alloys, hardness tests are for information only. See ASTM F 468M.

b. The yield and tensile strength values for full-size products shall be computed by dividing the yield and maximum tensile load by the stress area for the product diameter and thread pitch as given in table on tensile stress areas.

c. Yield strength is the stress at which an offset of 0.2 % gage length occurs.

d. Elongation is determined using a gage length of 4 diameters of test specimen in accordance with Test Methods E 8.

e. Full-size test mechanical properties apply to fasteners with a maximum diameter of 76 mm. Mechanical properties of larger sections shall be negotiated between the material manufacturer and the fastener producer.

f. Ti 5 Class A requires wedge tensile testing in accordance with 6.5, ASTM F 468M, paragraph 6.5.1. Ti 5 Class B requires wedge tensile testing in accordance with ASTM F 468M, paragraph 6.5.1.

MECHANICAL PROPERTIES OF CAST TITANIUM & TITANIUM ALLOYS[a]									
Casting Standards			Tensile Strength		Yield Strength			Hardness	
ASTM B 367	AMS 4985	AMS 4991	ksi	MPa	Ksi	MPa	% El	Rockwell max	HB max
C-2	---	---	50	345	40	275	15	96 HRB[b]	210[b]
C-3	---	---	65	450	55	380	12	24 HRC[b]	235[b]
C-5	---	---	130	895	120	825	6	39 HRC[b]	365[b]
C-6	---	---	115	795	105	725	8	36 HRC[b]	335[b]
Ti-Pd7B	---	---	50	345	40	275	15	96 HRB[b]	210[b]
Ti-Pd8A	---	---	65	450	55	380	12	24 HRC[b]	235[b]
Ti-Pd16	---	---	50	345	40	275	15	96 HRB[b]	210[b]
Ti-Pd17	---	---	35	240	25	170	20	24 HRC[b]	235[b]
Ti-Pd18	---	---	90	620	70	483	15	39 HRC[b]	365[b]
---	6Al4V[c]	---	130	895	120	825	6	39 HRC	---
---	6Al4V[d]	---	130	895	120	825	6	39 HRC	---
---	6Al4V[e]	---	125	860	108	745	4.5	39 HRC	---
---	---	6Al4V[d]	130	895	120	825	6	39 HRC[f]	---
---	---	6Al4V[e]	127	875	110	760	4.5	39 HRC[f]	---
---	---	6Al4V[c]	130	895	120	825	6	39 HRC[f]	---

a. Single values are minimum unless otherwise noted. Values for ASTM B 367 are supplementary requirements only.
b. Supplementary requirement applied only when specified by the purchaser. Values are averages of three tests. See ASTM B 367 for more details.
c. Separately-cast specimens or specimens cut from attached coupons.
d. Specimens cut from castings designated areas.
e. Specimens cut from castings non-designated areas.
f. Castings shall not be rejected on the basis of hardness if tensile property requirements of AMS 4991 are met.

Chapter 5

REACTIVE & REFRACTORY METALS

The refractory metals group includes niobium (also known as columbium), tantalum, molybdenum, tungsten, and rhenium. The name of this group of metals arises from their very high melting temperatures, which range from 2468 to 3410°C (4474 to 6170°F). The metals and their alloys find specialized applications in the electronics, aerospace, nuclear, and chemical process industries.

Except for niobium, the refractory metals are produced as metal powders which are consolidated by sintering or melting into ingots. These are then processed by combinations of forging, extrusion, and rolling into bar, plate, sheet, foil, and tubing. They can be machined, generally using carbide tools, and a range of techniques is available for their fabrication. Alloys of niobium and tantalum are the most easily fabricated, while more specialized techniques are required for molybdenum and tungsten. Joining is accomplished using electron beam, gas tungsten arc, and resistance welding processes.

Despite their high melting temperatures, the refractory metals react with oxidizing atmospheres at moderate temperatures and this has restricted their use as high temperature materials. In attempts to compensate for this, coatings of the silicide or aluminide type have been developed which enable niobium to be used at temperatures up to about 1650°C (3002°F). For the other refractory metals, coatings developments have been less successful to date, although research continues. Refractory metals and alloys in general have good resistance to corrosion by liquid metals and by acid solutions, and this is responsible for some of their applications.

Niobium (Columbium)

Although most of the niobium produced is used as alloy additions in the steel industry, the combination of relatively light weight and high temperature strength has led to the use of niobium alloys in the aerospace industry. In many cases these applications are only possible when the materials are protected by coatings, for example, a coating of Si-20%Cr-20%Fe applied as a slurry which is subsequently baked to stimulate reaction bonding and diffusion. Niobium alloys such as C-103 (UNS R04295) with 10%Hf and 1%Ti, C-129Y with 10%W, 10%Hf and 0.1%Y, Cb-752 (UNS R04271) with 10%W and 2.5%Zr, and FS-85 (28%Ta, 10%W, 1%Zr) find aerospace applications such as thrust chambers and radiation skirts for rocket and aircraft engines, rocket nozzles, thermal shields, leading edges and nose caps for hypersonic flight vehicles, and guidance structure for glide re-entry vehicles. A Nb-1%Zr alloy (commercial grade UNS R04261, reactor grade UNS R04251) finds applications in the nuclear industry. Several commercial and nuclear grades of unalloyed niobium (UNS R04200, UNS R04210, and UNS R04211) are also available.

Tantalum

The major application of tantalum is in electronics where it is used in the form of porous sintered powder metallurgy electrodes in electrolytic capacitors and as precision foil in foil capacitors, as well as lead wires, seals, and containment cans. Tantalum is also produced in the form of mill products including sheet, plate, rod, bar, and tubing. Tubing can be either seamless or welded and drawn. Tantalum and tantalum-clad steel are used in chemical process applications under many severe conditions including the condensing, reboiling, preheating, and cooling of nitric, hydrochloric, and sulphuric acids. It is used as heating elements and heat shields for furnaces and in specialized aerospace, nuclear, and biomedical applications. Unalloyed tantalum is designated by UNS R05200 (cast), UNS R05210, and UNS R05400 (sintered). Tantalum alloys include Ta-2.5%W (63 metal) which is used in chemical processing for heat exchangers, tower linings, valves, and tubing, and Ta-7.5%W, a powder product which is cold drawn to springs and other components for severe acid service. The alloy Ta-10%W (UNS R05255) finds high temperature applications up to 2480°C (4496°F) in the aerospace industry, for example as hot gas valves and rocket engine components, and also in corrosive and abrasive environments in the chemical process and nuclear industries. Other commercial tantalum alloys include T-111 (8%W, 2%Hf), T-222 (10%W, 10%Hf) and Ta-40%Nb (UNS R05240).

Molybdenum

Like niobium, most molybdenum production goes for use as an alloying element in steels and superalloys; however, some sheet, wire, bar, and tube are produced by forging, rolling and extrusion. Aerospace applications include high temperature structural parts such as nozzles,

SAE/AMS SPECIFICATIONS - REACTIVE & REFRACTORY ALLOYS	
AMS	**Title**
7817	Molybdenum Alloy Sheet, Strip, and Plate, 0.48Ti - 0.09Zr - 0.02C, Arc Cast, Stress Relieved, Noncurrent Oct. 85, UNS R03630
7819	Molybdenum Alloy Bars, 0.48Ti - 0.09Zr - 0.02C, Arc Cast, Stress Relieved, UNS R03630
7846	Tantalum Alloy Bars and Rods, 90Ta - 10W, Annealed, UNS R05255
7847	Tantalum Alloy Sheet, Strip, and Plate, 90Ta - 10W, UNS R05255
7848	Tantalum Alloy Bars and Rods, 90Ta - 10W, UNS R05255
7849	Tantalum Sheet, Strip, and Plate, Annealed, UNS R05210
7850	Columbium Sheet, Strip, Plate, and Foil, UNS R04211
7851	Foil, sheet, Strip, and Plate, Columbium Alloy, 10W - 2.5Zr, Recrystallized, UNS R04271
7852	Sheet, Strip, and Plate, Columbium Alloy, 10Hf - 1.0Ti, UNS R04295
7855	Columbium Alloy Bars, Rods, and Wire, 10W - 2.5Zr, Recrystallized, UNS R04271
7857	Columbium Alloy Bars, Rods, and Extrusions, 10Hf - 1.0Ti, Recrystallization Annealed, UNS R04295
7875	Powder, Chromium Carbide Plus Nickel-Chromium Alloy, 75Cr_2C_3 + 25 (80Ni - 20Cr Alloy)
7897	Tungsten Forgings, Pressed, Sintered, and Forged, UNS R07005, Noncurrent March 94
7898	Tungsten Sheet, Strip, Plate, and Foil, Pressed, Sintered, and Wrought, UNS R07006, Noncurrent March 94

ASTM SPECIFICATIONS - REACTIVE & REFRACTORY ALLOYS	
ASTM	**Title**
Molybdenum and Molybdenum Alloys	
B 386	Molybdenum and Molybdenum Alloy Plate, Sheet and Strip, and Foil
B 387	Molybdenum and Molybdenum Alloy Bar, Rod, and Wire
F 289	Molybdenum Wire and Rod for Electronic Applications
F 290	Round Wire for Winding Electron Tube Grid Laterals
Tantalum and Tantalum Alloys	
B 364	Tantalum and Tantalum Alloy Ingots
B 365	Tantalum and Tantalum Alloy Rod and Wire

Chapter 6

LEAD, TIN & ZINC ALLOYS

LEAD

The origins of metallic lead lie in the far distant past. Lead ores are relatively easy to reduce, and hence the metal has been known and used for both ornamental and structural purposes probably since before 5000 B.C. Today the uses of lead and its alloys are based on its unique combination of properties, among which are high density, castability, formability, conductivity, thermal expansion, and corrosion resistance combined with low tensile and creep strength, hardness, elastic stiffness, and melting point. The low creep strength is a serious limitation to the structural applications of lead, but this can be overcome by design or by the use of inserts or supports. Battery applications represent the most important uses of lead and its alloys, but they are also used as shielding, bearing materials, type metal, cable sheathing, and solders. These applications are discussed in more detail below.

Primary lead production comes from the smelting of the mineral galena (lead sulphide, PbS). The ore is concentrated, using flotation to separate the galena from associated minerals. The concentrate is sintered and roasted, then smelted in a blast furnace to produce an impure lead bullion which is purified in a sequence of processes to remove most of the residual copper, antimony, tin, arsenic, precious metals, and zinc. The final step is often an electrolytic refining. Purities as high as 99.99% are readily obtainable.

Lead is also extensively recycled. Scrap processing accounts for more than half of lead production, giving it the highest recycling rate of all the metals.

Pure lead has a face-centered cubic crystal structure, and this combined with its low melting temperature (327°C, 621°F) account for its high ductility. Compared to most of the common metals, it has a high density, its specific gravity being 11.3.

Categories

The commercial grades of lead and its alloys are shown in Table 1 along with the corresponding UNS designations. The initial letter in the UNS designations, "L", refers to low melting metals and alloys (as such, the L category also includes cadmium, lithium, tin, and their alloys). Cast and wrought lead alloys are available but the UNS categories do not distinguish between these.

Table 1 Commmercial Grades of Lead With UNS No.

Commercial purity lead	UNS L50000-L50099
Lead-silver alloys	UNS L50100-L50199
Lead-arsenic alloys	UNS L50300-L50399
Lead-barium alloys	UNS L50500-L50599
Lead-calcium alloys	UNS L50700-L50899
Lead-cadmium alloys	UNS L50900-L50999
Lead-copper alloys	UNS L51100-L51199
Lead-indium alloys	UNS L51500-L51599
Lead-lithium alloys	UNS L51700-L51799
Lead-antimony alloys	UNS L52500-L53799
Lead-tin alloys	UNS L54000-L55099
Lead-strontium alloys	UNS L55200-L55299

Commercial Purity Lead

The four grades of commercial purity lead are "chemical lead" (UNS L51120) and "acid-copper" lead (UNS L51121), both of which contain a minimum of 99.9% lead, along with "pure lead" also called "corroding lead" (UNS L50042) and "common lead" (UNS L50045) which contain a minimum of 99.94% lead. Corroding lead is named not for its corrosion resistance but rather for a process to which it was subjected in order to produce products such as oxides, pigments, and other chemicals. Chemical lead contains copper and silver impurities which confer on it an improved corrosion resistance and strength, so that it is particularly appropriate for use in the chemical industries.

Lead Alloys

The most common alloying elements in lead are antimony, tin, arsenic, and calcium. Antimony is added in amounts ranging up to 25%, but most commonly 2-5%, in order to improve the strength for applications such as

Cable Sheathing

Lead sheathing is often extruded around electrical power and communication cables for protection against moisture, corrosion, and mechanical damage. Alloys used include chemical lead, antimonial lead, arsenical lead, and lead-calcium alloys, some with additions of copper or tellurium. In all cases, the total amount of alloying element remains small (less than 1%) so that the sheathing can be readily extruded around the cable. Examples include the arsenical lead alloy UNS L50310, the antimonial leads UNS L52520 and L52535), and the calcium leads UNS L50710, L50712, and L50725.

Shielding and Damping

Lead and its alloys find many applications as shielding materials. Its high density provides it with good radiation shielding properties against x-rays and gamma rays, and it is frequently used for this purpose as a lining in concrete structures. The combination of high density, low stiffness, and high damping capacity gives lead excellent vibration and sound absorbing properties. It is widely used to isolate equipment and structures from vibration, for example as lead-steel composite pads under column footings in buildings. For sound absorption it is used either alone or in composites with polymer foams or sheets. Lead foils, either alone or as a sandwich rolled between thin layers of tin, are used as moisture barriers in the construction industry and as oxygen barriers on wine bottles.

Corrosion Resistant Sheet and Pipe

In addition, lead and its alloys are used in sheet form in corrosion-resistant applications, for example in the construction industry for roofing and flashing, in pans below shower and bath stalls, and in flooring. Sheet and piping made from chemical lead (UNS L51120) and alloys such as antimonial lead (e.g., the 6%Sb alloy UNS L53125) are also used in the chemical industry as well as in plumbing and water distribution and waste systems, with the more highly alloyed material used where resistance to creep and erosion is important.

Corrosion resistance can be imparted to mild steel sheet or plate by coating it with a lead-tin (3-15%Sn) alloy. This is known as a terne coating and the product is called terne sheet or terne plate.

Solders

Lead-tin alloys are very widely used as solders, since their low melting temperatures allow joining without damage to heat-sensitive materials. Depending on the composition, melting temperatures between 182° and 315°C (360 and 599°F) are possible, and commercial solders are available across the full range from pure tin to pure lead. The very low-tin solders (e.g., 5%Sn or 5/95 solder, UNS L54320) are used for coating, sealing and joining and at service temperatures as high as 120°C (248°F). Solders with higher amounts of tin (e.g., 10/90, UNS L54520; 15/85, L54560; 20/80, L54710) are used in the automotive industry, both for radiator joining applications and for body damage repairs. Solders 40/60 (UNS L54915) and 50/50 (UNS L55030) are general purpose solders used in the automotive, electrical and electronic, and construction industries, in the latter case for roofing seams. Some lead-tin based solders also contain additional alloying elements, notably antimony and silver for improved fatigue and creep resistance and improved performance at high and low temperatures. Examples include the lead-tin-silver alloys UNS L54525, L54750, and L54855, and the lead-tin-antimony alloys UNS L54211, L54321, and L54905.

Bearing Materials

Many bearing materials are lead-based alloys; these are often referred to as lead-base babbitt metals. There are two basic groups of these alloys, one being lead-tin-antimony often with arsenic as well, the other being lead-calcium-tin often with other alkaline earth metals. The first group is the most common and includes four arsenical alloys covered by ASTM B23 (Alloy 7, UNS L53585; Alloy 8, UNS L53565; Alloy 13, UNS L53346, and the most common, Alloy 15, UNS L53620). Alloy 15 is used in automotive engines, often as a continuously cast bimetallic strip (steel and babbitt metal). For service in applications such as rolling mill bearings, a higher (3%) arsenic alloy is used. Another lead-tin-antimony alloy, known as SAE 16 (UNS L52860), is used for automotive applications as an overlay, cast onto a porous sintered non-ferrous matrix which is bonded to steel. Alloys in the second group of babbitt metals, the lead-calcium-tin alloys, are used for railway applications and some diesel engine bearings.

Miscellaneous Applications

In addition to the applications discussed above, there are a number of miscellaneous uses for which the properties of lead alloys make them suitable materials. For example, the high density and excellent castability of lead make it a useful material for counterweights. Lead-silver and lead-calcium-tin alloys in the form of rolled sheet find uses as

SAE/AMS SPECIFICATIONS - SOLDER, BABBITT & LEAD ALLOYS	
AMS	**Title**
4750	Solder, , 45Sn – 55Pb, UNS L54950
4751	Tin-Lead Alloy Eutectic Solder, 63Sn - 37Pb, UNS L13630
4755	Solder, Lead-Silver, 94Pb - 5.5Ag, Cancelled (May 98), UNS L50180
4756	Solder, 97.5Pb - 1.5Ag - 1Sn, Cancelled (May 98), UNS L50131
4800	Bearings, Babbitt, 91Sn - 4.5Sb - 4.5Cu, UNS L13910
7721	Lead Alloy, Sheet and Extrusions, 93Pb - 6.5Sb - 0.5Sn, As Fabricated, UNS L53131

ASTM SPECIFICATIONS - LEAD, TIN & ZINC ALLOYS	
ASTM	**Title**
Lead & Tin Alloys	
B 23	White Metal Bearing Alloys (Known Commercially as “Babbitt Metal”)
B 29	Refined Lead
B 32	Solder Metal
B 102	Lead- and Tin-Alloy Die Castings
B 189	Lead-Coated and Lead-Alloy-Coated Soft Copper Wire For Electrical Purposes
B 339	Pig Tin
B 560	Modern Pewter Alloys
B 749	Lead and Lead Alloy Strip, Sheet, and Plate Products
B 774	Low Melting Point Alloys
Zinc & Zinc Alloys	
B 6	Zinc
B 69	Rolled Zinc
B 86	Zinc and Zinc-Aluminum (ZA) Alloy Foundry and Die Castings
B 240	Zinc and Zinc-Aluminum (ZA) Alloys in Ingot Form for Foundry and Die Castings
B 327	Master Alloys Used in Making Zinc Die Casting Alloys

COMMON NAMES OF LEAD, TIN & ZINC ALLOYS WITH UNS No.

UNS	Common Name	UNS	Common Name
L05120	Solder Alloy	L50065	Solder Alloy
L13008	88-10-2 Solder	L50070	Solder Alloy
L13600	Zinc Galvanizing Alloy Ingot	L50080	Solder Alloy
L13601	Zinc Slush Casting Alloy A	L50131	Zinc Anodes (Type III)
L13630	Zinc Slush Casting Alloy B	L50132	Zinc Die Casting Alloy (AC41A) Ingot
L13631	Zinc-Aluminum Casting Alloy ZA-12	L50150	Zinc Die Casting Alloy (AC41A)
L13650	Zinc Die Casting Alloy (AG40A) Ingot	L50151	Zinc Die Casting Alloy (AC43A)
L13700	Zinc-Aluminum Casting Alloy ZA-12 Ingot	L50180	Zinc Die Casting Alloy (AC43A) Ingot
L13701	Zinc-Aluminum Casting Alloy ZA-27	L51120	Plated Overlay for Bearings
L13820	Zinc Die Casting Alloy (AG40B)	L51121	SN5 Solder
L13840	Solder Alloy	L51123	15/85 Solder
L13870	Solder Alloy	L51124	2% Tin Antimonial Solder
L13890	Solder Alloy 20B	L51180	Solder Alloy
L13910	Solder Alloy 20C	L53131	10/90 Solder
L13911	5/95 Solder	L53340	30/70 Solder Alloy (Sn30B)
L13912	50/50 Solder	L53345	2% Tin Solder
L13913	Zinc Die Casting Alloy (AG40B) Ingot	L53346	25/75 Solder
L13940	Zinc Forming Die Alloy A (Kirksite I)	L53560	35/65 Solder
L13950	Zinc Forming Die Alloy B (Kirksite II)	L53565	40/60 Solder
L13960	Zinc-Aluminum Casting Alloy ZA-27 Ingot	L53585	45/55 Solder
L13961	Zinc-Aluminum Casting Alloy ZA-8	L53620	30/70 Solder Alloy (Sn30A)
L13963	5% Tin Antimonial Solder	L54210	Lead-Base Bearing Alloy
L13965	Zinc-Aluminum Casting Alloy ZA-8 Ingot	L54211	Lead Alloy Grade D
L50042	Solder Alloy	L54250	Copper-Lead Bearing Alloy
L50045	Prime Western Zinc	L54320	Modern Pewter Casting Alloys
L50050	Solder Alloy	L54321	Modern Pewter

CHEMICAL COMPOSITION OF ZINC ALLOYS

UNS	Chemical Composition
Z13000	Zn rem Al 0.005 max Cd 0.003 max Cu 0.002 max Fe 0.0014 max Pb 0.003 max
Z13001	Zn 99.990 min Al 0.002 max Cd 0.003 max Cu 0.002 max Fe 0.003 max Pb 0.003 max Sn 0.001 max
Z15001	Zn 99.90 min Al 0.01 max Cd 0.02 max Fe 0.02 max Pb 0.03 max
Z19001	Zn 98.0 min Al 0.01 max Cd 0.20 max Cu 0.20 max Fe 0.05 max Pb 0.5-1.4
Z21210[a]	Zn rem Al 0.001 max Cd 0.005 max Cu 0.001 max Fe 0.012 max Pb 0.10 max Sn 0.001 max
Z21220[a]	Zn rem Al 0.001 max Cd 0.05-0.08 Cu 0.005 max Fe 0.012 max Pb 0.05-0.10 Sn 0.001 max
Z21540[a]	Zn rem Al 0.001 max Cd 0.25-0.45 Cu 0.005 max Fe 0.002 max Pb 0.25-0.50
Z30500	Zn rem Al 5.25-5.75 Cd 0.005 max Cu 0.1 max Fe 0.10 max Pb 0.007 max Sn 0.005 max
Z32120	Zn rem Al 0.10-0.5 Cd 0.025-0.07 Cu 0.005 max Fe 0.005 max Pb 0.006 max Other 0.1 max
Z32121	Zn rem Al 0.1-0.5 Cd 0.025-0.15 Cu 0.005 max Fe 0.005 max Pb 0.006 max Si 0.125 max
Z33520	Zn rem Al 3.5-4.3 Cd 0.004 max Cu 0.25 max Fe 0.100 max Mg 0.02-0.05 Pb 0.005 max Sn 0.003 max
Z33521	Zn rem Al 3.9-4.3 Cd 0.003 max Cu 0.10 max Fe 0.075 max Pb 0.004 max Mg 0.025-0.05 Sn 0.002 max
Z33522	Zn rem Al 3.9-4.3 Cd 0.0020 max Cr 0.02 max Cu 0.10 max Fe 0.075 max Mg 0.010-0.020 Mn 0.05 max Ni 0.005-0.020 Pb 0.0020 max Si 0.035 max Sn 0.0010 max
Z33523	Zn rem Al 3.5-4.3 Cd 0.0020 max Cr 0.02 max Cu 0.25 max Fe 0.075 max Mg 0.005-0.020 Mn 0.5 max Ni 0.005-0.020 Pb 0.0030 max Si 0.035 max Sn 0.0010 max
Z34510	Zn rem Al 4.5-5.0 Cd 0.005 max Cu 0.2-0.3 Fe 0.100 max Pb 0.007 max Sn 0.005 max
Z35530	Zn rem Al 3.9-4.3 Cd 0.003 max Cu 0.75-1.25 Fe 0.075 max Pb 0.004 max Mg 0.03-0.06 Sn 0.002 max
Z35531	Zn rem Al 3.5-4.3 Cd 0.004 max Cu 0.75-1.25 Fe 0.100 max Mg 0.03-0.08 Pb 0.005 max Sn 0.003 max
Z35540	Zn rem Al 3.9-4.3 Cd 0.003 max Cu 2.6-2.9 Fe 0.075 max Pb 0.004 max Mg 0.025-0.050 Sn 0.002 max
Z35541	Zn rem Al 3.5-4.3 Cd 0.004 max Cu 2.5-3.0 Fe 0.100 max Mg 0.020-0.050 Pb 0.005 max Sn 0.003 max
Z35542	Zn rem Al 3.9-4.3 Cd 0.003 max Cu 2.5-2.9 Fe 0.075 max Mg 0.02-0.05 Pb 0.003 max Sn 0.001 max
Z35543	Zn rem Al 3.5-4.5 Cd 0.005 max Cu 2.5-3.5 Fe 0.100 max Mg 0.02-0.10 Pb 0.007 max Sn 0.005 max
Z35630	Zn rem Al 10.8-11.5 Cd 0.005 max Cu 0.50-1.2 Fe 0.065 max Mg 0.020-0.030 Pb 0.005 max Sn 0.002 max
Z35631	Zn rem Al 10.5-11.5 Cd 0.004 max Cu 0.5-1.2 Fe 0.075 max Pb 0.006 max Mg 0.015-0.030 Sn 0.003 max
Z35635	Zn rem Al 8.2-8.8 Cd 0.005 max Cu 0.8-1.3 Fe 0.10 max Mg 0.020-0.030 Pb 0.005 max Sn 0.002 max

Chapter 7

PRECIOUS METALS

The term precious metals is taken to include silver, gold, and the six platinum group metals - platinum, palladium, ruthenium, rhodium, osmium, and iridium. Gold and silver have been known and used for many millennia, as has platinum to a lesser extent. The others are recent discoveries. These metals and their alloys are used in the electronics, jewelry, dentistry, coinage, textile, automotive, aerospace, ceramic, and chemical industries. They all have high densities (specific gravities ranging from silver at 10.5 to iridium at 22.6), relatively good corrosion resistance, good electrical conductivity and light reflectivity, and relatively high cost. Despite the latter factor, they are often economically acceptable because of their properties and performance in service. Scrap values are high and recycling is common.

Products available include rod and wire drawn as fine as 7.5 microns (0.0003 in) diameter for some alloys, and rolled products such as sheet, strip, ribbon, and foil (in some cases as thin as 2.5 microns (0.0001 in). Tubing of various cross-sections is also available for various precious metal alloys in the form of seamless tube for small sizes down to 0.4 mm (0.16 in) outside diameter, and as seamed tubing for larger sizes up to 75 mm (3 in) inside diameter and in less ductile alloys. Powder products are produced for applications in the electronic industry, including inks and films, and for applications as protective coatings.

Base metal alloys clad with precious metals (via mechanical and thermal bonding) are available in a range of product forms including sheet, wire, and tubing. Precious metal coatings can be applied using such techniques as vacuum metallizing and sputtering, electroplating, and thermal decomposition (firing).

The purities of silver and gold are designated in terms of several systems which do not apply to other metals. Fineness is used to designate purity in parts per thousand by weight; hence, 995 fine gold is 99.5% gold, and 925 fine silver (sterling silver) is 92.5% silver. Gold bullion, as traded, is at least 995 fine and silver bullion at least 999 fine. Gold purity for jewelry applications is specified in karats, where 1 karat is 1/24th part of gold; hence, for example, 18 karat gold is 75% gold.

SILVER

Silver is characterized by its bright appearance, high thermal and electrical conductivities, reflectivity, and very high malleability. It is resistant to corrosion in many organic acids and in sodium and potassium hydroxide, but it is susceptible to corrosion in mineral acids. It resists oxidation at room temperature but is susceptible to attack by sulphur. Although its major use is in photographic emulsions, it finds wide applications as brazing filler metal alloys ("silver solder"), as well as in electrical contacts, bearings, jewelry, and tableware, batteries, mirror backings, dental alloys, catalysts, and coinage. Silver-clad base metals (copper, brass, nickel, iron) are also used, in particular in the electrical and chemical industries.

Silver and the other precious metals are described by the UNS system in a single category with the prefix letter P. Other than for unalloyed silver, the designation given is P07xxy, where xx gives the approximate silver content of the alloy in percent; hence, P07650 contains about 65%Ag. Refined silver is available at several levels of purity from 99.99% (UNS P07010) to 99.90% (UNS P07020).

Brazing Alloys

A very wide range of silver based brazing filler metal alloys is described by various standards, notably ASME SFA5.8 and AWS A5.8, which give alloy designations in the form BAg-x. These alloys are characterized by low melting temperatures and the ability to wet the solid base metals; hence, they are suitable filler metals for brazing steel, cast iron, stainless steel, and copper alloys to themselves and each other. They are also used in the brazing of some reactive and refractory metals, although the latter are restricted to low temperature use.

These brazing alloys are generally silver-copper-zinc alloys, some with additions of cadmium, manganese, nickel, or tin. The most widely used are the alloys BAg-1 (UNS P07450 which contains 45%Ag, 15%Cu, 16%Zn, 24%Cd) and BAg-1a (UNS P07500 containing 50%Ag, 15%Cu, 16%Zn, 18%Cd). The cadmium additions give these alloys particularly low melting temperatures, narrow melting temperature ranges, and high fluidities. Other brazing alloys include BAg-2 (UNS P07350 with 35%Ag, 26%Cu, 21%Zn, 18%Cd) and BAg-2a (UNS P07300 with 30%Ag, 27%Cu, 23%Zn, 20%Cd) which contain less silver and are therefore cheaper but have higher melting temperatures and are less fluid. For food processing applications, where toxicity must be considered, it is necessary to utilize brazing alloys which are free of cadmium; these alloys include BAg-4 (UNS P07400 with 40%Ag, 30%Cu, 28%Zn, 2%Ni), BAg-5 (UNS P07453 with 45%Ag, 30%Cu, 25%Zn), BAg-20 (UNS P07301 with 30%Ag, 38%Cu, 32%Zn), and BAg-28 (UNS P07401 with 40%Ag, 30%Cu, 28%Zn, 2%Sn). For the brazing of stainless steel, the nickel-bearing alloy BAg-3 (UNS P07501 with 50%Ag, 15%Cu, 16%Zn, 16%Cd, 3%Ni) is most commonly used, but many other silver-based brazing alloys are applicable as well.

The vacuum brazing grades have maximum contents specified for a number of impurities, notably cadmium, phosphorus, and zinc which have high vapour pressures. Typical examples include BVAg-0 (UNS P07017 with 99.95% Ag) and BVAg-8 (UNS P07727 with 72%Ag, 28%Cu). A few brazing alloys contain lithium in amounts less than 0.5%; brazing with these alloys, such as BAg-8a (UNS P07723 with 72%Ag, 27%Cu, 0.4%Li) and BAg-19 (UNS P07925 with 92%Ag, 8%Cu, 0.2%Li), can be performed without the use of a flux, since the alloys are self-fluxing in dry, non-oxidizing protective atmospheres.

Electrical Contacts

Silver is a useful material for medium- and heavy-duty electrical contacts, particularly when alloyed with a dispersion of cadmium oxide. Here, advantage is taken of the high thermal and electrical conductivity and low surface contact resistance of silver, and the ability of the particles of cadmium oxide to prevent sticking and welding and to minimize arc erosion. Under light-duty conditions (low voltage, low current) these materials are not suitable because of the tendency of silver to react with sulphur in the atmosphere to form a sulphide surface layer. The cadmium oxide dispersion can be formed either by powder metallurgical processing or by internal oxidation (e.g., the Ag-15%Cd alloy). Silver alloys containing approximately 0.25% each of magnesium, nickel, and in some cases copper, can also be dispersion strengthened by internal oxidation for use as electrical contact materials. Other silver-based alloys used for electrical contact purposes include fine silver, for low current applications, and alloys of silver with copper, palladium, platinum, or gold. These alloying elements increase the hardness, but decrease the electrical conductivity. Silver is also used in the form of an electroplated coating on electrical connection plugs and sockets.

Jewelry and Tableware Alloys, Coinage

The high reflectivity of silver makes it particularly attractive for applications in jewelry and tableware. Strength, hardness, and wear

COMMON NAMES OF PRECIOUS METALS WITH UNS No.			
UNS	**Common Name**	**UNS**	**Common Name**
P00140	10-Karat Green Gold Jewelry Alloy	P00225	14-Karat Yellow Gold Jewelry Alloy
P00145	10-Karat Red Gold Jewelry Alloy	P00280	18-Karat Green Gold Jewelry Alloy
P00125	10-Karat White Gold Jewelry Alloy	P00285	18-Karat Red Gold Jewelry Alloy
P00130	10-Karat White Gold Jewelry Alloy	P00270	18-Karat White Gold Jewelry Alloy
P00135	10-Karat White Gold Jewelry Alloy	P00275	18-Karat White Gold Jewelry Alloy
P00105	10-Karat Yellow Gold Jewelry Alloy	P00250	18-Karat Yellow Gold Jewelry Alloy
P00110	10-Karat Yellow Gold Jewelry Alloy	P00255	18-Karat Yellow Gold Jewelry Alloy
P00115	10-Karat Yellow Gold Jewelry Alloy	P00260	18-Karat Yellow Gold Jewelry Alloy
P00120	10-Karat Yellow Gold Jewelry Alloy	P00016	Gold
P00230	14-Karat Green Gold Jewelry Alloy	P00100	Gold Alloy (990) Gold
P00235	14-Karat Green Gold Jewelry Alloy	P00350	Gold Brazing Alloy
P00170	14-Karat Red Gold Jewelry Alloy	P00375	Gold Brazing Alloy
P00150	14-Karat White Gold Jewelry Alloy	P00500	Gold Brazing Alloy
P00155	14-Karat White Gold Jewelry Alloy	P00700	Gold Brazing Alloy
P00160	14-Karat White Gold Jewelry Alloy	P00800	Gold Brazing Alloy
P00165	14-Karat White Gold Jewelry Alloy	P00820	Gold Brazing Alloy
P00032	14-Karat Yellow Gold Jewelry Alloy	P00807	Gold Brazing Alloy (Vacuum Grade)
P00175	14-Karat Yellow Gold Jewelry Alloy	P00827	Gold Brazing Alloy (Vacuum Grade)
P00180	14-Karat Yellow Gold Jewelry Alloy	P00691	Gold Electrical Contact Alloy
P00185	14-Karat Yellow Gold Jewelry Alloy	P00692	Gold Electrical Contact Alloy
P00190	14-Karat Yellow Gold Jewelry Alloy	P00710	Gold Electrical Contact Alloy
P00195	14-Karat Yellow Gold Jewelry Alloy	P00750	Gold Electrical Contact Alloy
P00200	14-Karat Yellow Gold Jewelry Alloy	P00901	Gold Electrical Contact Alloy
P00205	14-Karat Yellow Gold Jewelry Alloy	P00927	Gold-Palladium Brazing Alloy (Vacuum Grade)
P00210	14-Karat Yellow Gold Jewelry Alloy	P00300	Gold-Palladium-Nickel Brazing Alloy
P00215	14-Karat Yellow Gold Jewelry Alloy	P00507	Gold-Palladium-Nickel Brazing Alloy (Vacuum Grade)
P00220	14-Karat Yellow Gold Jewelry Alloy	P00900	Gold-Silver Alloy

AMERICAN CROSS REFERENCED SPECIFICATIONS - PRECIOUS METALS[a] (Continued)					
UNS	**AMS**	**ASME**	**AWS**	**ASTM**	**MIL SPEC**
P07630	4774	SFA5.8 (BAg-21)	A5.8 (BAg-21)	---	---
P07650	---	SFA5.8 (BAg-9)	A5.8 (BAg-9)	---	---
P07687	---	SFA5.8 (BVAg-30)	A5.8 (BVAg-30)	---	---
P07700	---	SFA5.8 (BAg-10)	A5.8 (BAg-10)	---	---
P07720	---	SFA5.8 (BAg-8)	A5.8 (BAg-8)	---	---
P07723	---	SFA5.8 (BAg-8a)	A5.8 (BAg-8a)	---	---
P07727	---	SFA5.8 (BVAg-8)	A5.8 (BVAg-8)	---	---
P07728	---	SFA5.8 (BVAg-8b)	A5.8 (BVAg-8b)	---	---
P07850	4766	SFA5.8 (BAg-23)	A5.8 (BAg-23)	---	MIL-B-7883 (BAg-23)
P07900	---	---	---	B 617	---
P07925	4767	SFA5.8 (BAg-19)	A5.8 (BAg-19)	---	---

a. This cross-reference table lists the basic specification or standard number, and since these standards are constantly being revised, it should be kept in mind that they are presented herein as a guide and may not reflect the latest revision. b. No longer active.

CHEMICAL COMPOSITIONS OF PRECIOUS METALS	
UNS	**Chemical Composition**
P00010	Au 99.995 min Ag 0.001 max Bi 0.001 max Cr 0.0003 max Cu 0.001 max Fe 0.001 max Mg 0.001 max Mn 0.0003 max Pb 0.001 max Pd 0.001 max Si 0.001 max Sn 0.001 max
P00015	Au 99.99 min As 0.003 max Bi 0.002 max Cr 0.0003 max Cu 0.005 max Fe 0.002 max Mg 0.003 max Mn 0.0003 max Ni 0.0003 max Pb 0.002 max Pd 0.005 max Si 0.005 max Sn 0.001 max
P00016	Au 99.99 min Other Ag+Cu 0.009 max, each, other impurity 0.003 max
P00020	Au 99.95 min Ag 0.035 max Cu 0.02 max Fe 0.005 max Pb 0.005 max Pd 0.02 max Other Ag+Cu 0.04 max
P00025	Au 99.5 min
P00032	Au 58.33 (± 0.3) Cu 31.08 (± 1.0) rem Ag 3.5-4.5 Fe 0.05 (± 0.5) Ni 0.10 (± 0.5) Si 0.01 (± 0.5) Zn 6.43 (± 0.5)
P00100	Au 99.0 min Ti 1.0 (0.8 min)
P00105	Au 41.817 (± 0.3) Cu 38.5 (rem) Zn 12.68 (± 1.0) Ag 5.85 (± 0.5) Ni 1.15 (± 0.5)
P00110	Au 41.70 (± 0.3) Ag 11.66 (± 1.0) Zn 5.83 (± 0.5) B 0.02 Cu 40.81 (rem) Si 0.03

Chapter 8

MAGNESIUM & MAGNESIUM ALLOYS

Introduction

Magnesium is the lightest of the structural metals with a density of only 1.74 g/cm^3. However, magnesium is used as a structural metal in an alloyed form and most magnesium alloys have a density slightly higher than this. Magnesium is a reactive metal and is usually found in nature in the form of and oxide, carbonate or silicate, often in combination with calcium. This reactivity is one of the reasons why the production of magnesium metal requires large amounts of energy.

The world production of magnesium is small compared to the other structural metals such as steel and aluminum at only about 300,000 tons per annum. About half of this is used directly in aluminum alloys to harden and strengthen them. For example, the body of an aluminum can contains approximately 1.5% Mg and the can top about 4.5% Mg.

Refining of Magnesium

Magnesium is one of the metals like aluminum where very little post refining of the metal is conducted, other than the removal of physical impurities such as electrolyte and oxide (although some processes are available). The high temperature processes rely on the high vapor pressure of magnesium to transport high purity magnesium vapor. The electrolysis processes all rely on chemically clean feed materials and the operation of the electrolysis cells in a regime that favors magnesium reduction over the reduction of other alkali metal chlorides.

American Society for Testing and Materials (ASTM) Designation System

ASTM B 275, Codification of Certain Nonferrous Metals and alloys, Cast and Wrought, includes magnesium alloys as part of their designation system which is based on chemical composition. It consists of two letters representing the principal alloying elements arranged either alphabetically or in order of decreasing content. The letters are followed by their respective percentages rounded off to whole numbers, with a serial letter at the end. The serial letter indicates some variation within the same nominal composition. The alloying elements related to magnesium alloys are designated by the following letters:

A - Aluminum, E - rare earth metals, H - thorium, K - zirconium, L - lithium, M - manganese, Q - silver, S - silicon, and Z - zinc.

For example, ASTM B 90 alloy AZ61A would be a magnesium alloy forging containing 6% aluminum, 1% zinc, that is the first modification (A) in the series.

ASTM B 296, Temper Designations of Magnesium Alloys, Cast and Wrought, covers the designation for temper used for all forms of magnesium and magnesium alloy products, except ingots, and are based on the sequence of basic treatments used to produced various tempers. The temper designation follows the alloy designation, and are separated by a hyphen.

Basic temper designations consists of letters. Subdivisions of the basic tempers, where required, are indicated by a digit or digits following the letter. These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.

Temper Designation	Description
-F	as fabricated
-O	annealed, recrystallized
-H1	strain-hardened only
-H2	strain-hardened and then partially annealed
-H3	strain hardened and then stabilized
-W	solution heat-treated
-T	thermally treated to produce stable tempers other than F, O, or H

SAE/AMS SPECIFICATIONS - MAGNESIUM AND MAGNESIUM ALLOYS	
AMS	**Title**
4350	Magnesium Alloy, Extrusions 6.5Al - 1.0Zn, As Extruded (AZ61A-F), UNS M11610
4352	Magnesium Alloy, Extrusions 5.5Zn - 0.45Zr, Precipitation Heat Treated (ZK60A-T5), UNS M16600
4362	Forgings, Magnesium Alloy 5.5Zn - 0.45Zr Precipitation Heat Treated (AZ60A-T5), UNS M11600
4375	Sheet and Plate, Magnesium Alloy 3.0Al - 1.0Zn - 0.20Mn, Annealed and Recrystallized (AZ31B-0), UNS M11311
4376	Plate, Magnesium Alloy 3.0Al - 1.0Zn - 0.20Mn, Cold Rolled and Partially Annealed (AZ31B-H26), UNS M11311
4377	Sheet and Plate, Magnesium Alloy 3.0Al - 1.0Zn - 0.20Mn, Cold Rolled, Partially Annealed (AZ31B-H24), UNS M11311
4382	Magnesium Alloy, Plate, Extra Flat 3.0Al - 1.0Zn - 0.20Mn, Annealed (AZ31B-O), UNS M11311
4387	Magnesium Alloy Extrusions, 2.3Zn - 0.62Zr, As Extruded (ZK21A-F), UNS M16210
4395	Magnesium Alloy Welding Wire 9.0Al - 2.0Zn (AZ92A), UNS M11922
4396	Magnesium Alloy Welding Wire 3.3Ce - 2.5Zn - 0.72Zr (EZ33A), UNS M12330
4417	Castings, Sand, Magnesium Alloy, 1.5Ag - 2.1Di - 0.08Cu - 0.70Zr, Solution and Precipitation Heat Treated (EQ21-T6), UNS M18330
4418	Magnesium Alloy, Sand Castings, 2.5Ag - 2.1Di - 0.70Zr Solution and Precipitation Heat Treated (QE22A-T6), UNS M18220
4420	Magnesium Alloy Castings, Sand 6Al - 3Zn, As Cast (AZ63A-F), UNS M11630
4425	Magnesium Alloy Castings, Sand 5.8Zn - 2.5Re - 0.70Zr, Solution and Precipitation Heat Treated (ZE63-T6), UNS M16630
4426	Castings, Sand, Magnesium Alloy, 5.1Y - 3.0Re - 0.70Zr (WE54-T6), UNS M18410
4427	Magnesium Alloy Sand Castings 4.0Y - 2.3Nd - 0.70Zr Solution and Precipitation Heat Treated (WE43A-T6), UNS M18430
4434	Magnesium Alloy Castings, Sand, 9.0Al - 2.0Zn, Solution and Precipitation Heat Treated (AZ92-T6), UNS M11920
4437	Magnesium Alloy Castings, Sand, 8.7Al - 0.7Zn, Solution Heat Treated and Aged (AZ91C-T6), UNS M11914
4439	Magnesium Alloy Castings 4.2Zn - 1.2Ce - 0.70Zr (ZE41A-T5) Precipitation Heat Treated, UNS M16410
4442	Magnesium Alloy Castings, Sand 3.2Ce - 2.5Zn - 0.70Zr (EZ33A-T5) Precipitation Heat Treated, UNS M12330
4443	Magnesium Alloy Castings, 4.5Zn - 0.75Zr, Precipitation Heat Treated (ZK51A-T5), UNS M16510
4444	Magnesium Alloy Castings, Sand 6Zn - 0.80Zr, Precipitation Heat Treated (ZK61A-T5), UNS M16610
4446	Magnesium Alloy, Sand Castings 8.7Al - 0.70Zn - 0.26Mn Solution and Precipitation Heat Treated (AZ91E-T6), UNS M11919
4452	Magnesium Alloy, Investment Castings 8.7Al - 0.70Zn - 0.22Mn (AZ91C-T6) Solution and Precipitation Heat Treated, UNS M11914
4453	Magnesium Alloy, Investment Castings 9.0Al - 2.0Zn (AZ92A-T6) Solution and Precipitation Heat Treated, UNS M11920
4455	Magnesium Alloy, Investment Castings 10Al (AM100A-T6) Solution and Precipitation Heat Treated, UNS M10100

AMERICAN CROSS REFERENCED SPECIFICATIONS – MAGNESIUM AND MAGNESIUM ALLOYS

UNS	SAE	AMS	MIL	ASTM	ASME	AWS
M10101	---	---	---	B 93 (AM100A)	---	---
M10030	---	---	---	B 275 (A3A)	---	---
M10100	J465 (AM100-A)	4455, 4483	---	B 80 (AM100A), B 93 (AM100A), B 199 (AM100A), B 275 (AM100A), B 403 (AM100A)	---	---
M10102	---	---	---	B 275 (AM100B)	---	---
M10410	J465 (AS41-A)	---	---	B93, B 94 (AS41A), B 275 (AS41A)	---	---
M10411	---	---	---	B 93 (AS41A)	---	---
M10412	---	---	---	B 94 (AS41B)	---	---
M10413	---	---	---	B 93 (AS41B)	---	---
M10500	---	---	---	B 94 (AM50A)	---	---
M10501	---	---	---	B 93/B 93M	---	---
M10600	J465 (AM60-A)	---	---	B 93, B 94 (AM60A), B 275 (AM60A)	---	---
M10601	---	---	---	B 93 (AM60A)	---	---
M10602	---	---	---	B 94 (AM60B)	---	---
M10603	---	---	---	B 93 (AM60B)	---	---
M10800	---	---	---	B 275 (AM80A)	---	---
M10900	---	---	---	B 275 (AM90A)	---	---
M11100	---	---	---	B 275 (AZ10A)	---	---
M11101	---	---	---	B 275 (AZ101A)	SFA5.19 (ER AZ101A)	A5.19 (ER AZ101A)
M11125	---	---	---	B 275 (AZ125A)	---	---
M11210	---	---	---	B 275 (AZ21A)	---	---
M11310	---	---	---	B 275 (AZ31A)	---	---
M11311	J466 (AZ31B)	4375, 4376, 4377, 4382	---	B 90 (AZ31B), B 91 (AZ31B), B 107 (AZ31B), B 275 (AZ31B), B 843 (AZ31B)	---	---
M11312	---	---	---	B 90, B 107 (AZ31C), B 275 (AZ31C)	---	---

AMERICAN CROSS REFERENCED SPECIFICATIONS – MAGNESIUM AND MAGNESIUM ALLOYS (Continued)						
UNS	**SAE**	**AMS**	**MIL**	**ASTM**	**ASME**	**AWS**
M18430	---	---	---	B 80 (WE43A), B 93 (WE43A), B 275 (WE43A)	---	---
M18540	---	---	---	B 275 (TA54A)	---	---
M19001	---	---	---	---	SFA5.8 (BMg-1)	A5.8 (BMg-1)
M19980	---	---	---	B 92 (9980A), B 275 (9980A)	---	---
M19990	---	---	---	B 92 (9990A), B 275 (9990A)	---	---
M19991	---	---	---	B 92 (9990B)	---	---
M19995	---	---	---	B 92 (9995A), B 275 (9995A)	---	---
M19998	---	---	---	B 92 (9998A), B 275 (9998A)	---	---

CHEMICAL COMPOSITION OF MAGNESIUM CASTING ALLOYS												
Alloy Designation			**Elements, wt. %**									
UNS	**ASTM and SAE**	**Old SAE**	**Al**	**Mn, Min.**	**Zn**	**Th**	**Rare Earths**	**Zr**	**Cu, Max.**	**Ni, Max.**	**Si, Max.**	**Total Other Elements, Max.**
M10600	AM60A	---	5.5-6.5	0.13	0.22	---	---	---	0.35	0.03	0.50	---
M10100	AM100A	502	9.3.-10.7	0.10	0.30 max.	---	---	---	0.10	0.01	0.30	0.30
M10410	AS41A	---	3.7-4.8	0.22-0.48	0.10 max.	---	---	---	0.04	0.01	0.60-1.4	0.30
M11630	AZ63A	50	5.3-6.7	0.15	2.5-3.5	---	---	---	0.25	0.01	0.30	0.30
M11810	AZ81A	505	7.0-8.1	0.13	0.40-1.0	---	---	---	0.10	0.01	0.30	0.30
M11910	AZ91A	501	8.3-9.7	0.13	0.35-1.0	---	---	---	0.10	0.03	0.50	0.30
M11912	AZ91B	501A	8.3-9.7	0.13	0.35-1.0	---	---	---	0.35	0.03	0.50	0.30
M11914	AZ91C	504	8.1-9.3	0.13	0.4-1.0	---	---	---	0.10	0.01	0.30	0.30
M11920	AZ92A	500	8.3-9.7	0.10	1.6-2.4	---	---	---	0.25	0.01	0.30	0.30
M12330	EZ33A	506	---	---	2.0-3.1	---	2.5-4.0	0.50-1.0	0.10	0.01	---	0.30
M13310	HK31A	507	---	---	0.30 max.	2.5-4.0	---	0.40-1.0	0.10	0.01	---	0.30

ASTM B 403 - CHEMICAL COMPOSITION OF MAGNESIUM-ALLOY INVESTMENT CASTINGS[a]

ASTM[b]	UNS No.	Fe	Mg	Al	Mn	Zn	Zr	Rare Earths	Th	Cu	Ni	Si	Total Other Impurities[c]	Others Each
AM100A	M10100	---	rem.	9.3-10.7	0.10-0.35	0.30	---	---	---	0.10	0.01	0.30	0.30	---
AZ81A	M11810	---	rem.	7.0-8.1	0.13-0.35	0.40-1.0	---	---	---	0.10	0.01	0.30	0.30	---
AZ91C	M11914	---	rem.	8.1-9.3	0.13-0.35	0.40-1.0	---	---	---	0.10	0.01	0.30	0.30	---
AZ91E	M11919	0.005[d,e]	rem.	8.1-9.3	0.17-0.35	0.40-1.0	---	---	---	0.015	0.0010	0.20	0.30	0.01
AZ92A	M11920	---	rem.	8.3-9.7	0-0.35	1.6-2.4	---	---	---	0.10	0.01	0.30	0.30	---
EQ21A	M18330	---	rem.	---	---	---	0.40-1.0	1.5-3.0[f]	---	0.05-0.10	0.01	---	0.30	---
EZ33A	M12330	---	rem.	---	---	2.0-3.1	0.50-1.0	2.5-4.0	---	0.10	0.01	---	0.30	---
HK31A	M13310	---	rem.	---	---	0.30	0.40-1.0	---	2.5-4.0	0.10	0.01	---	0.30	---
K1A	M18010	---	rem.	---	---	---	0.40-1.0	---	---	---	---	---	0.30	---
QE22A[g]	M18220[g]	---	rem.	---	---	---	0.40-1.0	1.8-2.5[f]	---	0.10	0.01	---	0.30	---
ZK61A	M16610	---	rem.	---	---	5.5-6.5	0.6-1.0	---	---	0.10	0.01	---	0.30	---

a. Limits are in weight percent maximum unless shown as a range or stated otherwise.
b. These alloy designations were established in accordance with ASTM B 275.
c. Includes listed elements for which no specific limit is shown.
d. If iron content exceeds 0.005 %, the iron to manganese ratio shall not exceed 0.032.
e. Silver content for Alloy EQ21A shall be 1.3 to 1.7 %.
f. Rare earth elements are in the form of didymium.
g. Silver content for Alloy QE22A shall be 2.0 through 3.0 %.

ASTM B 91 - MECHANICAL PROPERTIES OF MAGNESIUM-ALLOY FORGINGS					
Alloy and Temper	**Tensile Strength, min**		**Yield Strength[a] (0.2% offset), min**		**Elongation in 2 in. (51 mm), or 4 x dia, min, %**
	ksi	**MPa**	**ksi**	**MPa**	
AZ31B–F	34.0	234	19.0	131	6
AZ61A–F	38.0	262	22.0	152	6
AZ80A–F	42.0	290	26.0	179	5
AZ80A–T5	42.0	290	28.0	193	2
ZK60A-T5 die forgings[b]	42.0	290	26.0	179	7
ZK60A-T6 die forgings[b]	43.0	296	32.0	221	4

a. See X1.1.6. of ASTM B 91.

b. Applicable only to die forgings not more than 3 in. (76 mm) in thickness. The tensile requirements for hand forgings will be lower and as agreed upon by the purchaser and manufacturer.

ASTM B 107 – MECHANICAL PROPERTIES OF MAGNESIUM-ALLOY EXTRUDED BARS, RODS, SHAPES, TUBES AND WIRE[a]										
UNS	**ASTM**	**Temper[a]**	**Form**	**Specified Diameter or Thickness in.[b,c]**	**Specified Cross-Sectional Area, in.^{2} or OD of Tube, in.**	**Tensile Strength, Min.**		**Yield Strength, (0.2% Offset), Min.**		**% Elongation in 2 in. (50 mm) or 4 x Dia., Min.[d,e]**
						ksi	**MPa**	**ksi**	**MPa**	
M11311	AZ31B	F	Bars, rods, profiles, and wire	< 0.249	All	35.0	240	21.0	145	7
				0.250-1.499	All	35.0	240	22.0	150	7
				1.500-2.499	All	34.0	235	22.0	150	7
				2.500-4.999	All	32.0	220	20.0	140	7
			Hollow profiles	All	All	32.0	220	16.0	110	8
			Tubes	0.028-0.250	< 6.000 (150.00)	32.0	220	20.0	140	8
				0.250-0.750	---	32.0	220	16.0	110	4

Chapter

9

CEMENTED CARBIDES

These materials are composites consisting of particles of a hard, brittle, nonmetallic refractory material, typically carbides but sometimes carbonitrides or nitrides, in a metallic binder (matrix) phase, typically cobalt but sometimes nickel, iron, or their alloys. The matrix phase, which imparts ductility, toughness, and thermal conductivity to the composite, typically occupies 10-15% of the volume. The outer surface may or may not be coated for improved surface properties. The original material in this category was WC-Co; however, there has been a long history of development which has led to many other formulations. Applications include metal cutting, mining, construction, rock drilling, metal forming, structural components, and wear parts, but of these metal cutting is the most important, accounting for approximately half of production. The steps involved in manufacture of these materials include powder preparation, then compaction or consolidation by pill or hydrostatic pressing or extrusion, followed by sintering, and finally forming. During sintering, the metallic binder melts and draws the carbide particles together. Pressure can be applied during the sintering, for example this can be carried out by hot isostatic pressing in a vacuum. The properties of sintered hardmetals are profoundly influenced by microstructure, including the compositions of the phases, and the sizes, shapes, and distributions of carbide particles. One of the problems which can arise is that when there is a deficiency of carbon, some of the original WC particles can dissolve, and particles of a mixed cobalt-tungsten carbide ("*eta* phase") can form, giving rise to serious embrittlement.

Carbides produced for use in hardmetals include WC, TiC, TaC, NbC, and solid solution mixed carbides such as WC-TiC, WC-TiC-TaC, and WC-TiC-(Ta,Nb)C.

The basic WC-Co alloys, referred to as straight grades, have excellent resistance to abrasive wear and find many applications in metal cutting. Although alloys ranging between 3% and 30%Co are produced, those most widely used in machining typically contain 3-12% Co and WC particles manufacturers can exhibit different properties and performance. Both machining and non-machining applications are included. The same limitations apply to the more recent ISO codes. ISO Recommendation R513 divides machining grades into three colour-coded groups: straight WC grades (letter K, colour red); alloyed WC grades (letter M, colour yellow); and highly alloyed grades (letter P, colour blue). Within each grade, a number is assigned giving the approximate position in the range between maximum hardness and maximum toughness (shock resistance). These are shown with their applications in Table 2. It must be noted that with this system the coding is assigned to a given material by its manufacturer and that quality control cannot be applied. The ISO R513 has been revised to take into account the increasing use of coated hardmetals, as well as the superhard ceramics, polycrystalline diamond, and cubic boron nitride.

Table 1 American Cemented Carbide Classifications

Buick Code	IndustryCode	Application
Machining - cast iron, nonferrous & nonmetallic materials		
TC-1	C-1	Roughing cuts
TC-2	C-2	General purpose
TC-3	C-3	Light finishing
TC-4	C-4	Precision machining
Machining - steel		
TC-5	C-5	Roughing cuts
TC-6	C-6	General purpose
TC-7	C-7	Light finishing
TC-8	C-8	Precision machining
Wear Surface		
TC-9	C-9	No shock
TC-10	C-10	Light shock
TC-11	C-11	Heavy shock
Impact		
TC-12	C-12	Light
TC-13	C-13	Medium
TC-14	C-14	Heavy
Miscellaneous		
---	C-15	Light cut hot flash weld removal
---	C-15A	Heavy cut hot flash weld removal
---	C-16	Rock bits
---	C-17	Cold Header dies
---	C-18	Wear at elevated temperatures and/or resistance to chemical reactions
---	C-19	Radioactive shielding, counterbalances and kinetics applications

Table 2 ISO Std. 513 Classification of Cutting Tool Materials

Material Categories	Color Code	ISO	Material Machined
Ferrous metals with long chips	Blue	P01	Steel, steel castings
		P10	Steel, steel castings
		P20	Steel, steel castings, malleable cast iron with long chips
		P30	Steel, steel castings, malleable cast iron with long chips
		P40	Steel, steel castings with sand inclusion and cavities
		P50	Steel, steel castings of medium or low tensile strength, with sand inclusion and cavities
Ferrous metals with long or short chips and nonferrous metals	Yellow	M10	Steel, steel castings, manganese steel, grey cast iron, alloy cast iron
		M20	Steel, steel castings, austenitic or manganese steel, grey cast iron
		M30	Steel, steel castings, austenitic steel, grey cast iron, high temperature resistant alloys
		M40	Mild free-cutting steel, low tensile steel, nonferrous metals, light alloys
Ferrous metals with short chips, nonferrous metals and nonmetallic materials	Red	K01	Very hard grey cast iron, chilled castings over 85 Shore, high silicon-aluminum alloys, hardened steel, highly abrasive plastics, hard cardboard, ceramics
		K10	Grey cast iron over 220 Brinell, malleable cast iron with short chips, hardened steel, silicon-aluminum alloys, copper alloys, plastic, glass, hard rubber, hard cardboard, porcelain, stone
		K20	Grey cast iron over 220 Brinell, nonferrous metals: copper, brass, aluminum
		K30	Low hardness grey cast iron, low tensile steel, compressed wood
		K40	Soft wood or hard wood, nonferrous metals

COATED CEMENTED CARBIDES CROSS REFERENCE

Trade Name	Company Name	Grade	Layer Composition(s)	Coating Depth, µm	ISO Code(s)
ACT	Advanced Carbide Tooling Ltd	ATN150	TiN	3-4	P35
Alberg	Alberg Remscheid - Alfred Berghaus GmbH & Co	ATN250	TiN	3-4	P25/K15
		MBK20	TiC+TiN	---	K10-K20
		MBP30	TiN+TiC+TiN	---	P25-P30
		MBP40	TiN+TiC+TiN	---	P30-P40
		MBP50	TiN+TiC+TiN	---	P40-P50
		MBTA20	TiN+Al_2O_3+TiN	---	P10-P20/K10-K20
		MBTA25	TiC+Al_2O_3+TiN	---	P15-P25
		MBTT30	TiC+Ti(C,N)+TiN	---	P20-P30
		MBTT40	TiC+Ti(C,N)+TiN	---	P30-P40
		PVD	TiN	---	---
Allenite Gold	Edgar Allen Danite Ltd	EM100	TiC+Ti(C,N)+TiN	10-14	M05-M20/K05-K30
		ES200	TiC+Ti(C,N)+TiN	10-14	P10-P25
		ES350	TiC+Ti(C,N)+TiN	10-14	P30-P40
ANC	American National Carbide Co	102	Ti(C,N)+TiC+TiN	8	K20-K30
		113	Ti(C,N)+TiC+TiN	8	P25-P40/K25-K40
		153	Ti(C,N)+TiC+TiN	8	P20-P30/K20-K30
		AOX	TiC+Al_2O_3	8	P15-P30/K15-K30
		CAD	TiC+Al_2O_3+TiN	10	P15-P30/K15-K30
		CAM	TiC+Al_2O_3+TiN	10	P20-P35/K20-K35
		TEX	Ti(C,N)+TiC+TiN	8	P20-P35/K20-K35
		TNT	Ti(C,N)+TiC+TiN	8	P15-P30/K15-K30
		TOX	TiC+Al_2O_3	8	P20-P35/K20-K35
		TXTZ	TiN+ZrN+TiN	4	P20-P35/K20-K35
		TZN	TiN+ZrN+TiN	4	P15-P30/K15-K30

INTERNATIONAL SPECIFICATION DESIGNATIONS & TITLES OF HARDMETALS (Cemented Carbides)	
Specification	**Titles**
ISO 3312	Sintered metal materials and hardmetals - Determination of Young modulus
ISO 3326	Hardmetals - Determination of (the magnetization) coercivity
ISO 3327	Hardmetals - Determination of transverse rupture strength
ISO 3369	Impermeable sintered metal materials and hardmetals - Determination of density
ISO 3738: Part 1	Hardmetals - Rockwell hardness test (Scale A) - Test method
ISO 3738: Part 2	Hardmetals - Rockwell hardness test (Scale A) - Preparation and calibration of standard test blocks
ISO 3878	Hardmetals - Vickers hardness test
ISO 3907	Hardmetals - Determination of total carbon content - Gravimetric method
ISO 3908	Hardmetals - Determination of insoluble (free) carbon content - Gravimetric method
ISO 3909	Hardmetals - Determination of cobalt - Potentiometric method
ISO 4499	Hardmetals - Metallographic determination of microstructure
ISO 4501	Hardmetals - Determination of titanium - Photometric peroxide method
ISO 4503	Hardmetals - Determination of contents of metallic elements by X-ray fluorescence - Fusion method
ISO 4505	Hardmetals - Metallographic determination of porosity and uncombined carbon
ISO 4506	Hardmetals - Compression test
ISO 4883	Hardmetals - Determination of contents of metallic elements by X-ray fluorescence - Solution method
ISO 4884	Hardmetals - Sampling and testing of powders using sintered test pieces
ISO 7627: Part 1	Hardmetals - Chemical analysis by flame atomic absorption spectrometry - General requirements
ISO 7627: Part 2	Hardmetals - Chemical analysis by flame atomic absorption spectrometry - Determination of calcium, potassium, magnesium and sodium in contents from 0.001 to 0.02% (m/m)
ISO 7627: Part 3	Hardmetals - Chemical analysis by flame atomic absorption spectrometry - Determination of cobalt, iron, manganese and nickel in contents from 0.01 to 0.5% (m/m)
ISO 7627: Part 4	Hardmetals - Chemical analysis by flame atomic absorption spectrometry - Determination of molybdenum, titanium and vanadium in contents from 0.01 to 0.5% (m/m)
ISO 7627: Part 5	Hardmetals - Chemical analysis by flame atomic absorption spectrometry - Determination of cobalt, iron, manganese, molybdenum, nickel, titanium and vanadium in contents from 0.5 to 2% (m/m)
ISO 7627: Part 6	Hardmetals - Chemical analysis by flame atomic absorption spectrometry - Determination of chromium in contents from 0.01 to 2% (m/m)

Appendix 1

HARDNESS CONVERSION TABLES

APPROXIMATE HARDNESS CONVERSION NUMBERS FOR NICKEL & HIGH-NICKEL ALLOYS									
Vickers[a]	**Brinell[b]**	**Rockwell Hardness Number[c]**							
HV	**HB**	**HRA**	**HRB**	**HRC**	**HRD**	**HRE**	**HRF**	**HRG**	**HRK**
513	479	75.5	---	50.0	63.0	---	---	---	---
481	450	74.5	---	48.0	61.5	---	---	---	---
452	425	73.5	---	46.0	60.0	---	---	---	---
427	403	72.5	---	44.0	58.5	---	---	---	---
404	382	71.5	---	42.0	57.0	---	---	---	---
382	363	70.5	---	40.0	55.5	---	---	---	---
362	346	69.5	---	38.0	54.0	---	---	---	---
344	329	68.5	---	36.0	52.5	---	---	---	---
326	313	67.5	---	34.0	50.5	---	---	---	---
309	298	66.5	106	32.0	49.5	---	116.5	94.0	---
285	275	64.5	104	28.5	46.5	---	115.5	91.0	---
266	258	63.0	102	25.5	44.5	---	114.5	87.5	---
248	241	61.5	100	22.5	42.0	---	113.0	84.5	---
234	228	60.5	98	20.0	40.0	---	112.0	81.5	---
220	215	59.0	96	17.0	38.0	---	111.0	78.5	100.0
209	204	57.5	94	14.5	36.0	---	110.0	75.5	98.0
198	194	56.5	92	12.0	34.0	---	108.5	72.0	96.5
188	184	55.0	90	9.0	32.0	108.5	107.5	69.0	94.5
179	176	53.5	88	6.5	30.0	107.0	106.5	65.5	93.0
171	168	52.5	86	4.0	28.0	106.0	105.0	62.5	91.0
164	161	51.5	84	2.0	26.5	104.5	104.0	59.5	89.0
157	155	50.0	82	---	24.5	103.0	103.0	56.5	87.5
151	149	49.0	80	---	22.5	102.0	101.5	53.0	85.5
145	144	47.5	78	---	21.0	100.5	100.5	50.0	83.5
140	139	46.5	76	---	19.0	99.5	99.5	47.0	82.0

APPROXIMATE HARDNESS CONVERSION NUMBERS FOR WROUGHT ALUMINUM PRODUCTS

Brinell	Vickers	Rockwell[a]			Rockwell Superficial[b]		
HB 500-kgf	HV 15-kgf	HRB	HRE	HRH	HR15-T	HR30-T	HR15-H
160	189	91	---	---	89	77	95
155	183	90	---	---	89	76	95
150	177	89	---	---	89	75	94
145	171	87	---	---	88	74	94
140	165	86	---	---	88	73	94
135	159	84	---	---	87	71	93
130	153	81	---	---	87	70	93
125	147	79	---	---	86	68	92
120	141	76	101	---	86	67	92
115	135	72	100	---	86	65	91
110	129	69	99	---	85	63	91
105	123	65	98	---	84	61	91
100	117	60	---	---	83	59	90
95	111	56	96	---	82	57	90
90	105	51	94	108	81	54	89
85	98	46	91	107	80	52	89
80	92	40	88	106	78	50	88
75	86	34	84	104	76	47	87
70	80	28	80	102	74	44	86
65	74	---	75	100	72	---	85
60	68	---	70	97	70	---	83
55	62	---	65	94	67	---	82
50	56	---	59	91	64	---	80
45	50	---	53	87	62	---	79
40	44	---	46	83	59	---	77

Appendix

2

METRIC CONVERSIONS

METRIC CONVERSION FACTORS

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

Appendix

3

IMPERIAL UNITS

DECIMAL EQUIVALENT OF FRACTIONS

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

Appendix

4

PIPE DIMENSIONS

DIMENSIONS OF WELDED AND SEAMLESS PIPE

Nominal Pipe Size	Outside Diameter	Nominal Wall Thickness (in) For						
		Schedule 5S	Schedule 10S	Schedule 10	Schedule 20	Schedule 30	Schedule Standard	Schedule 40
⅛	0.405	---	0.049	---	---	---	0.068	0.068
¼	0.540	---	0.065	---	---	---	0.088	0.088
⅜	0.675	---	0.065	---	---	---	0.091	0.091
½	0.840	0.065	0.083	---	---	---	0.109	0.109
¾	1.050	0.065	0.083	---	---	---	0.113	0.113
1	1.315	0.065	0.109	---	---	---	0.133	0.133
1 ¼	1.660	0.065	0.109	---	---	---	0.140	0.140
1 ½	1.900	0.065	0.109	---	---	---	0.145	0.145
2	2.375	0.065	0.109	---	---	---	0.154	0.154
2 ½	2.875	0.083	0.120	---	---	---	0.203	0.203
3	3.5	0.083	0.120	---	---	---	0.216	0.216
3 ½	4.0	0.083	0.120	---	---	---	0.226	0.226
4	4.5	0.083	0.120	---	---	---	0.237	0.237
5	5.563	0.109	0.134	---	---	---	0.258	0.258
6	6.625	0.109	0.134	---	---	---	0.280	0.280
8	8.625	0.109	0.148	---	0.250	0.277	0.322	0.322
10	10.75	0.134	0.165	---	0.250	0.307	0.365	0.365
12	12.75	0.156	0.180	---	0.250	0.330	0.375	0.406
14 O.D.	14.0	0.156	0.188	0.250	0.312	0.375	0.375	0.438
16 O.D.	16.0	0.165	0.188	0.250	0.312	0.375	0.375	0.500
18 O.D.	18.0	0.165	0.188	0.250	0.312	0.438	0,375	0.562
20 O.D.	20.0	0.188	0.218	0.250	0.375	0.500	0,375	0.594
22 O.D.	22.0	0.188	0.218	0.250	0.375	0.500	0.375	---
24 O.D.	24.0	0.218	0.250	0.250	0.375	0.562	0.375	0.688
26 O.D.	26.0	---	---	0.312	0.500	---	0.375	---

Appendix

5

PERIODIC TABLE

Periodic Table of the Elements

Nonmetals

Metals

Key to chart

Atomic Number → **50** ← Oxidation States +2 +4
Symbol → Sn
Atomic Weight → 118.69
-18-18-4 ← Electron Configuration

Transition Elements

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII			Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0	Orbit
1 H +1 -1 1.0079 1																	**2** He 0 4.00260 2	K
3 Li +1 6.939 2-1	**4** Be +2 9.0122 2-2											**5** B +3 10.81 2-3	**6** C +2 +4 -4 12.011 2-4	**7** N +1 +2 +3 +4 +5 -1 -2 -3 14.0067 2-5	**8** O -2 15.9994 2-6	**9** F -1 18.998403 2-7	**10** Ne 0 10.17$_9$ 2-8	K-L
11 Na +1 22.9898 2-8-1	**12** Mg +2 24.312 2-8-2											**13** Al +3 26.98154 2-8-3	**14** Si +2 +4 -4 28.08 2-8-4	**15** P +3 +5 -3 30.97376 2-8-5	**16** S +4 +6 -2 32.06 2-8-6	**17** Cl +1 +5 +7 -1 35.453 2-8-7	**18** Ar 0 39.948 2-8-8	K-L-M
19 K +1 39.09 -8-8-1	**20** Ca +2 40.08 -8-8-2	**21** Sc +3 44.9559 -8-9-2	**22** Ti +2 +3 +4 47.9 -8-10-2	**23** V +2 +3 +4 +5 50.941 -8-11-2	**24** Cr +2 +3 +6 51.996 -8-13-1	**25** Mn +2 +3 +4 +7 54.9380 -8-13-2	**26** Fe +2 +3 55.847 -8-14-2	**27** Co +2 +3 58.9332 -8-15-2	**28** Ni +2 +3 58.71 -8-16-2	**29** Cu +1 +2 63.54 -8-18-1	**30** Zn +2 65.38 -8-18-2	**31** Ga +3 69.72 -8-18-3	**32** Ge +2 +4 72.59 -8-18-4	**33** As +3 +5 -3 74.9216 -8-18-5	**34** Se +4 +6 -2 78.96 -8-18-6	**35** Br +1 +5 -1 79.904 -8-18-7	**36** Kr 0 83.80 -8-18-8	-L-M-N
37 Rb +1 85.467 -18-8-1	**38** Sr +2 87.62 -18-8-2	**39** Y +3 88.9059 -18-9-2	**40** Zr +4 91.22 -18-10-2	**41** Nb +3 +5 92.9064 -18-12-1	**42** Mo +6 95.94 -18-13-1	**43** Tc +4 +6 +7 98.9062 -18-13-2	**44** Ru +3 101.07 -18-15-1	**45** Rh +3 102.905 -18-16-1	**46** Pd +2 +4 106.4 -18-18-0	**47** Ag +1 107.868 -18-18-1	**48** Cd +2 112.40 -18-18-2	**49** In +3 114.82 -18-18-3	**50** Sn +2 +4 118.69 -18-18-4	**51** Sb +3 +5 -1 121.75 -18-18-5	**52** Te +4 +6 -2 127.60 -18-18-6	**53** I +1 +5 +7 -3 126.9045 -18-18-7	**54** Xe 0 131.30 -18-18-8	-M-N-O
55 Cs +1 132.9054 -18-8-1	**56** Ba +2 137.3 -18-8-2	**57*** La +3 138.9055 -18-9-2	**72** Hf +4 178.49 -32-10-2	**73** Ta +5 180.948 -32-11-2	**74** W +6 183.85 -32-12-2	**75** Re +4 +6 +7 186.207 -32-13-2	**76** Os +3 +4 190.2 -32-14-2	**77** Ir +3 +4 192.9 -32-15-2	**78** Pt +2 +4 195.09 -32-16-2	**79** Au +1 +3 196.9665 -32-18-1	**80** Hg +1 +2 200.59 -32-18-2	**81** Tl +1 +3 204.37 -32-19-3	**82** Pb +2 +4 207.19 -32-18-4	**83** Bi +3 +5 208.980 -32-18-5	**84** Po +2 +4 (209) -32-18-6	**85** At (210) -32-18-7	**86** Rn 0 (222) -32-18-8	-N-O-P
87 Fr +1 (223) -18-8-1	**88** Ra +2 226.0254 -18-8-2	**89**** Ac +3 (227) -18-9-2	**104** Rf +4 (261) -32-10-2	**105** Ha (262) -32-11-2	**106** (263) -32-12-2													-O-P-Q

Appendix

6

CASTI ENGINEERING AND SCIENTIFIC WEB PORTAL - SELECTED LINKS

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

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

Appendix 7

TRADENAMES & TRADEMARKS

TRADEMARK	COMPANY
ALCOA	Aluminum Company of America
AL 6XN, AL 6X	Allegheny Ludlum Corp
ALUMEL	Hoskins Manufacturing Co.
ARMCO 20-45-5	Armco Steel Corp.
CARPENTER, 20Cb3, 20Mo6	Carpenter Technology Corp.
PYROMET	Carpenter Technology Corp.
CHROMEL	Hoskin Manufacturing Co.
COLMONOY	Wall Colmonoy Corp.
CREUSOT UR SB 8	Creusot-Loire
DURATHERM	Vacuumschmelze GmbH
EATONITE	Eaton Corp.
ELGILOY	Elgiloy Limited Partnership
EVERDUR	Anaconda Co.
HASTELLOY, HAYNES, 242, 214, 230	Haynes International Inc.
230W, 556, B-3, C-22, G-30, G-50	Haynes International Inc.
H-9M, HR-120, HR-160	Haynes International Inc.
HAVAR	Hamilton Technology Inc.
IN-100, IN-102, RENE 41	Cannon-Muskegon Corp.
INCO, INCOLOY, INCONEL, NIMONIC	Inco Alloys International Inc.
MAR-M Alloy	Martin-Marietta Corp.
NICHROME	Harrison Alloys
RA330, RA330-04, RA-333	Rolled Alloys Inc.
SANICRO 28	Sandvik Steel Corp.
SM-2060	Svenska Metallverken A.B.
STELLITE, TRIBALOY	Stoody Deloro Stellite Inc.
TPM	American Manufacture
UDIMET	Specialty Metals inc.
VITALIUM	Howmet Corp.
WASPALOY	United Technologies

Appendix

8

CURRENT ASTM STANDARDS FOR NONFERROUS METALS

CURRENT ASTM STANDARDS FOR NONFERROUS METALS	
ASTM Spec.	**Title**
B 1-01	Standard Specification for Hard-Drawn Copper Wire
B 2-00	Standard Specification for Medium-Hard-Drawn Copper Wire
B 3-01	Standard Specification for Soft or Annealed Copper Wire
B 5-00	Standard Specification for High Conductivity Tough-Pitch Copper Refinery Shapes
B 6-00	Standard Specification for Zinc
B 8-99	Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft
B 9-90(1998)e1	Standard Specification for Bronze Trolley Wire
B 16/B 16M-00	Standard Specification for Free-Cutting Brass Rod, Bar and Shapes for Use in Screw Machines
B 19-01	Standard Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (Blanks)
B 21/B 21M-01	Standard Specification for Naval Brass Rod, Bar, and Shapes
B 22-95	Standard Specification for Bronze Castings for Bridges and Turntables
B 23-00	Standard Specification for White Metal Bearing Alloys (Known Commercially as "Babbitt Metal")
B 26/B 26M-01	Standard Specification for Aluminum-Alloy Sand Castings
B 29-92(1997)	Standard Specification for Refined Lead
B 30-00e2	Standard Specification for Copper Alloys in Ingot Form
B 32-00	Standard Specification for Solder Metal
B 33-00	Standard Specification for Tinned Soft or Annealed Copper Wire for Electrical Purposes
B 36/B 36M-01	Standard Specification for Brass Plate, Sheet, Strip, And Rolled Bar
B 37-96(2001)	Standard Specification for Aluminum for Use in Iron and Steel Manufacture
B 39-79(1999)	Standard Specification for Nickel
B 42-02	Standard Specification for Seamless Copper Pipe, Standard Sizes
B 43-98	Standard Specification for Seamless Red Brass Pipe, Standard Sizes
B 47-95a(2001)	Standard Specification for Copper Trolley Wire
B 48-00	Standard Specification for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors
B 49-98e2	Standard Specification for Copper Rod Drawing Stock for Electrical Purposes
B 66-95	Standard Specification for Bronze Castings for Steam Locomotive Wearing Parts
B 68-99	Standard Specification for Seamless Copper Tube, Bright Annealed

ASTM STANDARD CLASSIFICATIONS FOR NONFERROUS METALS	
ASTM Spec.	**Title**
B 224-98	Standard Classification of Coppers
B 601-01	Standard Classification for Temper Designations for Copper and Copper Alloys-Wrought and Cast
B 698-97	Standard Classification for Seamless Copper and Copper Alloy Plumbing Pipe and Tube

ASTM STANDARD GUIDES FOR NONFERROUS METALS	
ASTM Spec.	**Title**
B 177-01	Standard Guide for Engineering Chromium Electroplating
B 252-92(1998)	Standard Guide for Preparation of Zinc Alloy Die Castings for Electroplating and Conversion Coatings
B 253-87(1999)e1	Standard Guide for Preparation of Aluminum Alloys for Electroplating
B 319-91(1997)	Standard Guide for Preparation of Lead and Lead Alloys for Electroplating
B 480-88(2001)	Standard Guide for Preparation of Magnesium and Magnesium Alloys for Electroplating
B 497-00	Standard Guide for Measuring Voltage Drop on Closed Arcing Contacts
B 555-86(2002)	Standard Guide for Measurement of Electrodeposited Metallic Coating Thicknesses by the Dropping Test
B 556-90(2002)	Standard Guide for Measurement of Thin Chromium Coatings by the Spot Test
B 576-94(1999)	Standard Guide for Arc Erosion Testing of Electrical Contact Materials
B 600-91(2002)	Standard Guide for Descaling and Cleaning Titanium and Titanium Alloy Surfaces
B 613-76(2000)	Standard Guide for Preparing Specifications for Miniature Brushes of Composite Materials for Sliding Electric Contacts
B 659-90(1997)	Standard Guide for Measuring Thickness of Metallic and Inorganic Coatings
B 697-88(1999)	Standard Guide for Selection of Sampling Plans for Inspection of Electrodeposited Metallic and Inorganic Coatings
B 712-93(1999)	Standard Guide for Determination of Sodium and Potassium Content For Silver-Cadmium Oxide Contact Materials
B 765-93(2001)	Standard Guide for Selection of Porosity Tests for Electrodeposits and Related Metallic Coatings
B 767-88(2001)	Standard Guide for Determining Mass Per Unit Area of Electrodeposited and Related Coatings by Gravimetric and Other Chemical Analysis Procedures
B 772-97	Standard Guide for Specifying the Chemical Compositions for Electrical Contact Materials (Arcing and Nonarcing)
B 773-96(2002)e1	Standard Guide for Ultrasonic C-Scan Bond Evaluation of Brazed or Welded Electrical Contact Assemblies

ASTM STANDARD GUIDES FOR NONFERROUS METALS (Continued)	
ASTM Spec.	**Title**
B 781-93a(1999)	Standard Guide for Silver-Cadmium Oxide Contact Material
B 821-92(1997)	Standard Guide for Liquid Dispersion of Metal Powders and Related Compounds for Particle Size Analysis
B 832-93(1998)	Standard Guide for Electroforming with Nickel and Copper
B 844-98	Standard Guide for Silver-Tin Oxide Contact Material
B 845-97	Standard Guide for Mixed Flowing Gas (MFG) Tests for Electrical Contacts
B 850-98	Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement
B 854-98	Standard Guide for Measuring Electrical Contact Intermittences
B 909-00	Standard Guide for Plane Strain Fracture Toughness Testing of Non-Stress Relieved Aluminum Products

ASTM STANDARD PRACTICES FOR NONFERROUS METALS	
ASTM Spec.	**Title**
B 117-97	Standard Practice for Operating Salt Spray (Fog) Apparatus
B 183-79(1997)	Standard Practice for Preparation of Low-Carbon Steel for Electroplating
B 201-80(2000)	Standard Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces
B 208-96	Standard Practice for Preparing Tension Test Specimens for Copper-Base Alloys for Sand, Permanent Mold, Centrifugal, and Continuous Castings
B 215-96	Standard Practices for Sampling Finished Lots of Metal Powders
B 242-99	Standard Practice for Preparation of High-Carbon Steel For Electroplating
B 254-92(1998)	Standard Practice for Preparation of and Electroplating on Stainless Steel
B 275-02	Standard Practice for Codification of Certain Nonferrous Metals and Alloys, Cast and Wrought
B 281-88(2001)	Standard Practice for Preparation of Copper and Copper-Base Alloys for Electroplating and Conversion Coatings
B 296-96	Standard Practice for Temper Designations of Magnesium Alloys, Cast and Wrought
B 320-60(1997)	Standard Practice for Preparation of Iron Castings for Electroplating
B 322-99	Standard Practice for Cleaning Metals Prior to Electroplating
B 343-92a(1998)	Standard Practice for Preparation of Nickel for Electroplating with Nickel

Appendix

9

DISCONTINUED ASTM STANDARDS FOR NONFERROUS METALS

DISCONTINUED ASTM STANDARDS FOR NONFERROUS METALS	
Discontinued	**Replaced By**
B 4 (1980)	No Replacement
B 7 (1940)	B 30 – Copper-Base Alloys in Ingot Form
B 10 (1933)	No Replacement
B 11 (1980)	No Replacement
B 12 (1981)	B 133 – Discontinued 1994; Replaced by B 187 – Copper Bar, Bus Bar, Rod and Shapes
B 13 (1960)	No Replacement
B 14 (1955)	No Replacement
B 15 (1939)	B 124/B 124M – Copper and Copper Alloy Forging Rod, Bar and Shapes
B 16M (2000)	B 16/B 16M - Free-Cutting Brass Rod, Bar, and Shapes for Use in Screw Machines
B 17 (1925)	B 66 – Bronze Castings for Steam Locomotive Wearing Parts B 67 – Car and Tender Journal Bearings, Lined
B 18 (1941)	E 46 – Discontinued 1994; No Replacement
B 20 (1939)	Combined with B 19 – Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (Blanks)
B 21 (2001)	B 21/B 21M - Naval Brass Rod, Bar, and Shapes
B 21M (2001)	B 21/B 21M - Naval Brass Rod, Bar, and Shapes
B 24 (1955)	No Replacement
B 25 (1945)	B 209 – Aluminum and Aluminum-Alloy Sheet and Plate
B 27 (1942)	E 54 – Test Methods for Chemical Analysis of Special Brasses and Bronzes
B 28 (1942)	E 54 – Test Methods for Chemical Analysis of Special Brasses and Bronzes
B 31 (1932)	B 30 – Copper-Base Alloys in Ingot Form
B 34	Redesignated E 53 – Methods for Chemical Analysis of Copper
B 35 (1941)	E 37 – Test Methods for Chemical Analysis of Pig Lead
B 38 (1941)	E 40 – Discontinued 1993; Replaced by E 536 – Test Methods for Chemical Analysis of Zinc and Zinc Alloys
B 40 (1941)	E 34 – Test Methods for Chemical Analysis of Aluminum and Aluminum-Base Alloys
B 41 (1941)	E 39 – Discontinued 1995; No Replacement
B 44 (1936)	B 111 – Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock
B 45 (1941)	E 36 – Discontinued 1980; Replaced by E 478 – Test Methods for Chemical Analysis of Copper Alloys

Index