WELDING COPPER AND COPPER ALLOYS

CDA

Copper Development Association

Welding Copper and Copper Alloys

Published by AMERICAN WELDING SOCIETY
550 N. W. LeJeune Road, Miami, FL 33126

THE MATERIAL IN THIS BOOK HAS BEEN REPRINTED FROM VOLUME THREE
OF THE EIGHTH EDITION OF THE *WELDING HANDBOOK*

International Standard Book Number: 0-87171-505-8

American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126

THE WELDING HANDBOOK is a collective effort of many volunteer technical specialists to provide information to assist with the design and application of welding and allied processes.

Reasonable care is taken in the compilation and publication of the Welding Handbook to insure authenticity of the contents. However, no representation is made as to the accuracy or reliability of this information, and an independent, substantiating investigation should be undertaken by any user.

The information contained in the Welding Handbook shall not be construed as a grant of any right of manufacture, sale, use, or reproduction in connection with any method, process, apparatus, product, composition, or system, which is covered by patent, copyright, or trademark. Also, it shall not be construed as a defense against any liability for such infringement. Whether or not use of any information in the Handbook would result in an infringement of any patent, copyright, or trademark is a determination to be made by the user.

Printed in the United States of America

WELDING HANDBOOK COMMITTEE

B. R. Somers, Chairman	Lehigh University
P. I. Temple, 1st Vice Chairman	Detroit Edison
R. M. Walkosak, 2nd Vice Chairman	Westinghouse Electric Corporation
W. R. Oates, Secretary	American Welding Society
B. J. Bastian	Benmar Associates
H. R. Castner	Edison Welding Institute
D. J. Corrigall	Miller Electric Company
J. G. Feldstein	Foster Wheeler Energy Corporation
J. M. Gerken	Consultant
L. C. Heckendorn	Intech R&D, USA
S. D. Kiser	Inco Alloys International
J. C. Papritan	Ohio State University
D. V. Rypien	American Bureau of Shipping
R. P. Schuster	Harnischfeger Industries, Inc.
M. J. Tomsic	Plastronic, Incorporated
C. L. Tsai	Ohio State University

COPPER AND COPPER ALLOYS

PREPARED BY A COMMITTEE CONSISTING OF:

H. Castner, Chairman
Edison Welding Institute

C. W. Dralle
Ampco Metal, Inc.

C. E. Fuerstenau
Lucas-Milhaupt Inc.

D. B. Holliday
Westinghouse Marine Division

P. W. Holsberg
U. S. Department of the Navy

D. Medley
Wisconsin Centrifugal Casting

T. Mertes
Ampco Metal, Inc.

D. Peters
Copper Development Association

M. N. Rogers
Batesville Casket Company, Inc.

J. Turriff
Ampco Metal, Inc.

K. G. Wold
Siemens Power Corporation

WELDING HANDBOOK COMMITTEE MEMBER:
R. M. Walkosak
Westinghouse Electric Corporation

COPPER AND COPPER ALLOYS

INTRODUCTION

COPPER AND MANY of its alloys have a face-centered cubic lattice that accounts for its good formability and malleability. In pure form, copper has a density of 0.32 lb/in.^{3} (8.94 Mg/m^3), about three times that of aluminum. Electrical and thermal conductivity of copper is slightly lower than silver, but about one and one-half times that of aluminum. Copper and copper alloys are used for their electrical and thermal conductivity, corrosion resistance, metal-to-metal wear resistance, and distinctive aesthetic appearance.

The greatest single use of copper results from its high electrical conductivity. Copper is widely used for electrical conductors and for the manufacture of electrical equipment. Copper is the electrical conductivity standard of the engineering world with the rating of 100% IACS (International Annealed Copper Standard). The electrical conductivity of all materials are compared to the IACS standard. Some specially processed copper forms can reach 102% IACS.

Copper is resistant to oxidation, fresh and salt water, alkaline solutions and many organic chemicals. This good corrosion resistance makes copper alloys ideally suited for water tubing, valves, fittings, heat exchangers, chemical equipment, and bearings. Copper reacts with sulfur and ammonia compounds. Ammonium hydroxide solutions attack copper and copper alloys rapidly.

The pleasing color, relatively good strength, and good formability make copper and copper alloys highly favored for architectural applications such as decorative furnishings and roofing.

Copper and most copper alloys can be joined by welding, brazing, and soldering. These joining processes and applications are explained in this chapter. This chapter also describes the major classes of copper alloys, their metallurgy and processing, and how alloying elements affect their joining characteristics. Various sections of the chapter are identified with specific alloy groups. Readers interested in specific alloys may wish to skip to those sections.

ALLOYS

METALLURGY

MANY COMMON METALS are alloyed with copper, mostly within the limits of solid solution solubility. The principal alloying elements in copper alloys are aluminum, nickel, silicon, tin, and zinc. Small quantities of other elements also are added to improve mechanical properties, corrosion resistance, or machinability; to provide response to strengthening heat treatments; or to deoxidize the alloy.

CLASSIFICATION

COPPER AND COPPER alloys are classified into nine major groups:

(1) Coppers – 99.3% Cu minimum
(2) High-copper alloys – up to 5% alloying element
(3) Copper-zinc alloys (brass)
(4) Copper-tin alloys (phosphor bronze)
(5) Copper-aluminum alloys (aluminum bronze)
(6) Copper-silicon alloys (silicon bronze)
(7) Copper-nickel alloys
(8) Copper-nickel-zinc alloys (nickel-silvers)
(9) Special alloys

These alloys are further divided into the wrought and cast alloy categories shown in Table 3.1. The Unified Numbering System (UNS) has a five-digit number. Copper alloys C1xxxx to C7xxxx are wrought alloys, and C8xxxx to C9xxxx are cast alloys. Therefore, an alloy manufactured in both a wrought form and cast form can have two numbers depending upon method of manufacture. Copper and copper alloys have common names such as oxygen-free copper, beryllium copper, Muntz metal, phosphor bronze, and low-fuming bronze. These common or trade names are being replaced with UNS numbers.

Physical properties of copper alloys important to welding, brazing, and soldering include melting temperature range, coefficient of thermal expansion, and electrical and thermal conductivity. Physical properties for some of the most widely used copper alloys are listed in Table 3.2. The table data show that when alloying elements are added to copper, electrical and thermal conductivity decreases drastically. The electrical and thermal conductivity of an alloy will significantly affect the welding procedures used for the alloy.

Small additions of some elements (e.g., iron, silicon, tin, arsenic, and antimony) improve the corrosion and erosion resistance of copper alloys. Lead, selenium, and tellurium are added to copper alloys to improve machinability. Bismuth is beginning to be used for this purpose when lead-free alloys are desired.

Boron, phosphorus, silicon, and lithium are added to copper as deoxidizers during melting and refining. Silver and cadmium increase the softening temperature of copper. Cadmium, cobalt, zirconium, chromium, and beryllium additions to copper form precipitation hardening alloys that increase the strength of copper.

Many commercial copper alloys are single-phase solid solutions. Some copper alloys have two or more microstructural phases. These alloys can be hardened by precipitation of intermetallic compounds or by quenching from above the critical transformation temperature, which results in a martensitic transformation.

Solid-solution copper alloys are generally easily cold worked, although the force to cold work and the rate of work hardening increases with alloy content. Two-phase alloys harden more rapidly during cold working but usually have better hot-working characteristics than do solid solutions of the same alloy system. Ductility decreases and yield strength increases as the proportion of the second phase increases.

MAJOR ALLOYING ELEMENTS

Aluminum

THE COPPER-ALUMINUM ALLOYS may contain up to 15 percent aluminum as well as additions of iron, nickel, tin, and manganese. The solubility of aluminum in copper is 7.8 percent, although this is slightly increased with the usual addition of iron. Alloys with less than 8 percent aluminum are single-phase, with or without iron additions. When the aluminum is between 9 and 15 percent, the system is two-phase and capable of either a martensitic or a eutectoid type of transformation. Increasing amounts of aluminum increase tensile strength, increase yield strength and hardness, and decrease elongation of the alloy. Aluminum forms a refractory oxide that must be removed during welding, brazing, or soldering.

Arsenic

ARSENIC IS ADDED to copper alloys to inhibit dezincification corrosion of copper-zinc alloys in water. Arsenic additions to copper alloys do not cause welding problems unless the alloy also contains nickel. Arsenic is detrimental to the welding of copper alloys that contain nickel.

Beryllium

THE SOLUBILITY OF beryllium in copper is approximately 2 percent at 1600°F (871°C) and only 0.3 percent at room temperature. Therefore, beryllium easily forms a supersaturated solution with copper that will precipitate in an age-hardening treatment. Because thermal conductivity and melting point decrease with increasing beryllium content, the higher beryllium content alloys are more easily welded. Beryllium forms a refractory oxide that must be removed for welding, brazing, or soldering.

Boron

BORON STRENGTHENS AND deoxidizes copper. Boron deoxidized copper is weldable with matching filler metals, and other coppers are weldable with boron-containing filler metals.

Table 3.1
Classification of Copper and Copper Alloys

Category	Description	Range of UNS Numbers[a]
	Wrought alloys[b]	
Copper	Copper-99.3 percent minimum	C10100-C15760
High-copper alloys	Copper-96 to 99.2 percent	C16200-C19750
Brasses	Copper-zinc alloys	C20500-C28580
Leaded brasses	Copper-zinc-lead alloys	C31200-C38590
Tin brasses	Copper-zinc-tin alloys	C40400-C49080
Phosphor bronzes	Copper-tin alloys	C50100-C52400
Leaded phosphor bronzes	Copper-tin-lead-alloys	C53200-C54800
Aluminum bronzes	Copper-aluminum alloys	C60600-C64400
Silicon bronzes	Copper-silicon alloys	C64700-C66100
Miscellaneous brasses	Copper-zinc alloys	C66400-C69950
Copper-nickels	Nickel-3 to 30 percent	C70100-C72950
Nickel-silvers	Copper-nickel-zinc alloys	C73150-C79900
	Cast alloys[c]	
Coppers	Copper-99.3 percent minimum	C80100-C81200
High-copper alloys	Copper-94 to 99.2 percent	C81300-C82800
Red brasses	Copper-tin-zinc and copper-tin-zinc-lead alloys	C83300-C83810
Semi-red brasses		C84200-C84800
Yellow brasses		C85200-C85800
Manganese bronze	Copper-zinc-iron alloys	C86100-C86800
Silicon bronzes and silicon brasses	Copper-zinc-silicon alloys	C87300-C87900
Tin bronzes	Copper-tin alloys	C90200-C91700
Leaded tin bronzes	Copper-tin-lead alloys	C92200-C94500
Nickel-tin bronzes	Copper-tin-nickel alloys	C94700-C94900
Aluminum bronzes	Copper-aluminum-iron and copper-aluminum-iron-nickel alloys	C95200-C95900
Copper-nickels	Copper-nickel-iron alloys	C96200-C96900
Nickel-silvers	Copper-nickel-zinc alloys	C97300-C97800
Leaded coppers	Copper-lead alloys	C98200-C98840
Special alloys		C99300-C99750

a. Refer to ASTM/SAE Publication DS-56/HS 1086, *Metals and Alloys in the Unified Numbering System,* 6th Ed., 1993. ASTM, Philadelphia, Pa., and Society of Automotive Engineers, Warrendale, Pa.

b. For composition and properties, refer to *Standards Handbook, Part 2-Alloy Data, Wrought Copper and Copper Alloy Mill Products,* 8th Ed., New York: Copper Development Association, Inc., 1985.

c. For composition and properties, refer to *Standards Handbook, Part 7-Data/Specifications, Cast Copper and Copper Alloy Products,* New York: Copper Development Association, Inc., 1970.

Cadmium

THE SOLUBILITY OF cadmium in copper is approximately 0.5 percent at room temperature. The presence of cadmium in copper up to 1.25 percent causes no serious difficulty in fusion welding because it evaporates from copper rather easily at the welding temperature. A small amount of cadmium oxide may form in the molten metal, but it can be fluxed without difficulty. Cadmium-copper rod is Resistance Welding Manufacturers Association Class 1 alloy. The small amount of cadmium strengthens pure copper while maintaining a very high conductivity. This combination of properties makes this material ideal for electrodes used for resistance welding high-conductivity alloys such as aluminum. Cadmium-alloyed copper has been largely replaced by an overaged chromium-copper because of federal restrictions regarding the use of heavy metals in manufacturing.

Chromium

THE SOLUBILITY OF chromium in copper is approximately 0.55 percent at 1900 °F (1038 °C) and less than 0.05 percent at room temperature. The phase that forms during age hardening is almost pure chromium. Chromium coppers can develop a combination of high strength and good conductivity. Like aluminum and

Table 3.2
Physical Properties of Typical Wrought Copper Alloys

Alloy	UNS No.	Melting Range		Coefficient of Thermal Expansion at 68-572 °F (20-300 °C)		Thermal Conductivity at 68 °F (20 °C)		Electrical Conductivity, % IACS
		°F	°C	µin./(in.•°F)	µm/(m•K)	Btu/(ft•h•°F)	W/(m•K)	
Oxygen-free copper	C10200	1948-1991	1066-1088	9.8	17.6	214	370	101
Beryllium-copper	C17200	1590-1800	866-982	9.9	17.8	62-75	107-130	22
Commercial bronze	C22000	1870-1910	1021-1043	10.2	18.4	109	188	44
Red brass	C23000	1810-1880	988-1027	10.4	18.7	92	159	37
Cartridge brass	C26000	1680-1750	916-955	11.1	20.0	70	121	28
Phosphor bronze	C51000	1750-1920	955-1049	9.9	17.8	40	69	15
Phosphor bronze	C52400	1550-1830	843-999	10.2	18.4	29	50	11
Aluminum bronze	C61400	1905-1915	1041-1046	9.0	16.2	39	67	14
High-silicon bronze	C65500	1780-1880	971-1027	10.0	18.0	21	36	7
Manganese bronze	C67500	1590-1630	866-888	11.8	21.2	61	105	24
Copper-nickel, 10%	C70600	2010-2100	1099-1149	9.5	17.1	22	38	9
Copper-nickel, 30%	C71500	2140-2260	1171-1238	9.0	16.2	17	29	4.6
Nickel-silver, 65-15	C75200	1960-2030	1071-1110	9.0	16.2	19	33	6

beryllium, chromium can form a refractory oxide on the molten weld pool that makes oxyfuel gas welding difficult unless special fluxes are used. Arc welding should be done using a protective atmosphere over the molten weld pool.

Iron

THE SOLUBILITY OF iron in copper is approximately 3 percent at 1900 °F (1038 °C) and less than 0.1 percent at room temperature. Iron is added to aluminum bronze, manganese bronze, and copper-nickel alloys to increase their strength by solid solution and precipitation hardening. Iron increases the erosion and corrosion resistance of copper-nickel alloys. Iron must be kept in solid solution or in the form of an intermetallic to obtain the desired corrosion resistance benefit, particularly in copper-nickel alloys. Iron also acts as a grain refiner. Iron has little effect on weldability when used within the alloy specification limits.

Lead

LEAD IS ADDED to copper alloys to improve machinability or bearing properties and the pressure tightness of some cast copper alloys. Lead does not form a solid solution with copper and is almost completely insoluble (0.06 percent) in copper at room temperature. Lead is present as pure, discrete particles and is still liquid at 620 °F (327 °C). Leaded copper alloys are hot-short and susceptible to cracking during fusion welding. Lead is the most harmful element with respect to the weldability of copper alloys.

Manganese

MANGANESE IS HIGHLY soluble in copper. It is used in proportions of 0.05 to 3.0 percent in manganese bronze, deoxidized copper, and copper-silicon alloys. Manganese additions are not detrimental to the weldability of copper alloys. Manganese improves the hot working characteristics of multiphase copper alloys.

Nickel

COPPER AND NICKEL are completely solid soluble in all proportions. Although copper-nickel alloys are readily welded, residual elements may lead to embrittlement and hot cracking. There must be sufficient deoxidizer or desulfurizer in the welding filler metal used for copper-nickel to provide a residual amount in the solidified weld metal. Manganese is most often used for this purpose.

Phosphorus

PHOSPHORUS IS USED as a strengthener and deoxidizer in certain coppers and copper alloys. Phosphorus is soluble in copper up to 1.7 percent at the eutectic temperature of 1200 °F (649 °C), and approximately 0.4 percent at room temperature. When added to copper-zinc alloys, phosphorus inhibits dezincification. The amount of phosphorus that is usually present in copper alloys has no effect on weldability.

Silicon

THE SOLUBILITY OF silicon in copper is 5.3 percent at 1500 °F (816 °C) and 3.6 percent at room temperature. Silicon is used both as a deoxidizer and as an alloying element to improve strength, malleability, and ductility. Copper-silicon alloys have good weldability, but are hot-short at elevated temperatures. In welding, the cooling rate through this hot-short temperature range should be fast to prevent cracking.

Silicon oxide forms on copper-silicon alloys at temperatures as low as 400 °F (204 °C). This oxide will interfere with brazing and soldering operations unless a suitable flux is applied prior to heating.

Tin

THE SOLUBILITY OF tin in copper increases rapidly with temperature. At 1450 °F (788 °C), the solubility of tin is 13.5 percent; at room temperature, it is probably less than 1 percent. Alloys containing less than 2 percent tin may be single-phase when cooled rapidly.

Copper-tin alloys tend to be hot-short and to crack during fusion welding. Tin oxidizes when exposed to the atmosphere, and this oxide may reduce weld strength if trapped within the weld metal.

Zinc

ZINC IS THE most important alloying element used commercially with copper. Zinc is soluble in copper up to 32.5 percent at 1700 °F (927 °C) and 37 percent at room temperature. A characteristic of all copper-zinc alloys is the relative ease that zinc will volatilize from the molten metal with very slight superheat.

Zinc is also a residual element in aluminum bronze and copper-nickel and may cause porosity or cracking, or both.

MINOR ALLOYING ELEMENTS

CALCIUM, MAGNESIUM, LITHIUM, sodium, or combinations of these elements are added to copper alloys as deoxidizers. Very little of these oxidizing elements remain in copper alloys and are seldom a factor in welding.

Antimony, arsenic, phosphorus, bismuth, selenium, sulfur, and tellurium may cause hot cracking when alloyed in single-phase aluminum bronze and in copper-nickel alloys. The small amounts of antimony added to brasses have little influence on their weldability.

Carbon is practically insoluble in copper alloys unless large amounts of iron, manganese, or other strong carbide formers are present. Carbon embrittles copper alloys by precipitating in the grain boundaries as graphite or as an intermetallic carbide.

EFFECTS OF ALLOYING ELEMENTS ON JOINING

THE HIGH ELECTRICAL and thermal conductivity of copper and certain high-copper alloys has a marked effect on weldability. Welding heat is rapidly conducted into the base metal and may promote incomplete fusion in weldments. Preheating of copper alloys will reduce welding heat input requirements necessary for good fusion.

Copper alloys are often hardened by mechanical cold working, and any application of heat tends to soften them. The heat-affected zone (HAZ) of these weldments will be softer and weaker than the adjacent base metal. The HAZ tends to hot crack in severely cold-worked metal. In practice, there is a time-temperature reaction, so that a minimum preheat and interpass temperature control can keep the softening of the HAZ to a minimum.

Precipitation hardening in copper alloys is obtained when copper is alloyed with beryllium, chromium, boron, nickel-silicon, and zirconium. Alloys with these elements are classified as precipitation hardening.

For optimum results, components to be precipitation hardened should be welded in the annealed condition, followed by the precipitation hardening heat treatment. Welding, brazing, or soldering precipitation-hardened alloys may result in reduction of mechanical properties due to overaging.

Copper alloys with wide liquidus-to-solidus temperature ranges, such as copper-tin and copper-nickel, are susceptible to hot cracking. Because low-melting interdendritic liquid solidifies at a lower temperature than the bulk dendrite, shrinkage stresses may produce interdendritic separation during solidification. Hot cracking can be minimized by the following:

(1) Reducing restraint during welding
(2) Minimizing heat input and interpass temperature
(3) Reducing the size of the root opening and increasing the size of the root pass

Certain elements such as zinc, cadmium, and phosphorus have low boiling points. Vaporization of these elements during welding may result in porosity. Porosity can be minimized by increasing travel speed and using filler metal having low percentages of these volatile elements.

Surface oxides on aluminum bronze, beryllium copper, chromium copper, and silicon bronze are difficult to remove and can present problems when welding, brazing, or soldering. Surfaces to be joined must be clean, and special fluxing or shielding methods must be used to prevent surface oxides from reforming during the joining operation.

COPPER AND HIGH-COPPER ALLOYS

Oxygen-Free Copper

OXYGEN-FREE COPPERS (UNS Nos. C10100 to C10800) contain a maximum of 10 ppm oxygen and a minimum of 0.01 percent total of other elements. Oxygen-free copper is produced by melting and casting under a reducing atmosphere that prevents oxygen contamination. No deoxidizing agent is introduced in production of this type of copper, but oxygen can be absorbed from the atmosphere during heating at high temperatures. Absorbed oxygen can cause problems during subsequent welding or brazing of the copper.

Oxygen-free copper has mechanical properties similar to those of oxygen-bearing copper, but the microstructure is more uniform. Oxygen-free copper has excellent ductility and is readily joined by welding, brazing, and soldering. Silver may be added to oxygen-free copper to increase the elevated temperature strength without changing the electrical conductivity. The addition of silver prevents appreciable softening of cold-worked copper during short-term elevated temperature exposure. Silver increases the allowable creep stress or provides resistance to creep rupture over long time periods. The silver addition does not effect the joining characteristics.

Oxygen-Bearing Copper

OXYGEN-BEARING COPPERS include the electrolytic tough-pitch grades (UNS Nos. C11000-C11900) and fire-refined grades (UNS Nos. C12500-C13000).

Fire-refined coppers contain varying amounts of impurities including antimony, arsenic, bismuth and lead. Electrolytic tough-pitch coppers contain minimal impurities and have more uniform mechanical properties. The residual oxygen content of electrolytic tough-pitch and fire-refined copper is about the same. Impurities and residual oxygen may cause porosity and other discontinuities when these coppers are welded or brazed.

A copper-cuprous oxide eutectic is distributed as globules throughout wrought forms of oxygen-bearing copper. Though this condition does not effect mechanical properties or electrical and thermal conductivity, it makes the copper susceptible to embrittlement when heated in the presence of hydrogen. Hydrogen diffuses rapidly into the hot metal, reduces the oxides, and forms steam at the grain boundaries. The metal will rupture when stressed.

When oxygen-bearing coppers are heated to high temperatures, the copper oxide tends to concentrate in the grain boundaries causing major reduction in strength and ductility. Fusion welding of oxygen bearing copper for structural applications is not recommended. Embrittlement will be less severe with a rapid solid-state welding process such as friction welding. Appropriate silver brazing procedures and soft soldering can be successfully used to join oxygen-bearing copper.

Phosphorus-Deoxidized Copper

PHOSPHORUS-DEOXIDIZED COPPER (UNS Nos. C12000 and C12300) has 0.004 to 0.065 percent residual phosphorus. The electrical conductivity of these coppers decreases in proportion to the residual phosphorus. When the phosphorus content is 0.009, electrical conductivity is about 100% IACS. Electrical conductivity is about 85% IACS, for a phosphorus content of 0.02, and electrical conductivity is about 75% IACS for a phosphorus content of 0.04.

Free-Machining Copper

FREE-MACHINING COPPERS HAVE UNS Nos. C14500 through C14710 and contain additions of lead, tellurium, and selenium. Copper has very low solid-solution solubility for these elements. Lead disperses throughout the matrix as fine, discrete particles, while tellurium and sulfur form hard stringers in the matrix. These inclusions reduce the ductility of copper but enhance its machinability. Fusion welding is not recommended for free-machining coppers because these alloys are hot-short and very susceptible to cracking. Free-machining coppers are joined by brazing and soldering.

Precipitation-Hardenable Copper Alloys

PRECIPITATION-HARDENABLE COPPER ALLOYS have UNS Nos. C15000, C15100, C17000-C18400, and C64700-C64730. Small amounts of beryllium, chromium, or zirconium can be added to copper to form alloys that respond to precipitation hardening heat treatment to increase mechanical properties. These copper alloys are solution annealed (to a soft condition about RB 50) by heating to an elevated temperature that puts the alloying elements into solution. Rapid cooling by water quenching keeps the alloying elements in solid solution. The parts are then aged at temperatures of 600 to 900 °F (316 to 482 °C). During aging, a second phase precipitates within the matrix that inhibits plastic deformation, resulting in greatly enhanced mechanical properties. The solution annealed alloy can be cold worked prior to aging to achieve higher strength. Exposing precipitation-hardened alloys to welding or brazing temperatures will overage the exposed area. Overaging softens and results in lower mechanical properties. Mechanical property degradation is dependent upon the temperature and time at temperature. Welding may only overage the HAZ, but brazing may overage the entire part.

COPPER-ZINC ALLOYS (BRASS)

COPPER ALLOYS IN which zinc is the major alloying element are generally called *brasses* (UNS Nos. C20500-C49080, C66400-C69950, C83300-C86800). Some copper-zinc alloys have other common or trade names, such as commercial bronze, Muntz metal, manganese bronze, and low-fuming bronze. Other elements are occasionally added to brasses to enhance particular mechanical or corrosion characteristics. Additions of manganese, tin, iron, silicon, nickel, lead, or aluminum, either singly or collectively, rarely exceed 4 percent. Some of these special brasses are identified by the name of the second alloying element; two examples are aluminum brass and tin brass.

Addition of zinc to copper decreases the melting temperature, the density, the electrical and thermal conductivity, and the modulus of elasticity. Zinc additions increase the strength, hardness, ductility, and coefficient of thermal expansion. Hot-working properties of brass decrease with increasing zinc content up to about 20 percent.

The color of brass changes with increasing zinc content from reddish to gold to a light gold and finally to yellow. Selection of a welding filler metal may depend on matching the brass color when joint appearance is important.

Most brasses are single-phase, solid-solution copper-zinc alloys with good room-temperature ductility. Brasses containing about 36 percent or more zinc have two microstructural phases designated *alpha* and *beta*. The beta phase improves the hot-working characteristics of brass, but has little effect on electrical and thermal conductivity.

For joining considerations, brasses may be divided into three groups:

(1) Low-zinc brasses (zinc content 20 percent maximum) have good weldability.

(2) High-zinc brasses (zinc content greater than 20 percent) have only fair weldability.

(3) Leaded brasses are considered unweldable, but they can be brazed and soldered satisfactorily.

The cast brasses contain from 2 percent to 41 percent zinc (UNS Nos. C83300-C85800) but often have one or more additional alloying elements, including tin, lead, nickel, and phosphorus. Cast alloys are generally not as homogeneous as the wrought products. In addition to welding complications caused by lead and other alloy elements, the variation in microstructure may cause difficulty. Cast alloys without lead are only marginally weldable, and leaded brasses are generally unweldable.

Manganese bronzes (UNS Nos. C86100-C86800) are actually high tensile brasses that contain 22 to 38 percent zinc with varying amounts of manganese, aluminum, iron, and nickel. Manganese bronze is weldable provided that lead content is low. Gas shielded arc welding methods are recommended. Manganese bronzes can be brazed and soldered with special fluxes.

COPPER-TIN ALLOYS (PHOSPHOR BRONZE)

ALLOYS OF COPPER and tin contain between 1 percent and 10 percent tin. These alloys are known as *phosphor bronzes* because 0.03 to 0.04 percent phosphorus is added during casting as a deoxidizing agent. The wrought alloys have UNS Nos. C50100-C52400. The cast copper-tin alloys (UNS Nos. C90200-C91700) are similar in nature to the wrought alloys but often have additions of zinc or nickel and contain high amounts of tin, up to 20 percent. There are also leaded copper-tin alloys (UNS Nos. C92200-C94500).

In the completely homogenized condition, these alloys are single-phase alloys with a structure similar to alpha brass. The alloys with a tin content over 5 percent are difficult to cast without dendritic segregation and the formation of a beta phase. During cooling, this beta phase gives rise to a delta phase, which can be embrittling.

In the wrought form, copper-tin alloys are tough, hard and highly fatigue-resistant, particularly in the cold-worked condition. The phase diagram predicts the precipitation of a copper-tin compound at room temperature. However, this is not observed. Some very fine precipitation may occur during cold working and this would explain the very high strengths achieved in wrought material. Electrical and thermal conductivities are low for the low-tin-content alloys and very low for those with high-tin content.

Copper-tin alloys have a narrow plastic range and must be hot worked at temperatures from 1150 to 1250 °F (621 to 677 °C). Low-tin alloys (under 4 percent) have the best hot-working properties.

All of the copper-tin alloys have good cold-working properties and high strength and hardness in the hard-rolled tempers. After cold working, these alloys can be rendered soft and malleable by annealing at temperature between 900 and 1400 °F (482 and 760 °C), depending on the properties desired. In a stressed condition, these alloys are subject to hot cracking. The use of high preheat temperatures, high-heat input, and slow cooling rates should be avoided.

Leaded copper-tin alloys (UNS Nos. C53400 and C54400) contain 2.0 to 6.0 percent lead to improve machinability. Welding of these alloys is not recommended. However, welds can be made in some alloys. Leaded copper-tin alloys are often two-phase structures, have a wide freezing range, and may be severely cored unless homogenized. Weldability decreases as lead content increases. Leaded copper-tin alloys can be welded with care by the shielded metal arc welding (SMAW) process. Inert gas welding processes are not recommended because welds will contain porosity. These alloys may be brazed and soldered if not strained while in the hot-short range.

Arc welding of cast leaded copper-tin alloys (C92200-C94500) is not recommended; but these alloys can be brazed and soldered with care.

COPPER-ALUMINUM ALLOYS (ALUMINUM BRONZE)

COPPER-ALUMINUM ALLOYS called *aluminum bronzes* (UNS Nos. C60600-C64400, C95200-C95900), contain from 3 to 15 percent aluminum, with or without varying amounts of iron, nickel, manganese, and silicon. There are two types of aluminum bronzes, and the types are based on metallurgical structure and response to heat treatment. The first type includes the alpha or single-phase alloys (less than 7 percent aluminum) that cannot be hardened by heat treatment. The second type includes the two-phase, alpha-beta alloys. Both types have low electrical and thermal conductivity that enhances weldability.

The alpha aluminum bronzes are readily weldable without preheating. Aluminum bronzes with an aluminum content below approximately 8.5 percent have a tendency to be hot-short, and cracking may occur in the HAZ of highly stressed weldments.

The single-phase alloy welded with an electrode that straddles the aluminum solubility limit results in the weldment being two-phase at elevated temperature but has a lower alpha-beta content at room temperature. The resulting weldment has better hot-working characteristics at elevated temperatures and sufficient strength at room temperature to match the single-phase (alpha) base metal. Low residual-element content in UNS No. C61300 improves most welding properties.

Generally, aluminum bronzes containing from 9.5 to 11.5 percent aluminum have both alpha and beta phases in their microstructures. These two-phase alloys can be strengthened by heat treatment to produce a martensitic-type structure and tempered to obtain desired mechanical properties. Microstructures after heat treatment are analogous in many respects to those found in steels. Hardening is accomplished by quenching in water or oil from 1550 to 1850 °F (843 to 1010 °C), followed by tempering at of 800 to 1200 °F (427 to 649 °C). The specific heat treatment depends upon the composition of the alloy and the desired mechanical properties.

Two-phase alloys have very high tensile strengths compared to most other copper alloys. As the aluminum content of these alloys increases, ductility decreases and hardness increases. Alpha-beta alloys have a plastic range wider than the alpha alloys, and this contributes to their good weldability.

Aluminum bronzes resist oxidation and scaling at elevated temperatures due to the formation of aluminum oxide on the surface. All aluminum oxide must be removed before welding, brazing, or soldering.

The single-phase aluminum bronzes (UNS Nos. C60600, C61300, C61400) are produced as wrought alloys only, although the single-phase nickel aluminum bronzes (UNS Nos. C63200-C95800) are produced both as castings and wrought products. Duplex aluminum bronzes are produced both cast and wrought and have similar characteristics. The complex aluminum bronzes are temper annealed to resist dealuminification in a sea water environment and, unless welding is of a very minor nature, the part should be retempered or annealed after welding.

Nickel-aluminum bronzes contain from 8.5 to 11 percent aluminum and from 3 to 5 percent nickel; both have alpha and kappa in the microstructure. Alloys with an aluminum content in the upper end of the range can contain the eutectoid phase, gamma 2 (γ_2), when cooled slowly from elevated temperature. A temper anneal at 1150 to 1225 °F (620 to 663 °C), followed by a rapid air cool is recommended for alloys exposed to corrosive environments.

Nickel-aluminum bronze is susceptible to cracking when welded. Therefore, procedures for welding heavy sections recommend the use of a nickel-free filler metal (ECuAl-A2, ERCuAl-A2) to fill the joint because of its greater ductility. ECuAl-A2 or ERCuAl-A2 filler metal is recommended for the root pass and for all but the last two or three cover passes. The final two or three passes are made with a nickel- aluminum bronze filler metal (ECuNiAl, ERCuNiAl). If there is any possibility of the ECuAl-A2 or ERCuAl-A2 weld metal being exposed by subsequent drilling, machining, or similar process, this procedure should not be employed.

Nickel-aluminum bronze weldments should be temper annealed for service in corrosive environments.

COPPER-SILICON ALLOYS (SILICON BRONZE)

COPPER-SILICON ALLOYS (UNS No. C64700-C66100, C87300-C87900), known as silicon bronzes, are industrially important because of their high strength, excellent corrosion resistance, and good weldability. The wrought alloys (C64700-C66100) contain from 1.5 to 4 percent silicon and 1.5 percent or less of zinc, tin, manganese or iron. With the exception of alloy C87300, the cast silicon bronze alloys have higher zinc levels (4 to 30 percent) to improve castability.

The addition of silicon to copper increases tensile strength, hardness, and work-hardening rates. The ductility of silicon bronze decreases with increasing silicon content up to about 1 percent. Ductility then increases to a maximum value at 4 percent silicon. Electrical and thermal conductivity decreases as the silicon content increases. Silicon bronzes should be stress relieved or annealed prior to welding, and should be slowly heated to the temperature desired. Silicon bronzes are hot-short at elevated temperatures and should be rapidly cooled through the critical temperature range.

Iron additions increase tensile strength and hardness. Zinc or tin additions improve the fluidity of molten bronze and improve the quality of castings and of welds made using oxyfuel gas welding.

COPPER-NICKEL ALLOYS

COMMERCIAL COPPER-NICKEL ALLOYS (UNS NOS. C70100-C72950, C96200-C96900) have nickel contents ranging from 5 to 45 percent. Copper-nickel alloys most commonly used in welded fabrication contain 10 and 30 percent nickel and minor alloying elements such as iron, manganese, or zinc. Resistance to erosion corrosion requires that any iron should be in solid solution. Thermal processing of the copper-nickel alloy must be done in a manner that does not cause precipitation of iron compounds.

The copper-nickel alloys have moderately high tensile strengths that increase with nickel content. These alloys are ductile and relatively tough, and they have a relatively low electrical and thermal conductivity.

Like nickel and some nickel alloys, the copper-nickel alloys are susceptible to lead or sulfur embrittlement. Phosphorus and sulfur levels in these alloys should be a maximum of 0.02 percent to ensure sound welds. Contamination from sulfur-bearing marking crayons or cutting lubricants are likely to cause cracking during welding.

Most copper-nickel alloys do not contain a deoxidizer, which means that fusion welding requires addition of deoxidized filler metal to avoid porosity.

Special compositions of some copper-nickel alloys that contain titanium can be obtained. These special alloys are recommended for autogenous welding of thin sheet.

Silicon is added to cast alloys for added fluidity during casting and for added strength of the cast structure.

COPPER-NICKEL-ZINC ALLOYS (NICKEL-SILVER)

NICKEL IS ADDED to copper-zinc alloys to make them silvery in appearance for decorative purposes and to increase their strength and corrosion resistance. The resulting copper-nickel-zinc alloys (UNS Nos. C73200-C79900, C97300-C97800) are called nickel-silvers. These alloys are of two general types:

(1) Single-phase alloys containing 65 percent copper plus nickel and zinc

(2) Two-phase (alpha-beta) alloys containing 55 to 60 percent copper plus nickel and zinc

The welding metallurgy of these alloys is similar to that of the brasses.

JOINING PROCESS SELECTION

COPPER AND COPPER alloys can be joined by welding, brazing, and soldering processes. Table 3.3 summarizes the applicability of the most commonly used processes for major alloy classifications.

ARC WELDING

COPPER AND MOST copper alloys can be joined by arc welding. Welding processes that use gas shielding are generally preferred, although shielded metal arc welding (SMAW) can be used for many noncritical applications.

Argon, helium, or mixtures of the two are used as shielding gases for gas tungsten arc welding (GTAW), plasma arc welding (PAW), and gas metal arc welding (GMAW). In general, argon is used when manually welding material that is either less than 0.13 in. (3.3 mm) thick or has low thermal conductivity, or both.

Table 3.3
Applicable Joining Processes for Copper and Copper Alloys

Alloy	UNS No.	Oxyfuel Gas Welding	SMAW	GMAW	GTAW	Resistance Welding	Solid-State Welding	Brazing	Soldering	Electron Beam Welding
ETP Copper	C11000-C11900	NR	NR	F	F	NR	G	E	G	NR
Oxygen-Free Copper	C102000	F	NR	G	G	NR	E	E	E	G
Deoxidized Copper	C12000 C123000	G	NR	E	E	NR	E	E	E	G
Beryllium-Copper	C17000-C17500	NR	F	G	G	F	F	G	G	F
Cadmium/Chromium Copper	C16200 C18200	NR	NR	G	G	NR	F	G	G	F
Red Brass - 85%	C23000	F	NR	G	G	F	G	E	E	—
Low Brass - 80%	C24000	F	NR	G	G	G	G	E	E	—
Cartridge Brass - 70%	C26000	F	NR	F	F	G	G	E	E	—
Leaded Brasses	C31400-C38590	NR	NR	NR	NR	NR	NR	E	G	—
Phosphor Bronzes	C50100-C52400	F	F	G	G	G	G	E	E	—
Copper-Nickel - 30%	C71500	F	F	G	G	G	G	E	E	F
Copper-Nickel - 10%	C70600	F	G	E	E	G	G	E	E	G
Nickel-Silvers	C75200	G	NR	G	G	F	G	E	E	—
Aluminum Bronze	C61300 C61400	NR	G	E	E	G	G	F	NR	G
Silicon Bronzes	C65100 C65500	G	F	E	E	G	G	E	G	G

E = Excellent G = Good F = Fair NR = Not Recommended

Helium or a mixture of 75% helium-25% argon is recommended for machine welding of thin sections and for manual welding thicker sections or alloys having high thermal conductivity. Small additions of nitrogen or hydrogen to the argon shielding gas may be used to increase the effective heat input.

The SMAW process can be used to weld a range of thicknesses of copper alloys. Covered electrodes for SMAW of copper alloys are available in standard sizes ranging from 3/32 to 3/16 in. (2.4 mm to 4.8 mm). Other sizes are available in certain electrode classifications.[1]Submerged arc welding has been used for welding of copper alloys, although use of this process is not widespread.

Arc welding should be done in the flat position whenever practical. GTAW or SMAW is preferred for welding in positions other than flat, particularly in the overhead position. GMAW with pulsed power and small diameter electrodes is also suitable for the vertical and overhead positions with some copper alloys. Higher thermal conductivity and thermal expansion of copper and its alloys result in greater weld distortion than in comparable steel welds. The use of preheat, fixtures, proper welding sequence, and tack welds can minimize distortion or warping.

---

1. See ANSI/AWS A5.6, *Specification for Covered Copper and Copper Alloy Arc Welding Electrodes.*

OXYFUEL GAS WELDING

COPPER AND MANY copper alloys can be welded with the oxyfuel gas welding (OFW) process. The OFW process should only be used for small, noncritical applications, including repair welding. The relatively low heat input of the oxyacetylene flame makes welding slow compared to arc welding. Higher preheat temperatures or an auxiliary heat source may be required to counterbalance the low heat input, particularly with alloys with high thermal conductivity or with thick sections. Except for oxygen-free copper, a welding flux is required to exclude air from the weld metal at elevated temperatures.

LASER WELDING

LASER BEAM WELDING (LBW) of copper and its alloys has very limited applications. The primary difficulties with LBW of copper are the high reflectivity to the incident laser beam and the high thermal conductivity of copper and copper alloys. Copper reflects approximately 99 percent of the incident light energy of the far infrared wavelength of the CO_2 laser. This is the reason copper is commonly used for mirrors in CO_2 laser beam delivery systems. Reflectivity is temperature dependent; when a material gets hotter, the absorption of the incident light increases. However, the high thermal conductivity of copper prevents the metal from getting hotter, thereby maintaining high reflectivity.

Lasers with shorter wavelengths have successfully welded some copper alloys. Copper has slightly higher absorption of the incident light of Nd:YAG lasers with a wavelength of 1.06 µm. Plating copper with a thin layer of higher absorbing metal, such as nickel, has been demonstrated to improve coupling efficiency.

LBW is a fusion welding process so that the same considerations as other fusion processes apply. Higher cracking susceptibility may be encountered with copper alloys with wide liquidus-to-solidus temperature ranges due to the high solidification stresses resulting from the rapid cooling rates of LBW.

ELECTRON BEAM WELDING

COPPER AND ITS alloys can be readily joined by electron beam welding (EBW). The EBW process has been successfully applied for welding thin and thick gage copper alloys both in and out of vacuum. Filler metal can be added to a weld with an auxiliary wire feeder.

ULTRASONIC WELDING

COPPER-TO-COPPER ultrasonic welding is an attractive technique for microelectronic interconnections. Special care must be paid to joint preparation and cleaning or inconsistent joint quality will result.

RESISTANCE SPOT WELDING

THE EASE OF resistance spot welding (RSW) of copper and copper alloys varies inversely with their electrical and thermal conductivity. Many of the lower conductivity copper alloys are readily spot welded.

Spot welds can be made in sheet copper alloys having an electrical conductivity 30% IACS or less, including beryllium copper, many brasses and bronzes, nickel-silver, and copper-nickel alloys. Weld quality becomes less consistent as the electrical conductivity increases. Copper alloys with electrical conductivity over about 60 percent cannot be spot welded with conventional methods. Resistance spot welding of unalloyed copper is not practical.

RSW electrode forces for copper alloys are usually set to 50 to 70 percent of those used for the same thickness of steel. Welding current is higher and welding time is shorter than that used for steel. Tungsten or molybdenum-tipped RSW electrodes are preferred to minimize electrode sticking.

RESISTANCE SEAM WELDING

IT IS DIFFICULT to seam weld copper alloys because of excessive shunting of welding current, high thermal conductivity, and low electrode contact resistance. Seam welding is generally not practicable when the electrical conductivity exceeds 30 percent IACS. Copper alloys that can be spot welded can usually be seam welded.

FLASH WELDING

FLASH WELDING TECHNIQUES produce very good results on copper and copper alloys. The design of the equipment must provide accurate control of all factors, including upset pressure, platen travel, flash-off rate, current density, and flashing time.

Leaded copper alloys can be flash welded, but the integrity of the joint depends upon the alloy composition. Lead content of up to 1.0 percent is usually not detrimental.

Rapid upsetting at minimum pressure is necessary as soon as the abutting faces are molten because of the relatively low melting temperature and narrow plastic range of copper alloys. Low pressure is usually applied to the joint before the flashing current is initiated so that platen motion will begin immediately after flashing starts. Termination of flashing current is critical. Premature termination of current will result in lack of fusion at the weld interface. Excessive flashing will overheat the metal and result in improper upsetting.

FRICTION WELDING

ALTHOUGH LIMITED IN application, friction welding offers several advantages for joining copper and copper alloys. The heat-affected zone is very narrow, and the joint contains no cast metal microstructure. Joint properties are excellent.

The process can be used to join copper to itself, to copper alloys, and to other metals including aluminum, silver, carbon steel, stainless steel, and titanium.

HIGH-FREQUENCY WELDING

COPPER AND COPPER alloy tubing is frequently manufactured from strip in a tube mill using high-frequency resistance welding. The edges of the weld joint are resistance heated to welding temperature utilizing the skin effect with high-frequency current. The heated edges are forged together continuously in the tube mill to consummate a weld.

SOLID-STATE WELDING

COPPER CAN READILY be welded without melting using various combinations of temperatures, pressures, and deformations. Annealed copper can be cold welded at room temperature because of its excellent malleability. Copper tubing can be welded and pinched off using commercially available steel dies. Copper and copper alloys also can be diffusion welded and explosive welded.

BRAZING

COPPER AND ITS alloys are readily joined by brazing using an appropriate filler metal and flux or protective atmosphere. Any of the common heating methods can be used. Certain precautions are required with specific base metals to avoid embrittlement, cracking, or excessive alloying with the filler metal. Special fluxes are required with some alloys that form refractory surface oxides.

SOLDERING

COPPER AND MOST copper alloys are readily soldered with commercial solders. Most copper alloys are easily fluxed, except for those containing elements which form refractory oxides (e.g., beryllium, aluminum, silicon, or chromium). Special fluxes are required to remove refractory oxides that form on the surfaces of these alloys.

Soldering is primarily used for electrical connections, plumbing and other room-temperature applications. Joint strengths are much lower than those of brazed or welded joints.

WELDING

GENERAL CONSIDERATIONS

Filler Metals

COVERED ELECTRODES AND bare electrode wire and rods are available for welding copper and copper alloys to themselves and to other metals. These filler metals are included in the latest editions of: ANSI/AWS A5.6, *Specification for Covered Copper and Copper Alloy Arc Welding Electrodes*, and ANSI/AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes*. AWS classifications of filler metals for welding copper and copper alloys are listed in Table 3.4.

Copper Filler Metals. Bare copper electrodes and rods (ERCu) are generally produced with a minimum copper content of 98 percent. These electrodes and rods are used to weld deoxidized and electrolytic tough pitch copper with the gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW), and sometimes oxyfuel gas welding (OFW) processes. The electrical conductivity of ERCu electrodes is 25 to 40% IACS.

Covered electrodes (ECu) for shielded metal arc welding (SMAW) are designed for welding with direct current electrode positive (DCEP). The welding current is 30 to 40 percent higher than normally required for carbon steel electrodes of the same diameter.

Copper-Zinc (Brass) Filler Metals. Copper-zinc welding rods are available in the following classifications: RBCuZn-A (naval brass), RBCuZn-B (low-fuming brass), and RBCuZn-C (low-fuming brass). These welding rods are primarily used for OFW of brass and for braze welding copper, bronze, and nickel alloys. The RBCuZn-A welding rods contain 1 percent tin to improve corrosion resistance and strength. Electrical

Table 3.4
Filler Metals for Fusion Welding Copper Alloys

AWS Classification			
Covered Electrode[a]	Bare Wire[b]	Common Name	Base Metal Applications
ECu	ERCu	Copper	Coppers
ECuSi	ERCuSi-A	Silicon bronze	Silicon bronzes, brasses
ECuSn-A	ERCuSn-A	Phosphor bronze	Phosphor bronzes, brasses
ECuSn-C	ERCuSn-A	Phosphor bronze	Phosphor bronzes, brasses
ECuNi	ERCuNi	Copper-nickel	Copper-nickel alloys
ECuAl-A2	ERCuAl-A1	Aluminum bronze	Aluminum bronzes, brasses silicon bronzes, manganese bronzes
	ERCuAl-A2	—	
ECuAl-B	ERCuAl-A3	Aluminum bronze	Aluminum bronzes
ECuNiAl	ERCuNiAl	—	Nickel-aluminum bronzes
ECuMnNiAl	ERCuMnNiAl	—	Manganese-nickel-aluminum bronzes
	RBCuZn-A	Naval brass	Brasses, copper
	RBCuZn-B	Low-fuming brass	Brasses, manganese bronzes
	RBCuZn-C	Low-fuming brass	Brasses, manganese bronzes
	RBCuZn-D	—	Nickel-silver

a. See ANSI/AWS A5.6, *Specification for Covered Copper and Copper Alloy Arc Welding Electrodes.*

b. See ANSI/AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes,* and ANSI/AWS A5.8, *Specification for Filler Metals for Brazing and Braze Welding.*

conductivity of these rods is about 25% IACS, and the thermal conductivity is about 30 percent that of copper.

RBCuZn-B welding rods contain additions of manganese, iron, and nickel that increase hardness and strength. A small amount of silicon provides low-fuming characteristics. The RBCuZn-C welding rods are similar to RBCuZn-B rods in composition except that they do not contain nickel. The mechanical properties of as-deposited weld metal from both rods are similar to those of naval brass.

Copper-zinc filler metals cannot be used as electrodes for arc welding because of the high zinc content. The zinc vapor would volatilize from the molten weld pool, resulting in porous weld metal.

Copper-Tin (Phosphor Bronze) Filler Metals. Copper-tin, or phosphor bronze welding electrodes and rods include ECuSn-A, ERCuSn-A and ECuSn-C. The ECuSn-A composition contains about 5 percent tin, and the ECuSn-C composition has about 8 percent tin. Both electrodes are deoxidized with phosphorus. The electrodes can be used for welding bronze, brass, and also for copper if the presence of tin in the weld metal is not objectionable. These electrodes frequently are used for casting repairs. ERCuSn-A rods can be used with the GTAW process for joining phosphor bronze. The ECuSn-C electrodes provide weld metal with better strength and hardness than do ECuSn-A electrodes and are preferred for welding high-strength bronzes. Preheat and interpass temperature of about 400 °F (203 °C) is required when welding with these electrodes, especially for heavy sections.

Copper-Silicon (Silicon Bronze) Filler Metals. Copper-silicon (silicon bronze) electrodes are used in bare wire form (ERCuSi-A) for GMAW, for GTAW, and sometimes for OFW. Copper-silicon wires contain from 2.8 to 4.0 percent silicon with about 1.5 percent manganese, 1.0 percent tin, and 1.0 percent zinc. This filler wire is used for welding silicon bronzes and brasses as well as to braze weld galvanized steel. The tensile strength of copper-silicon weld metal is about twice that of ERCu weld metal. The electrical conductivity is about 6.5 percent IACS, and the thermal conductivity is about 8.4 percent of copper.

ECuSi covered electrodes are used primarily for welding copper-zinc alloys using direct current electrode positive. This electrode is occasionally used for welding silicon bronze, copper, and galvanized steel. The core wire of these covered electrodes contains about 3 percent silicon with small amounts of tin and manganese. The mechanical properties of the weld metal are usually slightly higher than those of copper-silicon base metal.

Copper-Aluminum (Aluminum Bronze). ERCuAl-A1 filler metal is an iron-free aluminum bronze. It is used as a surfacing alloy for wear-resistant surfaces having relatively light loads, for resistance to corrosive media such as salt and brackish water and for resistance to some commonly used acids. This alloy is not recommended for joining applications.

ECuAl-A2 covered electrodes for SMAW contain from 6.5 to 9 percent aluminum. ERCuAl-A2 bare wire electrodes for GTAW, GMAW and PAW contain from 8.5 to 11 percent aluminum. ERCuAl-A2 weld metal has a higher strength than the ECuAl-A2 weld metal. Both filler metals are used for joining aluminum bronze, silicon bronze, copper-nickel alloys, copper-zinc alloys, manganese bronze, and many combinations of dissimilar metals.

ECuAl-B covered electrodes contain 7.5 to 10 percent aluminum, and produce deposits with higher strength and hardness than the ERCuAl-A2 electrodes. These electrodes are used for surfacing applications and for repair welding of aluminum bronze castings of similar compositions.

ERCuAl-A3 electrodes and rods are used for repair welding of similar composition aluminum bronze castings using GMAW and GTAW processes. Their high aluminum content produces welds with less tendency to crack in highly stressed sections.

Copper-nickel-aluminum electrodes and bare-wire electrodes (ECuNiAl and ERCuNiAl) are used to join and repair both wrought and cast nickel aluminum bronze materials. These electrodes may be used for applications requiring good corrosion resistance and erosion or cavitation resistance in both salt and brackish water.

ECuMnNiAl covered electrodes and ERCuMnNiAl bare filler metal are used to join manganese-nickel-aluminum bronzes of similar compositions. These electrodes are used in applications requiring resistance to cavitation, erosion, and corrosion.

Copper-Nickel. Copper-nickel covered electrodes, (ECuNi) and bare electrode wire and rods (ERCuNi) are nominally 70 percent copper and 30 percent nickel. These filler metals contain titanium to deoxidize the weld pool and are used for welding all copper-nickel alloys.

Weld Joint Design

RECOMMENDED WELD JOINT designs for copper and copper alloys are shown in Figures 3.1 and 3.2. Figure 3.1 shows joint designs that are appropriate for GTAW and SMAW. Figure 3.2 shows joint designs for GMAW. These joint designs have larger groove angles than those used for steel. The larger groove angles are required to provide adequate fusion and penetration for copper alloys that have high thermal conductivity.

Surface Preparation

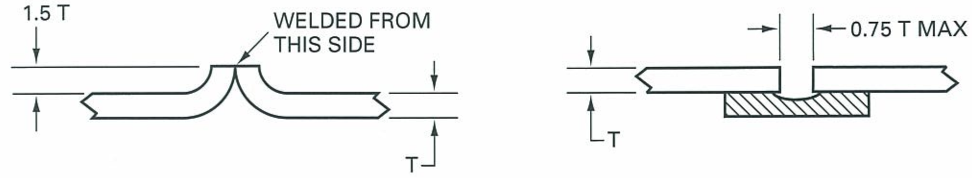
WELD JOINT FACES and adjacent surfaces should be clean and free of oil, grease, dirt, paint, and oxides prior to welding. Wire brushing is not a suitable cleaning method for copper alloys that develop a tenacious surface oxide, such as the aluminum bronzes. These alloys should be cleaned by appropriate chemical or abrasive methods. Degreasing is also recommended using a suitable solvent.

Preheating

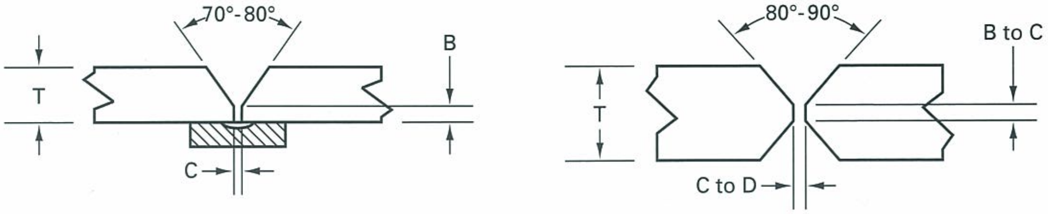
THE RELATIVELY HIGH thermal conductivity of copper and the high-copper alloys results in the rapid conduction of heat from the weld joint into the surrounding base metal. This makes achieving fusion and weld penetration difficult. Loss of heat from the weld area can be minimized using higher energy processes or higher welding currents. Preheating the base metal prior to welding is the most common method used to counteract the effects of thermal conduction.

Selection of a preheat temperature for a given application depends upon the welding process, the alloy being welded, the base metal thickness and to some extent the overall mass of the weldment. Thin sections or high-energy welding processes, such as electron beam or laser welding, generally require less preheat than do thick sections or low-energy welding processes. The use of the GMAW process normally requires lower preheat than GTAW or OFW. When welding conditions are similar, copper requires higher preheat temperatures than copper alloys because of high thermal conductivity. Aluminum-bronze and copper-nickel alloys should not be preheated. Suggested preheat temperatures are given in later tables for the particular alloy families and welding processes.

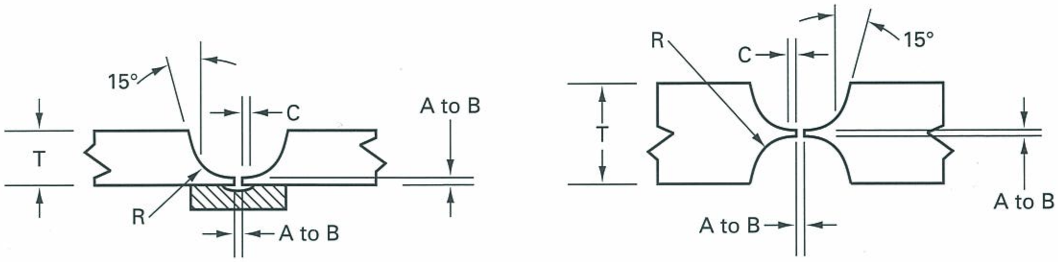
When preheat is used, the base metal adjacent to the joint must be heated uniformly to the specified temperature. The temperature should be maintained until



(A) Edge-Flange **(B) Square-Groove**



(C) Single-V-Groove **(D) Double-V-Groove**



(E) Single-U-Groove **(F) Double-U-Groove**

Note:
A = $^1/_{16}$ in. (1.6 mm), B = $^3/_{32}$ in. (2.4 mm), C = $^1/_8$ in. (3.2 mm), D = $^5/_{32}$ in. (4.0 mm),
R = $^1/_8$ in. (3.2 mm), T = thickness.

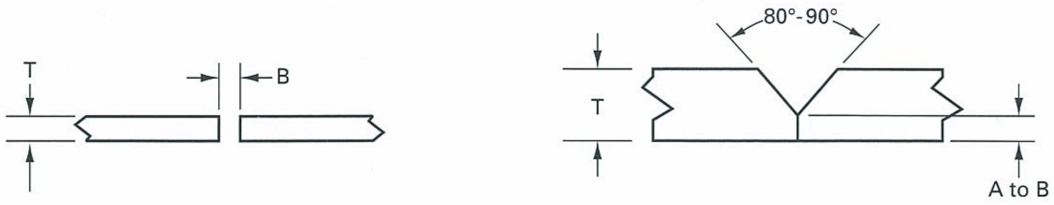
Figure 3.1—Joint Designs for Gas Tungsten Arc and Shielded Metal Arc Welding of Copper

welding of the joint is completed. When welding is interrupted, the joint area should be preheated before welding is resumed.

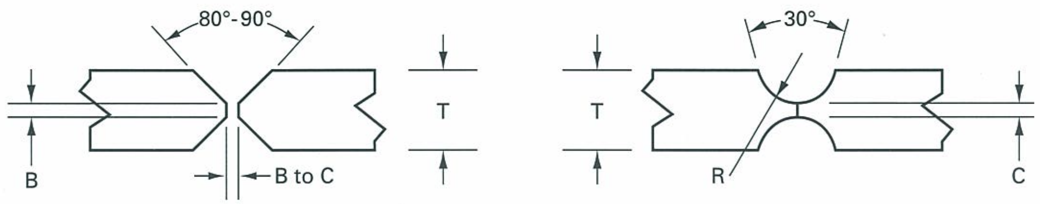
Postweld Heat Treatment

POSTWELD HEAT TREATMENT (PWHT) of copper and copper alloys may involve annealing, stress relieving, or precipitation hardening. The need for PWHT depends upon the base metal composition and the application of the weldment. PWHT may be required if the base metal can be strengthened by a heat treatment or if the service environment can cause stress-corrosion cracking.

Copper alloys that include the high-zinc brasses, manganese bronzes, nickel-manganese bronzes, some aluminum bronzes, and nickel-silvers are susceptible to stress-corrosion cracking. Stresses induced during welding of these alloys can lead to premature failure in certain corrosive environments. These alloys may be stress relieved or annealed after welding to reduce stresses. Copper alloys that respond to precipitation hardening include some high coppers, some copper-aluminum alloys, and copper-nickel castings containing beryllium or chromium. If these alloys are not heat-treated, the hardness in the weld area will vary as a result of aging or overaging caused by the welding heat.



(A) Square-Groove **(B) Single-V-Groove**



(C) Double-V-Groove **(D) Double-U-Groove**

Note:
A = 1/16 in. (1.6 mm), B = 3/32 in. (2.4 mm), C = 1/8 in. (3.2 mm), R = 1/4 in. (6.4 mm), T = thickness.

Figure 3.2—Joint Designs for Gas Metal Arc Welding of Copper

Stress Relief

STRESS RELIEF IS intended to reduce stresses from welding to relatively low values without effectively reducing mechanical properties. Stress relief is accomplished by heating the weldment to a temperature that is below the recrystallization temperature of the base metal. Typical stress relieving temperatures for some copper alloys are given in Table 3.5. Heating time must be adequate for the entire weldment to reach temperature. The weldment is usually held for at least one hour at the stress relief temperature and then slowly cooled. Weldments thicker than 1 in. (25.4 mm) must be held for longer periods, usually for 1 hour per in. (1 h per 25.4 mm) of thickness.

Annealing

ANNEALING IS USED to reduce stresses and to homogenize weldments of hardenable copper alloys to produce a metallurgical structure that will respond to heat treatment satisfactorily. Annealing is carried out

Table 3.5
Typical Stress Relieving Temperatures for Weldments of Copper Alloys

Common Name	UNS No.	Temperature* °F	Temperature* °C
Red brass	C23000	550	288
Admiralty brass	C44300-C44500	550	288
Naval brass	C46400-C46700	500	260
Aluminum bronze	C61400	650	343
Silicon bronze	C65500	650	343
Copper-nickel alloys	C70600-C71500	1000	538

* Heat slowly to and hold at temperature for at least one hour.

at temperatures considerably higher than those used for stress relieving, as shown in Table 3.6. Stress relaxation proceeds rapidly at the annealing temperature. Extended annealing times or annealing at the top of the temperature range can cause excessive grain growth that may reduce tensile strength and can cause other undesirable metallurgical effects.

Heat Treatment

HEAT TREATABLE COPPER alloys of greatest commercial use are those with UNS Nos. C17000, C17200, C17300, C17500, C17510, C18200, and C15000. These materials can be supplied in any form or condition the user requires. These heat treatable copper alloys are hardened by either of the following procedures:

(1) Solution anneal, then cold work, and then age harden.
(2) Solution anneal, then age harden from the solution anneal state without cold working.

For each heat treatable copper alloy, the solution anneal temperature and age hardening temperature vary depending upon alloy chemical composition.

When a heat treatable copper alloy has been welded or brazed, and to a lesser extent soldered, the mill supplied condition has been altered. To return the base metal, the heat-affected zone and the weld to approximately the mill supplied condition, it is necessary to heat treat the welded assembly. This involves solution annealing, followed by age hardening. It usually is not feasible to perform any cold work on a welded assembly after solution anneal.

Solution Annealing. The solution anneal for beryllium-copper UNS No. C17200 alloy (1.9 percent beryllium) is to heat the part to 1450 °F (788 °C). Depending on the thickness, the part is held at temperature for 30 minutes to 3 hours. Because beryllium-copper forms a tenacious and continuous oxide surface when heated in air or an oxidizing atmosphere, a slightly reducing atmosphere should be used to produce clean and bright parts after quenching.

The quenching is critical to avoid any precipitation of the beryllium intermetallic constituent. Rapid water quenching from the solution anneal temperature is the best method to insure retention in solid solution. For parts or castings that may crack, quenching in oil or forced air may be used but may result in some precipitation of beryllium intermetallic constituent.

Age Hardening. Solution annealed products are soft, having a hardness of 45 to 85 HRB. Weldments are seldom cold worked after the solution treatment. Hardening is accomplished by aging the part or welded assembly in a furnace at a temperature of 550 to 750 °F (290 to 400 °C) for about 3 hours. Again, to prevent oxidation, a slightly reducing atmosphere is preferred. After age hardening, the parts or assemblies may be returned to room temperature in any manner, i.e.,

Table 3.6
Annealing Temperature Ranges for Copper and Copper Alloys

Common name	UNS No.	Temperature Range* °F	Temperature Range* °C
Phosphor-deoxidized copper	C12200	700-1200	371-649
Beryllium-copper	C17000, C17200	1425-1475	774-802
Beryllium-copper	C17500	1675-1725	913-941
Red brass	C23000	800-1350	427-732
Yellow brass	C27000	800-1300	427-704
Muntz metal	C28000	800-1100	427-593
Admiralty	C44300-C44500	800-1100	427-593
Naval brass	C46400-C46700	800-1100	427-593
Phosphor bronze	C50500-C52400	900-1250	482-677
Aluminum bronze	C61400	1125-1650	607-899
Aluminum bronze	C62500	1100-1200	593-649
Silicon bronze	C65100, C65500	900-1300	482-704
Aluminum brass	C68700	800-1100	427-593
Copper-nickel, 10%	C70600	1100-1500	593-816
Copper-nickel, 30%	C71500	1200-1500	649-816
Nickel-silver	C74500	1100-1400	593-760

* Time at temperature - 15 to 30 min

furnace cooled, water quenched, or air quenched. The cooling method is usually immaterial.

UNS No. C17200 alloy, solution annealed and age hardened, will have a hardness of 35 to 40 HRC, depending on thickness.

Other Heat Treatable Copper Alloys. All beryllium-copper, chromium-copper, and zirconium-copper alloys may be heat treated in the manner described above for beryllium-copper alloy UNS No. C17200. Only the temperatures are adjusted to give optimum mechanical properties.

Fixturing

THE THERMAL COEFFICIENTS of expansion of copper and its alloys are about 1.5 times that of steel (see Table 3.2), so that distortion will be greater with copper alloys. Appropriate measures to control distortion and warping include suitable clamping fixtures, to position and restrain thin components, and frequent tack welds to align the joint for welding thick sections. The ends of the tack welds should be tapered to ensure good fusion with the first weld beads.

The root pass of multiple-pass welds should be rather large to avoid cracking. Fixturing and welding procedures must be designed to limit restraint of copper alloys that are likely to hot crack when highly restrained.

Backing strips or backing rings are used to control root penetration and fusion in groove welds. Copper and copper alloys that have the same or similar chemical composition as the base metal can be used for backing. Removable ceramic backing also may be suitable for use with copper and copper alloys.

Safe Practices

COPPER AND A number of alloying elements in copper alloys (arsenic, beryllium, cadmium, chromium, lead, manganese, and nickel) have low or very low permissible exposure limits as set by the American Conference of Governmental Industrial Hygienists. Special ventilation precautions are required when brazing, welding, soldering, or grinding copper or copper alloys to assure the level of contaminants in the atmosphere is below the limit allowed for human exposure. These precautions may include local exhaust ventilation, respiratory protection, or both. Refer to the latest edition of ANSI/AWS Z49.1, *Safety in Welding and Cutting*, for proper procedures.

Welding copper alloys containing appreciable amounts of beryllium, cadmium, or chromium may present health hazards to welders and others. Where copper alloys containing these elements are welded on more than an occasional basis, the user should consult the Occupational Safety and Health (OSHA) guidelines for the specific element. Exposure to welding fumes containing these elements may cause adverse health effects. Refer to the Supplementary Reading List at the end of this chapter for detailed literature citations.

Copper and zinc fume and dust can cause irritation of the upper respiratory tract, nausea, and metal fume fever. They may also cause skin irritation and dermatitis as well as eye problems. Cadmium and beryllium fume are toxic when inhaled.

Fluxes used for welding, brazing and soldering certain copper alloys may contain fluorides and chlorides. Fume from these fluxes can be very irritating to the eyes, nose, throat, and skin. Some fluorine compounds are toxic. Furnaces or retorts that use a flammable brazing atmosphere must be purged of air prior to heating. Furnaces using controlled atmospheres must be purged with air before personnel are permitted to enter it to avoid their suffocation.

Good personal hygiene should be practiced, particularly before eating. Food and beverages should not be stored or consumed in the work area. Contaminated clothing should be changed.

For a more detailed explanation of safe practices, see Chapter 16, "Safe Practices," *Welding Handbook,* 8th Ed., Vol. 1.

WELDING COPPER

FUSION WELDING OXYGEN-BEARING copper is difficult. The high oxygen and impurity level in fire-refined copper make this material particularly difficult to weld. Electrolytic tough-pitch copper (UNS No. C11000) has somewhat better weldability but must be welded with caution. Although preheat and high heat input are necessary to counteract the high thermal conductivity of these materials, high heat input degrades weld properties. Therefore, inert-gas shielded arc processes are recommended over OFW. Solid-state processes can also be effective for these materials.

Oxygen-free (UNS No. C10200) and deoxidized copper (UNS No. C12000) should be selected for welded components when the best combination of electrical conductivity, mechanical properties, and corrosion resistance are desired.

Copper is welded with ECu and ERCu filler metals whose composition is similar to the base metal although other compatible copper filler metals may be used to obtain desired properties.

The high thermal conductivity of copper often requires preheating to achieve complete fusion and adequate joint penetration. Preheating requirements depend upon material thickness, the welding process and heat input. Figures 3.3 and 3.4 illustrate the effects of preheat temperature on penetration in copper. Typical preheat temperatures are given in Table 3.7.

at temperatures considerably higher than those used for stress relieving, as shown in Table 3.6. Stress relaxation proceeds rapidly at the annealing temperature. Extended annealing times or annealing at the top of the temperature range can cause excessive grain growth that may reduce tensile strength and can cause other undesirable metallurgical effects.

Heat Treatment

HEAT TREATABLE COPPER alloys of greatest commercial use are those with UNS Nos. C17000, C17200, C17300, C17500, C17510, C18200, and C15000. These materials can be supplied in any form or condition the user requires. These heat treatable copper alloys are hardened by either of the following procedures:

(1) Solution anneal, then cold work, and then age harden.
(2) Solution anneal, then age harden from the solution anneal state without cold working.

For each heat treatable copper alloy, the solution anneal temperature and age hardening temperature vary depending upon alloy chemical composition.

When a heat treatable copper alloy has been welded or brazed, and to a lesser extent soldered, the mill supplied condition has been altered. To return the base metal, the heat-affected zone and the weld to approximately the mill supplied condition, it is necessary to heat treat the welded assembly. This involves solution annealing, followed by age hardening. It usually is not feasible to perform any cold work on a welded assembly after solution anneal.

Solution Annealing. The solution anneal for beryllium-copper UNS No. C17200 alloy (1.9 percent beryllium) is to heat the part to 1450 °F (788 °C). Depending on the thickness, the part is held at temperature for 30 minutes to 3 hours. Because beryllium-copper forms a tenacious and continuous oxide surface when heated in air or an oxidizing atmosphere, a slightly reducing atmosphere should be used to produce clean and bright parts after quenching.

The quenching is critical to avoid any precipitation of the beryllium intermetallic constituent. Rapid water quenching from the solution anneal temperature is the best method to insure retention in solid solution. For parts or castings that may crack, quenching in oil or forced air may be used but may result in some precipitation of beryllium intermetallic constituent.

Age Hardening. Solution annealed products are soft, having a hardness of 45 to 85 HRB. Weldments are seldom cold worked after the solution treatment. Hardening is accomplished by aging the part or welded assembly in a furnace at a temperature of 550 to 750 °F (290 to 400 °C) for about 3 hours. Again, to prevent oxidation, a slightly reducing atmosphere is preferred. After age hardening, the parts or assemblies may be returned to room temperature in any manner, i.e.,

Table 3.6
Annealing Temperature Ranges for Copper and Copper Alloys

Common name	UNS No.	Temperature Range* °F	Temperature Range* °C
Phosphor-deoxidized copper	C12200	700-1200	371-649
Beryllium-copper	C17000, C17200	1425-1475	774-802
Beryllium-copper	C17500	1675-1725	913-941
Red brass	C23000	800-1350	427-732
Yellow brass	C27000	800-1300	427-704
Muntz metal	C28000	800-1100	427-593
Admiralty	C44300-C44500	800-1100	427-593
Naval brass	C46400-C46700	800-1100	427-593
Phosphor bronze	C50500-C52400	900-1250	482-677
Aluminum bronze	C61400	1125-1650	607-899
Aluminum bronze	C62500	1100-1200	593-649
Silicon bronze	C65100, C65500	900-1300	482-704
Aluminum brass	C68700	800-1100	427-593
Copper-nickel, 10%	C70600	1100-1500	593-816
Copper-nickel, 30%	C71500	1200-1500	649-816
Nickel-silver	C74500	1100-1400	593-760

* Time at temperature - 15 to 30 min

furnace cooled, water quenched, or air quenched. The cooling method is usually immaterial.

UNS No. C17200 alloy, solution annealed and age hardened, will have a hardness of 35 to 40 HRC, depending on thickness.

Other Heat Treatable Copper Alloys. All beryllium-copper, chromium-copper, and zirconium-copper alloys may be heat treated in the manner described above for beryllium-copper alloy UNS No. C17200. Only the temperatures are adjusted to give optimum mechanical properties.

Fixturing

THE THERMAL COEFFICIENTS of expansion of copper and its alloys are about 1.5 times that of steel (see Table 3.2), so that distortion will be greater with copper alloys. Appropriate measures to control distortion and warping include suitable clamping fixtures, to position and restrain thin components, and frequent tack welds to align the joint for welding thick sections. The ends of the tack welds should be tapered to ensure good fusion with the first weld beads.

The root pass of multiple-pass welds should be rather large to avoid cracking. Fixturing and welding procedures must be designed to limit restraint of copper alloys that are likely to hot crack when highly restrained.

Backing strips or backing rings are used to control root penetration and fusion in groove welds. Copper and copper alloys that have the same or similar chemical composition as the base metal can be used for backing. Removable ceramic backing also may be suitable for use with copper and copper alloys.

Safe Practices

COPPER AND A number of alloying elements in copper alloys (arsenic, beryllium, cadmium, chromium, lead, manganese, and nickel) have low or very low permissible exposure limits as set by the American Conference of Governmental Industrial Hygienists. Special ventilation precautions are required when brazing, welding, soldering, or grinding copper or copper alloys to assure the level of contaminants in the atmosphere is below the limit allowed for human exposure. These precautions may include local exhaust ventilation, respiratory protection, or both. Refer to the latest edition of ANSI/AWS Z49.1, *Safety in Welding and Cutting*, for proper procedures.

Welding copper alloys containing appreciable amounts of beryllium, cadmium, or chromium may present health hazards to welders and others. Where copper alloys containing these elements are welded on more than an occasional basis, the user should consult the Occupational Safety and Health (OSHA) guidelines for the specific element. Exposure to welding fumes containing these elements may cause adverse health effects. Refer to the Supplementary Reading List at the end of this chapter for detailed literature citations.

Copper and zinc fume and dust can cause irritation of the upper respiratory tract, nausea, and metal fume fever. They may also cause skin irritation and dermatitis as well as eye problems. Cadmium and beryllium fume are toxic when inhaled.

Fluxes used for welding, brazing and soldering certain copper alloys may contain fluorides and chlorides. Fume from these fluxes can be very irritating to the eyes, nose, throat, and skin. Some fluorine compounds are toxic. Furnaces or retorts that use a flammable brazing atmosphere must be purged of air prior to heating. Furnaces using controlled atmospheres must be purged with air before personnel are permitted to enter it to avoid their suffocation.

Good personal hygiene should be practiced, particularly before eating. Food and beverages should not be stored or consumed in the work area. Contaminated clothing should be changed.

For a more detailed explanation of safe practices, see Chapter 16, "Safe Practices," *Welding Handbook,* 8th Ed., Vol. 1.

WELDING COPPER

FUSION WELDING OXYGEN-BEARING copper is difficult. The high oxygen and impurity level in fire-refined copper make this material particularly difficult to weld. Electrolytic tough-pitch copper (UNS No. C11000) has somewhat better weldability but must be welded with caution. Although preheat and high heat input are necessary to counteract the high thermal conductivity of these materials, high heat input degrades weld properties. Therefore, inert-gas shielded arc processes are recommended over OFW. Solid-state processes can also be effective for these materials.

Oxygen-free (UNS No. C10200) and deoxidized copper (UNS No. C12000) should be selected for welded components when the best combination of electrical conductivity, mechanical properties, and corrosion resistance are desired.

Copper is welded with ECu and ERCu filler metals whose composition is similar to the base metal although other compatible copper filler metals may be used to obtain desired properties.

The high thermal conductivity of copper often requires preheating to achieve complete fusion and adequate joint penetration. Preheating requirements depend upon material thickness, the welding process and heat input. Figures 3.3 and 3.4 illustrate the effects of preheat temperature on penetration in copper. Typical preheat temperatures are given in Table 3.7.

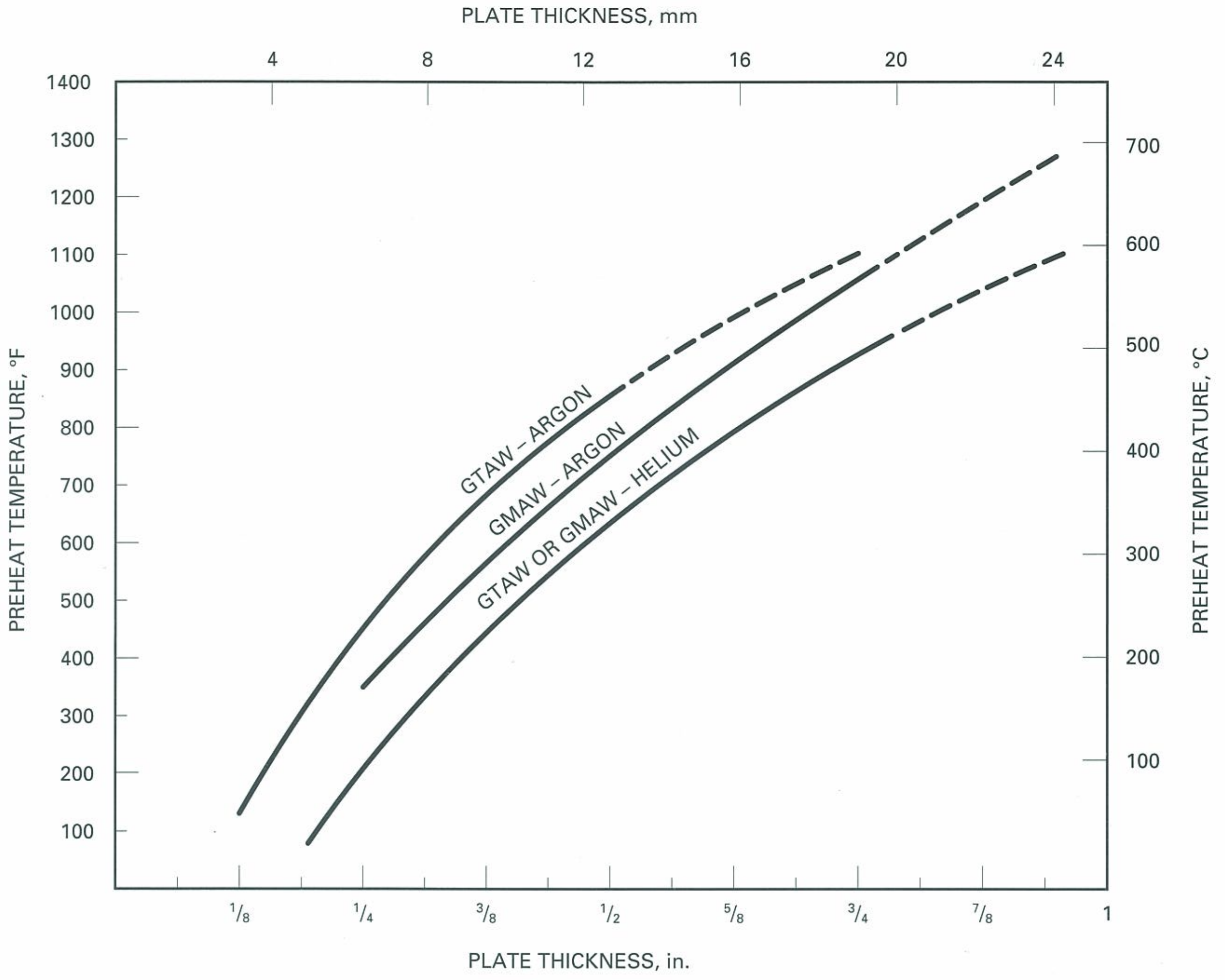


Figure 3.3—Effects of Process, Shielding Gas, and Metal Thickness on Preheat Requirements for Welding Copper

Gas Tungsten Arc Welding

GAS TUNGSTEN ARC welding (GTAW) is best suited for joining sections of copper up to 0.125 in. (3.2 mm) thick, but flat position welding of thicker sections also is performed successfully. Pulsed current is helpful for welding positions other than flat. Typical joint designs for GTAW of copper are shown in Figure 3.1.

Shielding Gases. Argon shielding gas is preferred for GTAW of copper up to 0.06 in. (1.5 mm) thick and helium is preferred for welding sections over 0.06 in. (1.5 mm). Compared to argon, helium produces deeper penetration or permits higher travel speed, or both, at the same welding current. Figure 3.4 illustrates the differences in penetration in copper with argon and helium shielding gases. Helium produces a more fluid weld pool that is cleaner, and the risk of oxide entrapment is considerably reduced. Mixtures of argon and helium result in intermediate welding characteristics. A mixture of 75% helium-25% argon produces a good balance between the good penetration of helium and the easier arc starting and greater arc stability of argon.

Welding Technique. Either forehand or backhand welding may be used for welding copper. Forehand welding is preferred for all welding positions and provides a more uniform, smaller bead than with backhand welding.

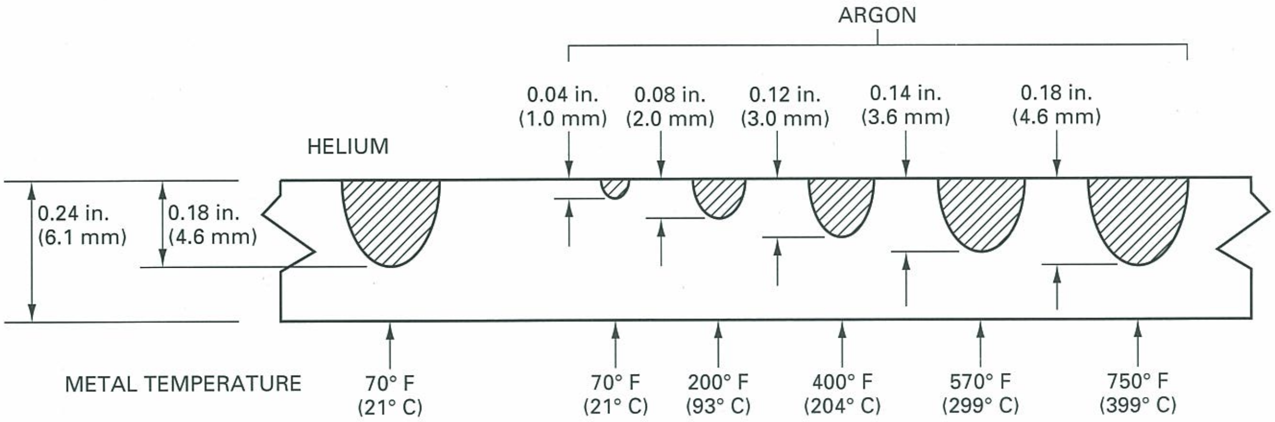


Figure 3.4—Effect of Shielding Gas and Preheat Temperature on Weld Bead Penetration in Copper when Gas Tungsten Arc Welded with 300 A dc at a Travel Speed of 8 in./min (3.4 mm/sec)

Stringer beads or narrow weave beads should be used for copper. Wide oscillation of the arc should be avoided because it exposes each edge of the bead to the atmosphere. The first bead should penetrate to the root of the joint and should be sufficiently thick to provide time for weld metal deoxidation and to avoid cracking of the weld bead.

Typical preheat temperatures and welding conditions for GTAW of copper are shown in Table 3.7. These conditions should only be used as a guide for establishing welding procedures. The high thermal conductivity of copper precludes recommending welding conditions suitable for all applications. The welding conditions should be adjusted to produce the desired weld bead shape. The limitation on travel speed is the weld bead shape. At excessive speeds, weld beads tend to be very convex in shape, causing underfill along the edges and poor fusion on subsequent weld passes.

Properties. Typical mechanical and electrical properties of copper weld metal are shown in Table 3.8. The data represents GTAW specimens tested in both the as-welded and annealed condition.

Gas Metal Arc Welding

ARGON OR A mixture of 75% helium-25% argon is recommended for gas shielding in gas metal arc welding (GMAW) of copper. Argon is normally used for 0.25 in. (6.4 mm) thickness and under. The helium-argon mixture is used for welding of thicker sections since preheat requirements are lower, joint penetration is better, and filler metal deposition rates are higher.

ERCu copper electrodes are recommended for GMAW of copper. These electrodes have the highest conductivity of any copper electrodes but contain minor alloying elements to improve weldability. The resulting weld has a lower conductivity than the base material. Copper alloy electrodes (copper-silicon and copper-aluminum) may be used to obtain desired joint mechanical properties when good electrical or thermal conductivity is not a major requirement. Electrode size will depend upon the base metal thickness and the joint design.

The filler metal should be deposited by stringer beads or narrow weave beads using spray transfer. Wide electrode weaving may result in oxidation at bead edges. Minimum conditions for spray transfer with steady current, copper electrodes and argon shielding are given in Table 3.9. Pulsed current can be used to achieve spray transfer over a wider range of welding currents.

Suggested joint designs for GMAW of copper are shown in Figure 3.2. Typical preheat temperatures and welding conditions are given in Table 3.10. These should be used as guidelines in establishing suitable welding conditions that are substantiated by appropriate tests. The forehand welding technique should be used in the flat position. In the vertical position, the progression of welding should be uphill. GMAW of copper should not be done in the overhead position. Pulsed current improves weld bead shape and operability for welding copper in positions other than flat.

Table 3.7
Typical Conditions for Manual Gas Tungsten Arc Welding of Copper

Metal Thickness	Joint Design[a]	Shielding Gas	Tungsten Electrode Diameter	Welding Rod Diameter	Preheat Temperature	Welding Current, A[b]	No. of Passes
0.01-0.03 in. (0.3-0.8 mm)	A	Ar	0.02, 0.04 in. (0.5, 1.0 mm)	— —	— —	15-60	1
0.04-0.07 in. (1.0-1.8 mm)	B	Ar	0.04, 0.062 in. (1.0, 1.6 mm)	0.062 in. (1.6 mm)	— —	40-170	1
0.09-0.19 in. (2.3-4.8 mm)	C	He	0.094 in. (2.4 mm)	0.094, 0.125 in. (2.4, 3.2 mm)	100°F (38°C)	100-300	1-2
0.25 in. (6.4 mm)	C	He	0.125 in. (3.2 mm)	0.125 in. (3.2 mm)	200°F (93°C)	250-375	2-3
0.38 in. (9.6 mm)	E	He	0.125 in. (3.2 mm)	0.125 in. (3.2 mm)	450°F (232°C)	300-375	2-3
0.5 in. (12.7 mm)	D	He	0.125, 0.156 in. (3.2, 4.0 mm)	0.125 in. (3.2 mm)	650°F (343°C)	350-420	4-6
0.63 in. and up (16 mm and up)	F	He	0.188 in. (4.8 mm)	0.125 in. (3.2 mm)	750°F min (399°C min)	400-475	As req'd

a. See Figure 3.1.

b. Direct current electrode negative.

Table 3.8
Typical Properties of Gas Tungsten Arc Weld Deposits of Copper

Test and Conditions	Tensile Strength		Yield Strength		Elongation, %	Impact Strength[a]		Electrical Conductivity, % IACS
	ksi	MPa	ksi	MPa		ft lb	J	
All weld metal test								
As-welded	27-32	186-220	15-20	103-138	20-40	20-40	27-54	—
Annealed at 1000°F (538°C)	27-32	186-220	12-18	83-124	20-40	—	—	—
Transverse tension test								
As-welded	29-32	200-220	10-13	69-159	—	—	—	—
Deposited metal conductivity[b]								
Oxygen-free copper	—	—	—	—	—	—	—	95
Phosphorous deoxidized copper	—	—	—	—	—	—	—	83
Phosphor bronze	—	—	—	—	—	—	—	37
Silicon bronze	—	—	—	—	—	—	—	26

a. Charpy keyhole specimens

b. Copper base metal welded with the given filler metal

Plasma Arc Welding

COPPER CAN BE welded with the plasma arc welding (PAW) process using ERCu filler metal. Argon, helium, or mixtures of the two are used for orifice and shielding gases depending on base metal thickness. As with GTAW, arc energy is higher with helium-rich mixtures. Hydrogen should not be added to either gas for welding copper.

Table 3.9
Approximate Gas Metal Arc Welding Conditions for Spray Transfer with Copper and Copper Alloy Electrodes and Argon Shielding

Electrode			Minimum* Welding Current, A	Arc Voltage, V	Filler Wire Feed		Minimum Current Density	
	Diameter							
Type	in.	mm			in./min	mm/s	kA/in.^{2}	kA/mm^2
ERCu (copper)	0.035	0.9	180	26	345	146	191	0.30
	0.045	1.1	210	25	250	106	134	0.21
	0.062	1.6	310	26	150	63	101	0.16
ERCuAl-A2 (aluminum bronze)	0.035	0.9	160	25	295	125	170	0.26
	0.045	1.1	210	25	260	110	134	0.21
	0.062	1.6	280	26	185	78	91	0.14
ERCuSi-A (silicon bronze)	0.035	0.9	165	24	420	178	176	0.27
	0.045	1.1	205	26-27	295	125	131	0.20
	0.062	1.6	270	27-28	190	80	88	0.14
ERCuNi (copper-nickel)	0.062	1.6	280	26	175	74	91	0.14

* Direct current electrode positive

Table 3.10
Typical Conditions for Gas Metal Arc Welding of Copper

Metal Thickness	Joint Design[a]	Shielding Gas	Electrode		Preheat Temperature	Welding Current, A[b]	Travel Speed	No. of Passes
			Diameter	Feed				
Up to 0.19 in. (up to 4.8 mm)	A	Ar	0.045 in. (1.1 mm)	180-315 in./min (76-133 mm/s)	100-200°F (38-93°C)	180-250	14-20 in./min (6-8 mm/s)	1-2
0.25 in. (6.4 mm)	B	75% He-25% Ar	0.062 in. (1.6 mm)	150-210 in./min (63-89 mm/s)	200°F (93°C)	250-325	10-18 in./min (4-8 mm/s)	1-2
0.38 in. (9.6 mm)	B	75% He-25% Ar	0.062 in. (1.6 mm)	190-230 in./min (80-97 mm/s)	425°F (218°C)	300-350	6-12 in./min (2-5 mm/s)	1-3
0.50 in. (12.7 mm)	C	75% He-25% Ar	0.062 in. (1.6 mm)	210-270 in./min (89-114 mm/s)	600°F (316°C)	330-400	8-14 in./min (3-6 mm/s)	2-4
0.63 in. and up (16 mm and up)	D	75% He-25% Ar	0.062 in. (1.6 mm)	210-270 in./min (89-114 mm/s)	800°F (427°C)	330-400	6-12 in./min (2-5 mm/s)	As req'd
0.63 in. and up (16 mm and up)	D	75% He-25% Ar	0.094 in. (2.4 mm)	150-190 in./min (63-80 mm/s)	800°F (427°C)	500-600	8-14 in./min (3-6 mm/s)	As req'd

a. Refer to Figure 3.2.

b. Constant-potential power source; direct current electrode positive using a short arc length that provides steady and quiet operation.

Shielded Metal Arc Welding

COPPER MAY BE welded with ECu covered electrodes, but weld quality is not as good as that obtained with the gas shielded welding processes. Best results with shielded metal arc welding (SMAW) are obtained when welding deoxidized copper. The electrodes may be used to weld oxygen-free and tough-pitch coppers, but the welded joints will contain porosity and oxide inclusions.

Copper may be welded with an alloy covered electrode, such as ECuSi or ECuSn-A electrodes. These electrodes are used for the following:

(1) Minor repair of relatively thin sections
(2) Fillet welded joints with limited access
(3) Welding copper to other metals

Joint designs should be similar to those shown in Figure 3.1. A grooved copper backing may be used to control the root surface contour.

Electrode size selected should be as large as practical for the base metal thickness. Welding should be done using direct current electrode positive of sufficient amperage to provide good filler metal fluidity. Either a weave or stringer bead technique may be used to fill the joint. Flat position welding using a preheat of 500 °F (260 °C) or higher is used for joints thicker than 0.13 in. (3.3 mm).

Oxyfuel Gas Welding

THE OXYGEN-FREE and deoxidized coppers can be welded using the oxyfuel gas welding (OFW) process, but welding travel speed is slower than for arc welding. ERCu welding electrodes and appropriate flux are used for oxyacetylene welding (OAW) welding.

Preheat and auxiliary heating are recommended with thicknesses over 0.13 in. (3.3 mm) to obtain good fusion.

Type ERCu or ERCuSi filler metal can also be used for OFW of copper, depending upon the desired joint properties. When commercial flux designed for welding copper alloys is used, the welding rod and the joint surfaces should be coated with flux.

The OFW flame should be neutral when flux is used, and slightly oxidizing when welding without flux. The welding tip size should be one to two sizes larger than the tip used for the same thickness of steel. Typical welding tip sizes and joint designs are given in Table 3.11.

Backhand welding is generally preferred for the flat position. Backhand technique can give a thicker bead than forehand welding, and oxide entrapment is less. Control of the molten weld pool is greatly improved when the joint axis is tilted about 10 to 15 degrees and the direction of welding is uphill.

Long seams should not be tack welded. The initial root opening should increase along the joint length with a taper that will close gradually as welding proceeds along the joint. A rule-of-thumb is to increase the root opening 0.015 units for each unit of joint length.

Completed weld beads may be peened to relieve welding stresses and increase the weld metal strength by cold working. Peening may be done either while the weld metal is still warm or after it cools to room temperature.

Other Processes

COPPER CAN BE electron beam welded and copper tubing is high-frequency resistance welded. The solid-state processes, including friction welding and cold welding, also are effective for welding copper.

Table 3.11
Suggested Joint Designs and Welding Tip Sizes for Oxyacetylene Welding of Copper

Metal Thickness			Root Opening		Welding Tip Drill Size No.	Remarks
in.	mm	Joint Design	in.	mm		
0.06	1.5	Edge-flange	0	0	55 to 58	—
0.06	1.5	Square-groove	0.06-0.09	1.5-2.3	55 to 58	—
0.13	3.3	Square-groove	0.09-0.13	2.3-3.3	51 to 54	—
0.19	4.8	60° to 90° single-V-groove	0.13-0.18	3.3-4.6	48 to 50	Auxiliary heating required
0.25	6.4	60° to 90° single-V-groove	0.13-0.18	3.3-4.6	43 to 46	Auxiliary heating required
0.38	9.6	60° to 90° single-V-groove	0.18	4.6	38 to 41	Auxiliary heating required
0.50-0.75	12.7-19.0	90° double-V-groove	0.18	4.6	38 to 41	Weld both sides simultaneously in vertical position

WELDING HIGH-COPPER ALLOYS

HIGH-COPPER ALLOYS include beryllium-copper (UNS Nos. C17000-17500), cadmium-copper (UNS No. C14300), chromium-copper (UNS No. C18200), chromium-zirconium-copper (UNS No. C18150), zirconium-copper (UNS No. C15000), and nickel-silicon-chromium-copper (UNS No. C18000).

Cadmium-copper has good electrical conductivity and is strengthened by cold working. Beryllium-chromium- and zirconium-copper can be strengthened by a precipitation-hardening heat treatment, either alone or in combination with cold working. Nickel-silicon-chromium alloys are strengthened by precipitation hardening, either alone or in combination with cold working.

Welding will soften the HAZ in the precipitation-hardened, high-copper alloys by annealing or overaging. The characteristics of each alloy and its condition should be considered when establishing welding procedures and manufacturing sequences. For maximum properties, beryllium- chromium- and zirconium-copper assemblies should be welded before either heat treatment or cold working.

Cadmium- and Chromium-Coppers

THE PROCEDURES RECOMMENDED for arc and OFW of copper are good bases to use for developing welding procedures for cadmium- and chromium copper. These alloys have lower electrical and thermal conductivity than copper, and they can be welded at lower preheat temperatures and heat input than those required for copper.

Cadmium-copper can be joined by the gas shielded welding processes, OFW, and flash welding. OFW welding of cadmium-copper requires a flux containing sodium fluoride and either fused borax or boric acid, or both, to dissolve cadmium oxides. Chromium-copper can be welded with gas shielded processes and flash welding, but OFW should not be used because of problems caused by chromium oxide formation on weld faces.

Beryllium-Coppers

TWO TYPES OF beryllium-copper are available. One type (low-beryllium copper) contains about 0.5 percent beryllium and 1.5 or 2.5 percent cobalt and has relatively good electrical conductivity. The other type (high-beryllium copper) contains about 2 percent beryllium and 0.2 percent cobalt or nickel. It has good strength in the precipitation-hardened condition but low electrical conductivity, about 20% IACS.

High-beryllium copper is more readily welded than low-beryllium copper. Addition of beryllium to copper lowers the melting point, increases the fluidity of the molten metal, and decreases thermal conductivity, all of which contribute to better weldability.

A difficulty common to beryllium-copper is formation of surface oxide. Beryllium forms a tenacious oxide that inhibits wetting and fusion during welding. Cleanliness of faying surfaces and surrounding surfaces before and during welding is essential for good results.

Sound welds can be made in the low-beryllium alloy, but cracking during welding or postweld heat treatment is a problem. Low-beryllium copper can be joined more readily with a filler metal of higher beryllium content.

Beryllium-copper components can be repaired by SMAW with aluminum bronze electrodes or by GTAW with silicon bronze filler metal when welds with high mechanical properties are not required. Joint designs similar to those shown in Figures 3.1 and 3.2 are suitable for GTAW and GMAW respectively.

Typical conditions used for welding beryllium copper are given in Table 3.12. These data may be used as a guide in establishing suitable welding conditions.

Stabilized AC power is preferred for manual GTAW welding of thin sections [less than 0.25 in. (6.4 mm)] to take advantage of its surface cleaning action. Direct current electrode negative (DCEN) is recommended for welding heavier sections and can be used for manual and mechanized GTAW, provided adequate gas shielding is used to prevent oxidation.

Preheat is not usually required for welding sections of 0.13 in. (3.3 mm) and less in thickness. Preheat temperatures for high thermal conductivity alloys should be those recommended for copper. For the high-strength alloys, preheat temperatures of 300 to 400 °F (136 to 204 °C) are sufficient.

After welding, optimum mechanical properties are obtained by a solution anneal heat treatment followed by cold working, if possible, and age hardening, as the data in Table 3.13 indicate. The characteristics of the weld metal must be considered in planning a postweld heat treatment when the filler metal composition is different from that of the base metal.

Components in the precipitation-hardened condition should not be welded because of the danger of cracking the heat-affected zone. Thin sections should be welded in the solution annealed condition.

In multipass welding of heavy sections, early passes are overaged by the heat of later passes. Therefore, where multiple-pass welding is required, the base metal should be in the overaged condition because it is more stable metallurgically in this condition than in the solution heat-treated condition.

Table 3.12
Typical Conditions for Arc Welding Beryllium Coppers

	GTAW				GMAW
	Manual		Automatic		Manual
Variable	Alloy C17200	Alloy C17500	Alloy C17200	Alloy C17200	Alloy C17000
Thickness, in.	0.125	0.25	0.020	0.090	1.0
(mm)	(3.2)	(6.4)	(0.5)	(2.3)	(25.4)
Joint design	C[a]	E[a]	B[a]	B[a]	D[b]
Preheat temp., °F	70	300	70	70	300
(°C)	(21)	(149)	(21)	(21)	(149)
Filler metal diam., in.	0.125	0.125	—	0.062	0.062
(mm)	(3.2)	(3.2)	—	(1.6)	(1.6)
Filler metal feed, in./min	—	—	—	—	190-200
(mm/s)	—	—	—	—	(80-85)
Shielding gas	Ar	Ar	Ar	65% Ar-35%He	Ar
Welding power	ACHF	ACHF	DCEN	DCEN	DCEP
Welding current, A	180	225-245	43	150	325-350
Arc voltage, V	—	22-24	12	11.5	29-30
Travel speed, in./min	—	—	27	20	—
(mm/s)	—	—	(11)	(8)	—

a. Refer to Figure 3.1.

b. Refer to Figure 3.2.

Table 3.13
Typical Mechanical Properties of Welded Joints in Beryllium Copper

	Tensile Strength		Yield Strength	
Alloy and Condition*	ksi	MPa	ksi	MPa
C17200 (Cu-2Be)				
As-welded	60-70	414-484	30-33	207-228
Aged only	130-155	896-1069	125-150	861-1034
Solutioned and aged	150-175	1034-1207	145-170	1000-1172
C17500 (Cu-2.5 Co-0.5Be)				
As-welded	50-55	345-379	30-45	207-310
Aged only	80-95	552-655	65-85	448-586
Solutioned and aged	100-110	689-758	75-85	517-586

* Welded in the solution heat-treated condition

WELDING COPPER-ZINC ALLOYS (BRASSES)

COPPER-ZINC ALLOYS CAN be joined by arc welding, OFW, resistance spot, flash, and friction welding processes. The electrical and thermal conductivity of brasses decreases with increasing zinc content so that high-zinc brasses require lower preheat temperatures and welding heat input than low-zinc brasses. Since zinc vaporizes from molten brass, zinc fuming is the major problem when welding brasses and is worse for the high-zinc brasses. Other alloying elements such as aluminum and nickel may slightly increase cracking tendency and increase oxide formation. For these reasons, low-zinc brasses have good weldability, high-zinc brasses only fair weldability, and leaded alpha brasses (64 - 95% Cu) are not suitable for welding. Lead makes these copper-zinc alloys very sensitive to hot cracking. The low-leaded alpha-beta brasses are weldable under conditions of low restraint, provided low weld strength can be tolerated.

Gas Tungsten Arc Welding

THE BRASSES ARE commonly joined by gas tungsten arc welding (GTAW) in sections up to 0.38 in (9.7mm) thick. Thin brass sheets can be welded together without filler metal addition, but addition of filler metal is recommended when welding sections over 0.062 in. (1.6 mm) thick. Phosphor bronze (ERCuSn-A) filler metal provides a good color match with some brasses, but silicon bronze (ERCuSi-A) filler metals reduce zinc fuming. Aluminum bronze (ERCuAl-A2) filler metal can be used to provide good joint strength for high-zinc brasses, but aluminum bronze filler metal is not effective in controlling zinc fuming so that welds tend to be porous.

V-groove weld joints having a groove angle of 75 to 90 degrees should be used to insure good joint penetration for thicknesses over 0.188 in. (4.8 mm). A preheat temperature of 200 to 600 °F (93 to 316 °C) should be used on heavier sections. The preheat temperature can be lowered for the high-zinc brasses.

Welding procedures can be designed to minimize zinc fuming by directing the welding arc onto the filler rod or the molten weld pool rather than on the base metal. The base metal is heated to fusion temperature by conduction from the molten weld pool rather than by direct impingement of the arc.

Gas Metal Arc Welding

GAS METAL ARC welding (GMAW) is used primarily to join relatively thick sections of brass and is suitable for thicknesses over 0.13 in. (3.3 mm). Zinc fuming is more severe with GMAW than with GTAW. Argon shielding is normally used, but helium-argon mixtures can provide higher heat input. Silicon bronze (ERCuSi-A), phosphor bronze (ERCuSn-A) or aluminum bronze (ERCuAl-A2) bare electrodes are recommended. The phosphor bronze electrode will produce weld metal having good color match with most brass, but the silicon bronze electrode has better fluidity. The aluminum bronze electrode is best for welding high-strength brasses to produce weldments with equivalent base metal strength. V-groove weld joints with a 60 to 70 degree groove angle or U-groove joints are recommended when using aluminum bronze filler metal.

A preheat in the range of 200 to 600 °F (93 to 316 °C) is recommended for the low-zinc brasses because of their relatively high thermal conductivity. Preheat should not be used for GMAW of high-zinc brasses, but can be used to reduce the required welding current, and thus reduce zinc fuming. During welding, the arc should be directed on the molten weld pool to minimize zinc fuming.

Shielded Metal Arc Welding

BRASSES CAN BE welded with phosphor bronze (ECuSn-A or ECuSn-C), silicon bronze (ECuSi), or aluminum bronze (ECuAl-A2) covered electrodes. The selection criteria for covered electrodes is similar to that previously described for bare electrodes used with GMAW.

The weldability of brasses with shielded metal arc welding (SMAW) is not as good as with GMAW, and relatively large groove angles are needed for good joint penetration and avoidance of slag entrapment. For best results, welding should be done in the flat position, using a backing of copper or brass.

The preheat and interpass temperature for the low brasses should be in the 400 to 500 °F (204 to 260 °C) range, and in the 500 to 700 °F (260 to 371 °C) range for the high brasses. Low preheat temperature will provide better weld joint mechanical properties when using phosphor bronze electrodes. Fast welding speed and a welding current in the high end of the recommended range for the electrode should be used to deposit stringer beads in the joint. The arc should be directed on the molten weld pool to minimize zinc fuming.

Oxyfuel Gas Welding

THE OXYFUEL GAS welding (OFW) procedures that are used for copper are also suitable for the brasses. The low brasses are readily joined by OFW, and the process is particularly suited for piping because it can be performed in all welding positions. Silicon bronze (ERCuSi-A) welding rod or one of the brass welding rods (RBCuZn-A, RBCuZn-B, or RBCuZn-C) may be used.[2] Brass welding rods containing 38 to 41 percent zinc develop a significant proportion of the hard, strong beta phase in the weld metal. This beta phase is soft and ductile at elevated temperatures, and cracking is not a problem.

Very little zinc oxide appears on the molten weld metal surfaces when OFW with a neutral or slightly oxidizing flame. When a strongly oxidizing flame is used, an oxide film forms on the molten weld metal sur face that suppresses evaporation of zinc, provided the weld metal is not overheated.

For OFW of high brasses, RBCuZn-B or RBCuZn-C welding rods are used. These low-fuming rods have compositions similar to the high brasses. A flux of AWS classification FB3-C, FB3-D, or FB3-K is required, and the torch flame should be adjusted to slightly oxidizing to control fuming.[3] Preheating and an auxiliary heat source may also be necessary.

WELDING COPPER-NICKEL-ZINC ALLOYS (NICKEL-SILVER)

NICKEL-SILVERS ARE SELDOM welded, although welding of nickel-silver is similar to brass having comparable zinc content. Nickel-silvers are frequently used in decorative applications where color match is important. No zinc-free filler metals are available that give a good color match for gas shielded arc welding. GTAW without filler metal addition is usually restricted to welding thicknesses of 0.094 in. (2.4 mm) or less. Square groove butt, lap, or edge joints should be used.

For a wide range of thicknesses, OFW may be performed using RBCuZn-D welding rods with a slightly oxidizing flame An AWS classification FB3-D brazing flux should be applied to both the joint area and the welding rod before and during welding.

If SMAW is to be performed, manganese bronze or copper-nickel filler metal will result in a close color match. Care must be exercised to prevent undercutting, since the melting points of these alloys are appreciably above nickel-silvers.

Annealing is recommended prior to welding severely restrained cold-worked material. Postweld stress relief is suggested for components subjected to corrosive environments. Preheat is recommended to avoid cracking of single-phase alloys, which have poor elevated-temperature ductility and susceptibility to hot cracking.

Resistance welding is practical because nickel-silvers have conductivities that are among the lowest of all copper alloys. Welding machines should have low inertia heads and electronic controls for best results. Power requirements are usually 125 to 150 percent of those required for comparable thicknesses of steel. Nickel-silvers can be successfully stud welded.

WELDING COPPER-TIN ALLOYS (PHOSPHOR BRONZE)

THE COPPER-TIN alloys, called *phosphor bronzes*, have rather wide freezing ranges, solidifying with large, weak dendritic grain structures. Welding procedures are designed to prevent the tendency of the weld to crack. Hot peening of each layer of multiple-pass welds will reduce welding stresses and the likelihood of cracking. Welding of leaded copper-tin alloys is not recommended. However, some leaded alloys can be welded if care is exercised. Weldability decreases with increasing lead content. Shielded metal arc welding (SMAW) generally gives better results on leaded alloys than does gas metal arc welding (GMAW).

Joint Preparation

A SINGLE-V-groove weld should be used to join copper-tin alloys in the thickness range of 0.15 to 0.50 in. (4 to 13 mm). The groove angle should be 60 to 70 degrees for GMAW and 90 degrees for SMAW. For greater thicknesses, a single- or double-U-groove weld having a 0.25-in. (6.4-mm) groove radius and a 70 degree groove angle is recommended for good access and fusion. A square-groove weld can be used for thicknesses under 0.15 in. (3.8 mm).

Preheat and Postheat

PHOSPHOR BRONZE WELD metal tends to flow sluggishly because of its wide melting range. Preheating to 350 to 400 °F (177 to 204 °C) and maintaining this interpass temperature improves metal fluidity when welding thick sections. The maximum interpass temperature should not exceed 400 °F (204 °C) to avoid hot cracking. Preheat is not essential when using GMAW spray transfer. For maximum weld ductility or stress corrosion resistance, postweld heat treatment at 900 °F (482 °C), followed by rapid cooling to room temperature, is recommended.

Gas Metal Arc Welding

GMAW IS RECOMMENDED for joining large phosphor bronze fabrications and thick sections using direct

---

[2] For information on the brass welding rods, see ANSI/AWS A5.8, *Specification for Filler Metals for Brazing and Braze Welding*, and ANSI/AWS A5.27, *Specification for Copper and Copper Alloy Rods for Oxyfuel Welding*.

[3] See ANSI/AWS A5.31, *Specification for Fluxes for Brazing and Braze Welding*.

current electrode positive, ERCuSn-A filler metal, and argon shielding.

Table 3.14 gives suggested GMAW welding parameters that can be used to establish welding procedures for phosphor bronzes. The molten weld pool should be kept small using stringer beads at rather high travel speed. Hot peening of each layer will reduce welding stresses and the likelihood of cracking.

Gas Tungsten Arc Welding

GAS TUNGSTEN ARC welding (GTAW) is used primarily for repair of castings and joining of phosphor bronze sheet with ERCuSn-A filler metal. As with GMAW, hot peening of each layer of weld metal is beneficial. Either stabilized ac or dc, electrode negative welding current can be used with helium or argon shielding.

Shielded Metal Arc Welding

PHOSPHOR BRONZE COVERED electrodes (ECuSn-A or ECuSn-C) are available for joining bronzes of similar chemical compositions. Filler metal should be deposited as stringer beads using direct current electrode positive, to obtain the best mechanical properties. Postweld annealing at 900 °F (482 °C) is not always necessary, but it is desirable for maximum ductility, particularly if the welded assembly is to be cold worked. Moisture, both on the work and in the electrode coverings, must be strictly avoided. Baking the electrodes at 250 to 300 °F (121 to 149 °C) immediately before use reduces moisture content in the covering to an acceptable level.

Oxyfuel Gas Welding

OXYFUEL GAS WELDING (OFW) is not recommended for joining the phosphor bronzes. The wide heat-affected zone and the slow cooling rate may result in hot cracking since phosphor bronzes are hot short. In an emergency, OFW with ERCuSn-A welding rods can be used if arc welding equipment is not available. If a color match is not essential, braze welding can be done with an OFW torch and RBCuZn-C welding rod. One should use a commercial brazing flux and a neutral flame.

WELDING COPPER-ALUMINUM ALLOYS (ALUMINUM BRONZE)

Weldability

SINGLE-PHASE ALUMINUM bronzes containing less than 7 percent aluminum are hot-short and difficult to weld. Weldments in these alloys may crack in the HAZ. Single-phase alloys containing more than 8 percent aluminum and two-phase alloys are considered weldable when using welding procedures designed to avoid cracking.

UNS Nos. C61300 and C61400 alloys (7 percent aluminum) are frequently fabricated for use in heat exchangers, piping, and vessels. UNS No. C61300 alloy is often preferred because of its good weldability. Both cast and wrought alloys with a higher aluminum content may be joined by arc welding. Problems with fluxing aluminum oxide from the weld metal precludes the use of oxyfuel gas welding (OFW).

Table 3.14
Parameters for Gas Metal Arc Welding of Phosphor Bronze

Metal Thickness		Joint Design			Electrode Diameter[a]		Arc Voltage, V	Welding[b] Current, A
		Groove Type	Root Opening					
in.	mm		in.	mm	in.	mm		
0.06	1.5	Square	0.05	1.3	0.030	0.8	25-26	130-140
0.13	3.3	Square	0.09	2.3	0.035	0.9	26-27	140-160
0.25	6.4	V-groove	0.06	1.5	0.045	1.1	27-28	165-185
0.50	12.7	V-groove	0.09	2.3	0.062	1.6	29-30	315-335
0.75	19.0	Note c	0-0.09	0-2.3	0.078	2.0	31-32	365-385
1.00	25.4	Note c	0-0.09	0-2.3	0.094	2.4	33-34	440-460

a. ERCuSn-A phosphor bronze electrodes and argon shielding

b. Direct current electrode positive

c. Double-V-groove or double-U-groove

Filler Metals

WELDING ELECTRODES AND filler metals recommended for joining the weldable aluminum bronzes are given in Table 3.15. Typical mechanical properties of weld metal deposited by arc welding are shown in Table 3.16. Weld metal deposited with gas metal arc welding (GMAW) is slightly stronger and harder than that deposited with covered electrodes. This is attributed to the higher welding speeds and better shielding with GMAW.

Joint Design

FOR SECTION THICKNESS up to and including 0.13 in. (3.3 mm), square-groove welds are used with a root opening of up to 75 percent of the thickness. For thicknesses of 0.15 to 0.75 in. (3.8 mm to 19 mm), a single-V-groove weld is used. The groove angle should be 60 to 70 degrees for GTAW and GMAW and 90 degrees for SMAW A double-V- or double-U-groove weld should be used for section thicknesses over 0.75 in. (19 mm) U-groove joints should have a 0.25-in. (6.4-mm) groove radius.

Preheat

PREHEAT IS OFTEN unnecessary when welding the aluminum bronzes. The preheat and interpass temperatures should not exceed 300 °F (149 °C) for alloys with less than 10 percent aluminum, including the nickel aluminum bronzes. The weldments should be air cooled to room temperature.

When the aluminum content is from 10 to 13 percent, a preheat of 300 °F (149 °C) and interpass temperature of about 500 °F (260 °C) is recommended for thick sections. Rapid air cooling of the weldment is necessary.

Gas Metal Arc Welding

GAS METAL ARC welding (GMAW) is suitable for aluminum bronze sections of 0.18 in. (4.6 mm) and

Table 3.15
Suggested Filler Metals for Arc Welding Aluminum Bronzes*

UNS No.	SMAW	GTAW or GMAW
C61300 C61400 C61800 C62300	ECuAl-A2	ERCuAl-A2
C61900 C62400	ECuAl-B	ERCuAl-A2
C62200 C62500	ECuAl-B	ERCuAl-A3
C63000 C63200	ECuNiAl	ERCuNiAl
C63300	ECuMnNiAl	ERCuMnNiAl

* Also see ANSI/AWS A5.6, *Specification for Covered Copper and Copper Alloy Arc Welding Electrodes*, and ANSI/AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes.*

Table 3.16
Typical Mechanical Properties of Aluminum Bronze Weld Metal

	Tensile Strength		Yield Strength[b]			
Electrode[a]	ksi	MPa	ksi	MPa	Elongation in 2 in. (51 mm), %	Brinell Hardness, HB[c]
			Gas Metal Arc Welding			
ERCuAl-A2	79	545	35	241	28	160
ERCuAl-A3	90	621	45	310	18	207
ERCuNiAl	104	717	59	407	22	196
ERCuMnNiAl	110	758	67	462	27	217
			Shielded Metal Arc Welding			
ECuAl-A2	77	531	35	241	27	140
ECuAl-B	89	614	47	324	15	177
ECuNiAl	99	683	58	400	25	187
ECuMnNiAl	95	655	56	386	27	185

a. Refer to specifications ANSI/AWS A5.6 and ANSI/AWS A5.7 (see Table 3.15 footnote).

b. 0.5 percent offset.

c. 3000 kg load.

thicker. Argon shielding is used for most joining and surfacing applications, while a 75% argon-25% helium mixture is helpful when welding thick sections where increased welding heat and penetration are required. To maintain proper gas coverage, the welding torch should be tilted 35 to 45 degrees in the forehand direction of travel with an electrode extension of 0.38 to 0.50 in. (9.6 to 13 mm). When welding in a position other than flat, a pulsed current power source or globular type of metal transfer is used. Table 3.17 gives suggested welding parameters for various electrode sizes. Minimum welding conditions for GMAW spray transfer with ERCuAl-A2 electrodes are given in Table 3.9.

Gas Tungsten Arc Welding

GAS TUNGSTEN ARC welding (GTAW) is recommended for critical applications, regardless of section thickness, with either stabilized ac or dc power. Alternating current with argon shielding provides arc cleaning action during welding to remove oxides from the joint faces. For better penetration or faster travel, direct current electrode negative should be used with helium but can be used with argon or a mixture of argon and helium. Preheat is used only for thick sections with this process.

Shielded Metal Arc Welding

SHIELDED METAL ARC welding (SMAW) of aluminum bronze is done with the covered electrodes that are listed in Table 3.15. Direct current electrode positive should be used with these electrodes. Representative welding current ranges for aluminum bronze covered electrodes are given in Table 3.17. Use of a short arc length and stringer or weave beads are recommended. To avoid inclusions, each bead must be thoroughly cleaned of slag before the next bead is applied. SMAW should only be used where it is inconvenient or uneconomical to use GMAW, because SMAW welding speeds are significantly lower.

WELDING COPPER-SILICON ALLOYS (SILICON BRONZE)

THE SILICON BRONZES have good weldability. Characteristics of these bronzes that contribute to this are their low thermal conductivity, good deoxidation of the weld metal by the silicon, and the protection offered by the resulting slag. Silicon bronze weld metal has good fluidity, but the molten slag is viscous. Silicon bronzes have a relatively narrow hot-short temperature range just below the solidus and must be rapidly cooled through this critical range to avoid weld cracking.

Heat loss to the surrounding base metal is low, and high welding speed can be used. Preheat is unnecessary, and interpass temperature should not exceed 200 °F (93 °C). For butt joints, the groove angle of V-groove welds should be 60 degrees or larger. Square-groove welds can be used to join sections up to 0.13 in. (3.3 mm) thick with or without filler metal. Copper backing may be used to control melt-through.

Gas Tungsten Arc Welding

THE SILICON BRONZES are readily gas tungsten arc welded (GTAW) in all positions using ERCuSi-A welding rods. Aluminum bronze welding rod ERCuAl-A2 may also be used. Welding is performed with dc power using argon or helium shielding. Welding with ac power using argon shielding takes advantage of the arc cleaning action. Representative welding conditions for

Table 3.17
Typical Operating Parameters for Arc Welding Aluminum Bronze

Electrode Size		Gas Metal Arc Welding		Shielded Metal Arc Welding Current, A*
in.	mm	Arc Voltage, V	Welding Current, A*	
0.030	0.8	25-26	130-140	—
0.035	0.9	26-27	140-160	—
0.045	1.1	27-28	165-185	—
1/16	1.6	29-30	315-335	—
5/64	2.0	31-32	365-385	50-70
3/32	2.4	33-34	440-460	60-80
1/8	3.2	—	—	100-120
5/32	4.0	—	—	130-150
3/16	4.8	—	—	170-190
1/4	6.4	—	—	235-255

* Direct current electrode positive

GTAW silicon bronzes in thicknesses of from 0.06 to 0.50 in. (1.5 mm to 12.7 mm) are given in Table 3.18.

Gas Metal Arc Welding

GAS METAL ARC welding (GMAW) may is used for joining the silicon bronzes in sections over 0.25 in. (6.4 mm) thick. ERCuSi-A electrodes, argon shielding, and relatively high travel speeds are used with this process. When making multiple-pass welds, the oxide should be removed by wire brushing between passes. Representative welding conditions for GMAW of butt joints are given in Table 3.19. The welding conditions necessary for spray transfer with ERCuSi-A electrodes are listed in Table 3.9.

Shielded Metal Arc Welding

SILICON BRONZES CAN be welded with ECuAl-A2 or ECuSi covered electrodes. Square-groove welds are suitable for thicknesses up to 0.156 in. (4 mm); single- or double-V-groove welds are used for shielded metal arc welding (SMAW) with thicker sections.

Welding in the flat position is preferred, but ECuSi electrodes can be used to weld in the vertical and overhead positions. Preheat is not needed, and the interpass temperature should not exceed 200 °F (93 °C). Stringer beads should be deposited with a welding current near the middle of the manufacturer's recommended range for the electrode size used. The arc length should be short, and the travel speed should be adjusted to give a small weld pool.

Oxyfuel Gas Welding

OXYFUEL GAS WELDING (OFW) should only be used when arc welding equipment is not available. Silicon bronzes can be oxyfuel gas welded using ERCuSi-A welding rod with a suitable flux and using a slightly oxidizing flame. Fixturing should not unduly restrict movement of the components during welding, and welding should be performed rapidly. Either forehand or backhand welding can be used, with the former preferred for thin sections.

WELDING COPPER-NICKEL ALLOYS

COPPER-NICKEL ALLOYS are readily welded with gas shielded arc welding processes, SMAW, SAW and OFW processes. Preheat is not required and the interpass temperature should not exceed 350 °F (177 °C). Surfaces to be welded shall be clean, free of oxides and other contamination, including sulfur that may cause HAZ intergranular cracking. A 70Cu-30Ni filler metal (ERCuNi and ECuNi) is recommended for welding all the grades of copper-nickel.Where a color match is required, filler metal of matching composition should be used.

Gas Tungsten Arc Welding

COPPER-NICKEL ALLOYS can be welded in all positions using the gas metal arc welding (GTAW) process. Direct current electrode negative, is recommended, although alternating current is used for automatic welding if arc length is accurately controlled. Manual welding is normally used for sheet and plate of thicknesses up to 0.25 in. (6.4 mm) and for tube and pipe. Thicker sections may be welded with GTAW, but GMAW would be more economical and reduce heat input.

The GTAW process provides high quality welds capable of meeting stringent X-ray acceptance standards. Multipass GTAW welds are best deposited using a stringer-bead technique with an arc length of 0.125 to 0.188 in. (3.2 mm to 4.7 mm).

Argon or helium may be used for shielding gas, but argon is generally used to provide improved arc control. Weld quality and soundness depend on careful attention to arc length and filler metal addition. ERCuNi filler metal contains titanium to deoxidize the weld and

Table 3.18
Typical Welding Rods and Welding Currents for Gas Tungsten Arc Welding of Silicon Bronze

Thickness		Welding Rod Diameter		Welding Current,* A
in.	mm	in.	mm	
0.06	1.5	0.062	1.6	100-130
0.13	3.3	0.094	2.4	130-160
0.19	4.8	0.125	3.2	150-225
0.25	6.4	0.125, 0.188	3.2 - 4.8	150-300
0.50	12.7	0.125, 0.188	3.2 - 4.8	250-325

* Direct current electrode negative with argon shielding in the flat position.

Table 3.19
Typical Conditions for Gas Metal Arc Welding of Silicon Bronze

Thickness		Groove Type	Root Face		Root Opening		Pass No.	Welding[a] Current, A	Arc Voltage, V	Electrode Feed[b]		Travel Speed	
in.	mm		in.	mm	in.	mm				in./min	mm/s	in./min	mm/s
0.25	6.4	Square	—	—	0.06	1.5	1	300	26	215	91	15	6
0.25	6.4	Square	—	—	0.13	3.3	1	305	21	305	129	15	6
0.25	6.4	60° single-V	—	—	0	0	1	300	26	215	91	13	5
0.38	9.6	60° single-V	0.06	1.5	0	0	1	300	26	215	91	10	4
0.38	9.6	60° single-V	0.06	1.5	0	0	1	300	26	215	91	21	9
							2	300	26	215	91	18	8
0.38	9.6	60° single-V	0.13	3.3	0	0	1	300	26	215	91	15	6
							2	300	26	215	91	16	7
							3	300	26	215	91	36	15
0.38	9.6	60° single-V	0.13	3.3	0	0	1	310	26	215	91	24	10
							2	310	26	215	91	16	7
0.38	9.6	60° double-V	0.06	1.5	0	0	1	310	26	215	91	18	8
							2	310	26	215	91	21	9
0.50	12.7	60° single-V	0.06	1.5	0	0	1	315	21	305	129	12	5
							2	315	21	305	129	13	5
							3	315	21	305	129	12	5
0.50	12.7	60° single-V	0.06	1.5	0	0	1	320	21	305	129	13	5
							2	320	21	305	129	7	5
0.50	12.7	60° single-V	0.13	3.3	0	0	1	310	26	215	91	18	8
							2	310	26	215	91	12	5
							3	310	26	215	91	18	8
0.50	12.7	60° double-V	0.06	1.5	0	0	1	310	26-28	215	91	12	5
							2	310	26-28	215	91	13	5

a. Direct current electrode positive and argon shielding

b. 0.062-in. (1.6-mm) diameter ERCuSi-A electrode avoid porosity. Autogenous welds or welds without sufficient filler metal addition can contain porosity.

Autogenous welds are possible in sheet up to 0.06 in. (1.5 mm) thick, although weld porosity may be a problem in the absence of deoxidation from the filler metal. Close control of arc length is recommended to minimize porosity.

Gas Metal Arc Welding

COPPER-NICKEL ALLOYS are welded with the gas metal arc welding (GMAW) process using direct current electrode positive current with either spray or short-circuiting transfer (see Table 3.20). Best results are obtained when welding section thicknesses of 0.25 in. (6.4 mm) and greater with spray transfer using either steady or pulsed current. The approximate welding conditions for steady current GMAW spray transfer with a 0.062 in. (1.6 mm) diameter ERCuNi electrode are given in Table 3.9. Pulsed current offers advantages when joining thin sections or welding in positions other than the flat position.

While argon is the recommended shielding gas for most applications, argon-helium mixtures give increased penetration in thick sections.

Proper joint design is important to obtain good complete fusion. V-groove and U-groove joints are recommended for GMAW. A typical V-groove has a 75 degree groove angle with a 0.062 in. (1.6 mm) root face and root opening. A single-V-groove design is satisfactory for section thicknesses from 0.28 to 0.50 in. (7.1 mm to 12.7 mm). Above 0.50 in. (12.7 mm), a double-V-groove or U-groove is recommended to reduce distortion. Copper or copper alloy backing or ceramic backing tape may be used with single-V-groove welds to control root surface contour. Care must be exercised to prevent gas entrapment in the root pass if X-ray quality is required.

Shielded Metal Arc Welding

COPPER-NICKEL ALLOYS may be welded with the shielded metal arc welding (SMAW) process using ECuNi covered electrodes. The electrode diameter for a particular application should be one size smaller than a comparable steel electrode for a similar steel application.

Copper-nickel weld metal is not as fluid as carbon-steel weld metal. Careful electrode manipulation is required to produce a good bead contour, and it is essential to maintain a short arc length. A weave bead is preferred with the weave width not exceeding three times the electrode core diameter. Stringer-bead technique may be used for welding deep groove welds. Slag must be thoroughly removed from each bead before depositing the next bead.

Representative joint designs and welding conditions for SMAW of 0.25 in. (6.4 mm) thick plate are given in Table 3.21. Square-groove joints with a root opening about one half the section thickness can be used on section thicknesses of less than 0.125 in. (3.2 mm). For thicker sections, V-groove and U-groove joint designs similar to those recommended for GMAW should be used.

Oxyfuel Gas Welding

COPPER-NICKEL ALLOYS can be welded using the oxyfuel gas welding (OFW) process, but its use should be limited to applications where arc welding equipment is not available. Welding is performed using ERCuNi welding rods with a soft and slightly reducing flame. An oxidizing flame will form a cuprous oxide that will dissolve in molten metal, reduce corrosion resistance, and cause embrittlement. Preheat is not recommended. Liberal use of a flux made especially for nickel or copper-nickel alloys is necessary to protect the welding rod and base metal from oxidation.

Table 3.20
Representative Conditions for Gas Metal Arc Welding of Copper-Nickel Alloy Plate

Thickness		Electrode Feed[a]		Arc Voltage,	Welding Current,[b]
in.	mm	in./min	mm/s	V	A
0.25	6.4	180-220	76-93	22-28	270-330
0.38	9.6	200-240	85-102	22-28	300-360
0.50	12.7	220-240	93-102	22-28	350-400
0.75	19.0	220-240	93-102	24-28	350-400
1.0	25.4	220-240	93-102	26-28	350-400
over 1.0	over 25.4	240-260	102-110	26-28	370-420

a. ERCuNi electrode, 0.062-in. (1.6-mm) diameter

b. Direct current electrode positive and argon shielding

Table 3.21
Representative Conditions for Shielded Metal Arc Welding of 1/4 in. (6.4 mm) Thick, 90% Copper-10% Nickel Alloy Plate

Welding Position	Joint Design		Root Opening		Weld Pass	Electrode Size		Welding[b] Current, A
	Groove Type	Groove Angle, Degrees	in.	mm		in.	mm	
Flat	Square	—	0.13	3.3	1, 2	1/8	3.2	115-120
Vertical[c]	Double-V	75-80	0.09-0.13	2.3-3.3	1, 2	3/32	2.4	85-90
Vertical[c]	Fillet	80	0	0	1	3/32	2.4	85
Horizontal	Single-V	75-80	0.06-0.13	1.5-3.3	1[d]	3/32	2.4	100
					2	1/8	3.2	100
Flat and overhead	Single-V	75-80	0.09-0.13	2.3-3.3	1[e]	1/8	3.2	110-115
					2	3/32	2.4	95-100

a. ECuNi covered electrodes.

b. Direct current electrode positive.

c. Direction of welding is up.

d. Backing weld pass. Back gouge before welding the other side (Pass 2).

e. Back gouge the root of the joint before completing the back weld (Pass 2).

Submerged Arc Welding

COPPER-NICKEL ALLOYS may be welded with the submerged arc welding (SAW) process. Section thicknesses greater than 0.50 in. (12.7 mm) are practical. V-groove and U-groove joint designs similar to those used in GMAW are satisfactory. Commercially available fluxes designed for welding copper-nickel should be used. Welding conditions, varying according to the flux used, are provided by the flux manufacturer. Careful attention to bead layer sequence is essential when multipass welds are deposited in a deep groove to ensure complete fusion while maintaining a flat bead contour. X-ray quality results are obtained when the technique is performed correctly.

BRAZING

BRAZING IS AN excellent process for joining copper and copper alloys. Surface oxides are easily fluxed during brazing except refractory oxides on aluminum bronzes (containing more than 8 percent aluminum), which require special techniques. When brazing is selected as the joining process, important considerations are brazing temperature, type of loading, joint strength, galvanic corrosion, and interaction between the base and filler metals at the service temperature.

All of the common brazing processes can be used except for special cases, such as resistance or induction brazing of copper and copper alloys that have high electrical conductivity.[4]

Both lap and butt joints may be used for brazements. The joint clearance must provide for capillary flow of the selected brazing filler metal throughout the joint at brazing temperature, and the thermal expansion characteristics of the alloy must be considered. A joint clearance of 0.001 to 0.005 in. (0.025 to 0.13 mm) will develop the maximum joint strength and soundness. Larger clearances may be used if reduction in joint strength is acceptable. When designing a brazed joint for a specific application, the properties and compatibility of the base metal-filler metal combination must be properly evaluated for the environment in which the brazed joint will operate.

For electrical conductivity applications, brazing filler metals generally have low electrical conductivity

---

[4] Additional information may be found in the *Welding Handbook*, 8th Ed., Vol. 2, 380-422, and the *Brazing Handbook*, 279-296. American Welding Society, 1991.

Table 3.22
Guide to Brazing Copper and Copper Alloys

Material	Commonly Used Brazing Filler Metals	AWS Brazing Atmospheres[c]	AWS Brazing Flux	Remarks
Coppers	BCuP-2[a], BCuP-3, BCuP-5[a], RBCuZn, BAg-1a, BAg-1, BAg-2, BAg-5, BAg-6, BAg-18	1, 2, or 5	FB3-A, C, D, E, I, J	Oxygen-bearing coppers should not be brazed in hydrogen-containing atmospheres.
High coppers	BAg-8, BAg-1	Note b	FB3-A	—
Red brasses	BAg-1a, BAg-1, BAg-2, BCuP-5, BCup-3, BAg-5, BAg-6, RBCuZn	1, 2, or 5	FB3-A, C, D, E, I, J	—
Yellow brasses	BCuP-4, BAg-1a, BAg-1, BAg-5, BAg-6, BCuP-5, BCuP-3	3, 4, or 5	FB3-A, C, E	Keep brazing cycle short.
Leaded brasses	BAg-1a, BAg-1, BAg-2, BAg-7, BAg-18, BCuP-5	3, 4, or 5	FB3-A, C, E	Keep brazing cycle short and stress relieve before brazing.
Tin brasses	BAg-1a, BAg-1, BAg-2, BAg-5, BAg-6, BCuP-5, BCuP-3 (RBCuZn for low tin)	3, 4, or 5	FB3-A, C, E	—
Phosphor bronzes	BAg-1a, BAg-1, BAg-2, BCuP-5, BCuP-3, BAg-5, BAg-6	1, 2, or 5	FB3-A, C, E	Stress relieve before brazing.
Silicon bronzes	BAg-1a, BAg-1, BAg-2	4 or 5	FB3-A, C, E	Stress relieve before brazing. Abrasive cleaning may be helpful.
Aluminum bronzes	BAg-3, BAg-1a, BAg-1, BAg-2	4 or 5	FB4-A	—
Copper-nickel	BAg-1a, BAg-1, BAg-2, BAg-18, BAg-5, BCuP-5, BCuP-3	1, 2, or 5	FB3-A, C, E	Stress relieve before brazing.
Nickel silvers	BAg-1a, BAg-1, BAg-2, BAg-5, BAg-6, BCuP-5, BCuP-3	3, 4, or 5	FB3-A, C, E	Stress relieve before brazing and heat uniformly.

a. Protective atmosphere or flux is not required for brazing copper with BCuP fillers.

b. Furnace brazing without flux is possible if the parts are first nickel or copper plated. Braze following the procedures recommended for nickel or copper.

c. Hydrogen, inert gas, or vacuum atmospheres usually are also acceptable (AWS Type 7, 9, or 10). Brazing atmospheres are listed below:

AWS Brazing Atmosphere	Source	Maximum Dew Point of Incoming Gas
1	Combusted fuel gas (low hydrogen)	Room temp.
2	Combusted fuel gas (decarburizing)	Room temp.
3	Combusted fuel gas, dried	-40 °F (-40 °C)
4	Combusted fuel gas, dried (carburizing)	-40 °F (-40 °C)
5	Dissociated ammonia	-65 °F (-54 °C)
6A	Cryogenic and purified N_2+H_2	-90 °F (-68 °C)
6B	Cryogenic and purified N_2+H_2+CO	-20 °F (-29 °C)
6C	Cryogenic and purified N_2	-90 °F (-68 °C)
7	Hydrogen, deoxygenated and dried	-75 °F (-59 °C)
9	Purified inert gas	—
10	Vacuum	—

compared to copper. Nevertheless, a braze joint when properly designed will not add appreciable resistance to the circuit. For example, silver filler metal has little effect on the resistance in properly fitted braze joints having a joint clearance of 0.003 in. (0.08 mm).

FILLER METALS

ALL OF THE silver (BAg), copper-phosphorus (BCuP), gold (BAu), and copper-zinc (RBCuZn) filler metals are suitable for brazing copper, provided their liquidus temperature is sufficiently lower than the melting range of the base material.[5] The brazing filler metals that are commonly used for copper and copper alloys are listed in Table 3.22. Filler metals also are listed by chemical composition and brazing temperature range in Table 3.23.

All BAg filler metals may be used with any copper or copper alloy. BAu filler metals are used for electronic applications where the vapor pressure of the brazing filler metal is important.

BCuP filler metals can be used to braze most copper alloys, including some copper-nickel alloys containing less than 10 percent nickel. Any copper-nickel alloy should be evaluated by an appropriate brazing test because of the possibility of creating brittle joints. No flux is required to braze copper with BCuP. Beryllium-copper should not be brazed with BCuP since it will result in porous joints with low strength.

When corrosion resistance is not important, the RBCuZn filler metals may be used to join the coppers, copper-nickel, copper-silicon, and copper-tin alloys. The RBCuZn liquidus temperature is too high for brazing the brasses and nickel silvers. Torch brazing the aluminium bronzes precludes the use of high brazing temperature RBCuZn.

FLUXES AND ATMOSPHERES

RECOMMENDED BRAZING FLUXES and furnace atmospheres for brazing coppers and copper alloys are shown in Table 3.22. Flux classification FB3-A, FB3-C, and FB3-D are suitable for use with BAg and BCuP filler metals for brazing all copper alloys except the aluminum bronzes. A more reactive flux classification FB4-A is used for aluminum bronze. Flux classifications FB3-C, FB3-D, and FB3-K are required with RBCuZn filler metals because of their high brazing temperatures.

Combusted fuel gases are economical brazing atmospheres for copper and copper alloys, except for oxygen-bearing copper. Atmospheres with a high-hydrogen content cannot be used when brazing oxygen-bearing copper; hydrogen diffuses into the copper, reduces copper oxide, and forms water vapor that will rupture the copper. Inert gases that have proper dew points also are suitable atmospheres for brazing copper and copper alloys.

Table 3.23
Commonly Used Brazing Filler Materials for Copper and Copper Alloys*

AWS Classification	UNS No.	Composition, wt. %								Brazing Temperature Range	
		Ag	Cu	Zn	Cd	Sn	Fe	Ni	P	°F	°C
BAg-1	P07450	44-46	14-16	14-18	23-25	—	—	—	—	1145-1400	618-760
BAg-1a	P07500	49-51	14.5-16.5	14.5-18.5	17-19	—	—	—	—	1175-1400	635-760
BAg-2	P07350	34-36	25-27	19-23	17-19	—	—	—	—	1295-1550	702-843
BAg-3	P07501	49-51	14.5-16.5	13.5-17.5	15-17	—	—	2.5-3.5	—	1270-1500	688-816
BAg-5	P07453	44-46	29-31	23-27	—	—	—	—	—	1370-1550	743-843
BAg-6	P07503	49-51	33-35	14-18	—	—	—	—	—	1425-1600	774-871
BAg-7	P07563	55-57	21-23	15-19	—	4.5-5.5	—	—	—	1205-1400	652-760
BAg-8	P07720	71-73	Bal.	—	—	—	—	—	—	1435-1650	780-899
BAg-18	P07600	59-61	Bal.	—	—	9.5-10.5	—	—	—	1325-1550	718-843
BCu-1	C14180	—	99.9 min	—	—	—	—	—	0.75	2000-2100	1093-1149
RBCuZn-A	C47000	—	57-61	Bal.	—	0.25-1.0	—	—	—	1670-1750	910-955
RBCuZn-C	C68100	—	56-60	Bal.	—	0.8-1.1	0.25-1.2	—	—	1670-1750	910-955
RBCuZn-D	C77300	—	46-50	Bal.	—	—	9-11	—	0.25	1720-1800	938-982
BCuP-2	C55181	—	Bal.	—	—	—	—	—	7.0-7.5	1350-1550	732-843
BCuP-3	C55281	4.8-5.2	Bal.	—	—	—	—	—	5.8-6.2	1325-1500	718-816
BCuP-4	C55283	5.8-6.2	Bal.	—	—	—	—	—	7.0-7.5	1275-1450	691-788
BCuP-5	C55284	14.5-15.5	Bal.	—	—	—	—	—	4.8-5.2	1300-1500	704-816

* Refer to ANSI/AWS A5.8, *Specification for Filler Metals for Brazing and Braze Welding.*

---

[5] All brazing filler metals are covered in ANSI/AWS A5.8, *Specification for Filler Metals for Brazing and Braze Welding.*

Vacuum is a suitable brazing environment, provided neither base metal nor filler metal contains elements that have high vapor pressures at brazing temperature. Zinc, phosphorus, and cadmium are example of elements that vaporize when heated in vacuum.

SURFACE PREPARATION

GOOD WETTING AND flow of filler metal in brazed joints can only be achieved when the joint surfaces are clean and free of oxides, dirt, and other foreign substances. Standard solvent or alkaline degreasing procedures are suitable for cleaning copper base metals. Mechanical methods may be used to remove surface oxides, but care should be taken to leave the metal free of undesirable films or deposits. Chemical removal of surface oxides requires an appropriate pickling solution.

Workers must be trained in proper safety practices for handling and mixing acid solutions to prevent injury when acid cleaning is used. Workers also must be supplied with protective clothing and equipment including eye, face, and body protection. Work areas must be properly ventilated and equipped with safety showers and eyewash stations. Proper dilution and disposal of acid solutions also is required.

Typical chemical cleaning procedures are as follows:

Copper

IMMERSE IN COLD 5 to 15 percent by volume sulfuric acid for 1 to 5 minutes; rinse in cold water followed by hot water rinse, and air blast dry.

Beryllium-Copper

USE THE FOLLOWING two steps:

(1) Immerse in 20 percent by volume sulfuric acid at 160 to 180 °F (71 to 82 °C) until the dark scale is removed, then water rinse.

(2) Dip in cold 30 percent nitric acid solution for 15 to 30 seconds, then rinse in hot water, and air blast dry.

Chromium-Copper and Copper-Nickel Alloys

IMMERSE IN HOT 5 percent by volume sulfuric acid for 1 to 5 minutes. Cold water rinse followed by hot water rinse, and air blast dry.

Brass and Nickel-Silver

IMMERSE IN COLD 5 percent by volume sulfuric acid-cold rinse, hot rinse, and air blast dry.

Silicon Bronze

IMMERSE FIRST IN hot 5 percent by volume sulfuric acid, rinse in cold water, and immerse in a cold mixture of 2 percent by volume hydrofluoric acid and 5 to 15 percent by volume sulfuric acid for 1 to 10 minutes. Cold rinse followed by hot rinse, and air blast dry.

Aluminum Bronze

TOUGH ALUMINUM OXIDE can be removed or loosened using a strong alkali solution of sodium hydroxide (10 wt. percent) at 170 °F (75 °C). Immerse for 2 to 5 minutes and cold rinse followed by successive immersions in two solutions:

(1) Cold 2 percent hydrofluoric acid and 3 percent sulfuric acid mixture for 1 to 5 minutes; cold water rinse, then immerse in:

(2) A solution of 5 percent by volume sulfuric acid at 80 to 120 °F (27 to 49 °C) for 1 to 5 minutes, cold water rinse, hot water rinse, and air blast dry.

Copper Plate

IT IS OFTEN desirable to copper plate the faces of copper alloys that contain strong oxide-forming elements to simplify brazing and fluxing requirements. Copper plate about 0.001 in. (0.025 mm) thick is used on chromium-copper alloys while about 0.0005 in. (0.013 mm) thickness is sufficient on beryllium copper, aluminum bronze, and silicon bronze.

BRAZING COPPER

OXYGEN-FREE, HIGH conductivity copper and deoxidized copper are readily brazed by furnace or torch methods. Boron-deoxidized copper is sometimes preferred when brazing at high temperatures because grain growth is less pronounced than with the other coppers.

Oxygen-bearing coppers are susceptible to oxide migration and hydrogen embrittlement at elevated temperatures. These coppers should be furnace brazed in an inert atmosphere or torch brazed with a neutral or slightly oxidizing flame.

The copper-phosphorus and copper-silver-phosphorus filler metals (BCuP) are considered self-fluxing on copper. A flux is beneficial for massive copper assemblies where prolonged heating results in excessive oxidation. During brazing, the filler metal loses some phosphorus, which results in a slight increase in the remelt temperature. Joints brazed with phosphorus-containing filler metal should not be exposed to sulfurous atmospheres at elevated temperature. Exposure for long periods results in corrosive attack of the joint.

With the copper-zinc (RBCuZn) filler metals, the recommended brazing temperatures should not be exceeded to avoid volatilization of zinc and resulting porosity in the joint. When torch brazing, an oxidizing flame will reduce zinc fuming. The corrosion resistance of these filler metals is inferior to that of copper.

A lap joint will develop the full strength of annealed copper at room temperature when the overlap is at least three times the thickness of the thinner member. As the service temperature increases, the brazing filler metal strength decreases more rapidly than does the strength of the copper or copper alloy, and failure will eventually occur through the joint. The tensile strength at room, elevated, and sub-zero temperatures for single-lap brazed joints in copper is shown in Table 3.24. Typical creep properties for tough-pitch copper brazed with BAg-1A, BAg-6, and BCup-5 filler metals are shown in Figure 3.5. At 77 and 260 °F (25 and 127 °C), failures were in the base metal.

BRAZING HIGH-COPPER ALLOYS

Beryllium-Copper

THE SURFACES OF beryllium-copper components must be cleaned prior to brazing. The oxide scale can be removed by pickling.

The 2 percent beryllium-copper can be brazed by either of two methods. The more common procedure involves simultaneous brazing and solution heat treatment at 1450 °F (788 °C) in a furnace. The silver-copper eutectic filler metal, BAg-8, is generally used with an AWS flux classification FB3-A. The furnace temperature is quickly lowered to 1400 °F (760 °C) to solidify the brazing filler metal. The brazement is then quenched in cold water, and finally age hardened at 600 to 650 °F (316 to 343 °C).

A second method, used with thin sections that can be heated rapidly (preferably in one minute or less), permits brazing at a temperature below the beryllium-copper solution anneal temperature. The brazement can be precipitation hardened without having to be solution treated. Fast heating rates can be attained using an OAW torch or by resistance heating. Brazing is satisfactorily performed using BAg-1 filler metal and flux classification FB3-A, but other silver brazing filler metals may be suitable for special applications.

The 0.5 percent beryllium-copper alloys are solution heat-treated at 1700 °F (927 °C), quenched in cold water, and age hardened between 850 and 900 °F (454 and 482 °C). This alloy can be brazed rapidly with BAg-1 filler metal at about 1200 °F (649 °C) after being precipitation hardened, but the base metal is overaged during brazing resulting in hardness and strength property loses.

Chromium-Copper and Zirconium-Copper

CHROMIUM-COPPER AND ZIRCONIUM-COPPER are solution heat-treated at 1650 to 1850 °F (700 to 1010 °C), quenched, and age hardened at 900 °F (482 °C). Brazing with BAg filler metals and a fluoride-type flux should be performed after a solution heat treatment and before age hardening. The mechanical properties of the base metal after brazing and precipitation hardening will be lower than those of the solution treated and age-hardened material that has not been brazed.

Brazing followed by solution treatment and age hardening of chromium-copper results in near optimum

Table 3.24
Tensile Strength of Single-Lap Brazed Joints in Deoxidized Copper*

Brazing Filler Metal	Tensile Strength					
	-321 °F (-196 °C)		72 °F (22 °C)		400 °F (204 °C)	
	ksi	MPa	ksi	MPa	ksi	MPa
BAg-1	30.1	208	19.0	131	9.7	67
BAg-6	28.0	193	17.6	121	—	—
BAg-8	24.7	170	17.6	121	—	—
BCuP-2	17.9	123	18.6	197	10.7	74
BCuP-4	21.4	150	19.1	132	—	—
BCup-5	21.9	151	17.9	123	10.8	74

* Specimens were made from 0.25 in. (6.4 mm) thick sheet; joints had an overlap of 0.15 in. (3.8 mm) and no braze fillet.

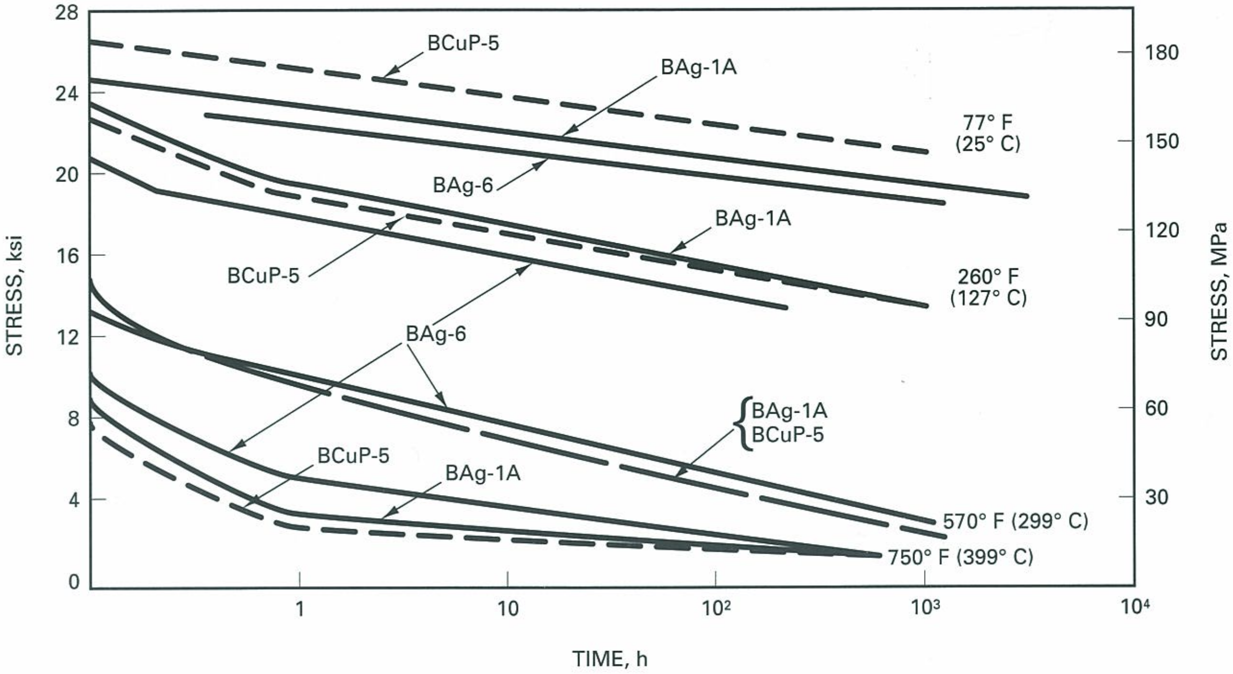


Figure 3.5—Stress-Rupture Strength Curves for Copper Brazed with Three Filler Metals Using a Plug and Ring Creep Specimen

mechanical properties. Distortion caused by quenching from the solution anneal temperature should be evaluated for each application.

Cadmium-Copper

CADMIUM-COPPERS ARE BRAZED in the same manner as deoxidized copper.

BRAZING COPPER-ZINC ALLOYS (BRASS)

ALL BRASSES CAN be brazed with BAg and BCuP, and RBCuZn filler metals. AWS classification FB3-C flux is used with BAg and BCuP filler metals, and FB3-Kwith RBCuZn filler metals.

Zinc fuming above 750 °F (399 °C) is reduced by fluxing the parts before furnace brazing, even when a protective atmosphere is used. Torch brazing with an oxidizing flame is also used to reduce zinc fuming. Brasses subject to cracking when heated too rapidly (i.e., leaded brasses) should be heated uniformly and slowly to the brazing temperature. Sharp corners and other stress risers that localize thermal strain during heating should be avoided. Good practice dictates heating parts slowly to brazing temperature.

Brasses containing aluminum or silicon require cleaning and brazing procedures similar to those used for aluminum or silicon bronze. Lead in brass may alloy with the brazing filler metal and cause brittleness, especially when the lead content exceeds 3 percent. This can reduce the strength of the joint. Leaded brasses require complete flux coverage both to prevent the formation of lead oxide or dross and to maintain good flow and wetting during brazing.

Stress-relieving before brazing and slow, uniform heating minimizes the tendency of high-leaded brasses to crack. Rapid heating to the brazing temperature is to be avoided.

BRAZING COPPER-TIN ALLOYS (PHOSPHOR BRONZE)

IN A STRESSED condition, phosphor bronzes are subject to cracking during heating. Good practice dictates that the parts to be brazed are processed as follows:

(1) Stress relieve or anneal before brazing.

(2) Support with suitable fixtures for maintaining a stress-free condition during brazing.

(3) Apply flux to completely cover the joint surfaces.

(4) Use a slow heating cycle.

All of the phosphor bronzes can be brazed with BAg and BCuP filler metals, although alloys with low-tin content can be brazed with RBCuZn filler metal.

The phosphor bronze parts are sometimes made by compacting and sintering powdered metal. Before they are brazed, areas of powdered metal parts away from the braze joint must be treated to seal pores in order to restrict the penetration of the brazing filler metal. Pores can be sealed by painting the surface of a powdered metal part with a colloidal graphite suspension and then baking at a low temperature followed by a cleaning procedure.

BRAZING COPPER-ALUMINUM ALLOYS (ALUMINUM BRONZE)

ALUMINUM BRONZE IS brazed with BAg brazing filler metals and AWS classification FB4-A flux. Refractory aluminum oxide forms at brazing temperature on the surfaces of bronze containing more than 8 percent aluminum. The brazing procedures must prevent aluminum oxide formation to obtain satisfactory flow and wetting of joint surfaces. In furnace brazing, flux should be used in addition to the protective atmosphere.

Copper plating on joint surfaces prevents formation of aluminum oxide during brazing. Copper plated parts are brazed using procedures suitable for brazing copper.

BRAZING COPPER-SILICON ALLOYS (SILICON BRONZE)

COPPER-SILICON ALLOYS should be cleaned and then either coated with flux or copper plated before brazing; this prevents the formation of refractory silicon oxide on joint surfaces during brazing. Copper plating is recommended as the method that produces best results. Mechanical or chemical cleaning is used to remove oxide contamination from the joint surfaces. Silver brazing filler metals and AWS classification FB3-C flux are used to braze copper-silicon alloys.

When furnace brazing, a flux should be used in combination with a protective atmosphere. Silicon bronze is subject both to intergranular penetration by the filler metal and to hot-shortness when stressed. Components should be stress-relieved before brazing, adequately supported by fixtures during heating, and brazed below 1400 °F (760 °C).

BRAZING COPPER-NICKEL ALLOYS

COPPER-NICKEL ALLOYS are brazed with BAg and BCuP filler metals, although BCuP filler metal forms a brittle nickel phosphide with alloys containing more than 10 percent nickel. The structure and properties of joints brazed with BCuP filler metal should be thoroughly evaluated for the intended application. AWS classification FB3-C flux is suitable for most applications.

The base metal surfaces must be free of sulfur or lead that could cause cracking during the brazing cycle. Solvent or alkaline degreasing procedures are used to remove grease or oil. Surface oxides can be removed by either mechanical or chemical cleaning, or both.

Copper-nickel alloys in a cold-worked condition are susceptible to intergranular penetration by molten filler metal. They should be stress-relieved before brazing to prevent cracking.

BRAZING COPPER-NICKEL-ZINC ALLOYS (NICKEL-SILVER)

NICKEL-SILVERS CAN be brazed using the same filler metals and procedures for brazing brasses. If RBCuZn filler metal is used, precautions should be taken when brazing at relatively high temperatures. These alloys in the stressed condition are subject to intergranular penetration by the filler metal and should be stress-relieved before brazing. Nickel-silvers have poor thermal conductivity and should be heated slowly and uniformly to brazing temperature in the presence of sufficient flux.

BRAZING DISSIMILAR METALS

DISSIMILAR COPPER ALLOYS can be brazed readily. Copper alloys are brazed to steel, stainless steel, and nickel alloys. Suggested brazing filler metals for dissimilar metal combinations are given in Table 3.25.

Table 3.25
Recommended Filler Metals for Brazing Copper Alloys to Other Metals

Carbon and Low Alloy Steels	Cast Iron	Stainless Steels	Tool Steels	Nickel Alloys	Titanium Alloys	Reactive Metals	Refractory Metals
BAg	BAg	BAg	BAg	BAg	BAg	BAg	BAg
BAu	BAu	BAu	BAu	BAu	—	—	—
RBCuZn	RBCuZn	—	RBCuZn	RBCuZn	—	—	—
—	—	—	BNi	—	—	—	—

SOLDERING

COPPER AND COPPER alloys are among the most frequently soldered engineering materials. The degree of solderability, as shown in Table 3.26, ranges from excellent to difficult.[6] No serious problems arise in soldering most copper alloys, but alloys containing beryllium, silicon, or aluminum require special fluxes to remove surface oxides.

The high thermal conductivity of copper and some of its alloys require a high rate of heat input when localized heating is used.

SOLDERS

THE MOST WIDELY used solders for joining copper and its alloys are the tin-lead solders, although in drinking water application tin-antimony or tin-silver solder is used to eliminate possible lead contamination of the water. Tin readily alloys and diffuses into copper and copper alloys. Copper alloys accept a certain amount of tin into solid solution, but one or more intermetallic phases (probably Cu_6Sn_5) will form when the solid solubility limit is exceeded. An intermetallic phase forms at the faying surfaces of solder joints, and faying surfaces tends to be brittle, so that their thickness should be minimized by proper selection of process variables

---

[6] Additional information on soldering, solders, and fluxes may be found in the *Welding Handbook*, Vol. 2, 8th Ed., 423-447, and the *Soldering Manual*, 2nd Ed., American Welding Society, 1977.

Table 3.26
Solderability of Copper and Copper Alloys

Base Metal	Solderability
Copper (Includes tough-pitch, oxygen-free, phosphorized, arsenical, silver-bearing, leaded, tellurium, and selenium copper.)	Excellent. Rosin or other noncorrosive flux is suitable when properly cleaned.
Copper-tin alloys	Good. Easily soldered with activated rosin and intermediate fluxes.
Copper-zinc alloys	Good. Easily soldered with activated rosin and intermediate flux.
Copper-nickel alloys	Good. Easily soldered with intermediate and corrosive fluxes.
Copper-chromium and copper-beryllium	Good. Require intermediate and corrosive fluxes and precleaning.
Copper-silicon alloys	Fair. Silicon produces refractory oxides that require use of corrosive fluxes. Should be properly cleaned.
Copper-aluminum alloys	Difficult. High aluminum alloys are soldered with help of very corrosive fluxes. Precoating may be necessary.
High-tensile manganese bronze	Not recommended. Should be plated to ensure consistent solderability.

and service conditions.As the thickness of the intermetallic layer increases, the strength of the soldered joint will decrease, and service at elevated temperatures accelerates this change.

FLUXES

ORGANIC AND ROSIN types of noncorrosive fluxes are excellent for soldering coppers and may be used with some success on copper alloys containing tin and zinc, if surfaces to be soldered are precleaned. These fluxes are used for soldering electrical connections and electronic components. A light coat of flux should be applied to precleaned faying surfaces.

The inorganic corrosive fluxes can be used on all the copper alloys, but they are required only on those alloys that develop refractory surface oxides, such as silicon and aluminum bronze. Aluminum bronze is especially difficult to solder and requires special fluxes or copper plating. Inorganic chloride fluxes are useful for soldering the silicon bronzes and copper-nickels.

Oxide films reform quickly on cleaned copper alloys, and fluxing and soldering should be done immediately after cleaning. Copper tube systems soldered with 50% tin-50% lead or 95% tin-5% antimony solder require a mildly corrosive liquid flux or petrolatum pastes containing zinc and ammonium chlorides. Many liquid fluxes for plumbing application are self-cleaning, but there is always a risk of corrosive action continuing after soldering.

A highly corrosive flux can remove some oxides and dirty films, but there is always an uncertainty whether uniform cleaning has been achieved and whether corrosive action continues after soldering. Optimum soldering always starts with clean surfaces and a minimum amount of flux.

SURFACE PREPARATION

SOLVENT OR ALKALINE degreasing and pickling are suitable for cleaning copper base metals, with mechanical methods used to remove oxides. Chemical removal of oxides requires proper choice of a pickling solution followed by thorough rinsing. Typical procedures used for chemical cleaning are the same as those described previously for brazing.

COATED COPPER ALLOYS

THE MOST COMMONLY employed coating for copper alloys are tin, lead, tin-lead, nickel, chromium, and silver. Soldering procedures depend upon coating characteristics. Except for chromium plate, none of the coating materials present any serious soldering difficulty. Before soldering chromium-plated copper, the chromium must be removed from the joint faces. Thermal conductivity of the base metal must be considered.

FLUX REMOVAL

AFTER THE JOINT is soldered, flux residues that may prove harmful to the serviceability of the joint must be removed. Removal of flux residues is especially important when the joints will be exposed to humid environments. Organic and inorganic flux residues that contain salts and acids should be removed completely.

Non-activated rosin flux residues may remain on the soldered joint unless appearance is important or the joint area is to be painted or otherwise coated. Activated rosin fluxes are treated in the same manner as organic fluxes for structural soldering, but they should be removed for critical electronic applications.

Zinc chloride fluxes leave a fused residue that absorbs water from the atmosphere. Removal of this residue is best accomplished by thorough washing in a hot solution of 2% concentrated hydrochloric acid [2.5 oz./gal (20 ml/L)], followed by a hot water rinse and air blast drying. The acid solution removes the white zinc oxychloride crust, which is insoluble in water. Complete removal sometimes requires additional rinsing in hot water that contains some washing soda (sodium carbonate), followed by a clear water rinse. Mechanical scrubbing may also be necessary.

The residues from the organic fluxes are quite soluble in hot water. Double rinsing is always advisable. Oily or greasy paste flux residues may be removed with an organic solvent. Soldering pastes are emulsions of petroleum jelly and a water solution of zinc-ammonium chloride. The corrosive chloride residue must be removed from the soldered joint.

When rosin residues are to be removed, alcohol or chlorinated hydrocarbons are used. Certain rosin activators are soluble in water but not in organic solvents. This flux residue is removed using organic solvents, followed by water rinsing.

MECHANICAL PROPERTIES

THE MECHANICAL PROPERTIES of a soldered joint depend upon a number of process variables in addition to the solder composition. These variables include the solder thickness in the joint, base metal composition, type of flux, soldering temperature, soldering time, and cooling rate.

Soldered joints are normally designed to be loaded in shear. Shear strength and creep strength in shear are the important mechanical properties. For specialized applications such as auto radiators, peel strength and fracture initiation strength may be important, and in a few cases, tensile strength is of interest.

Shear Strength

SHEAR STRENGTH IS determined using single- or double-lap flat specimens or sleeve-type cylindrical specimens. Testing is done with a cross-head speed of 1.0 or 0.1 in./min (25.4 or 2.54 mm/min). The shear strengths of copper joints soldered with lead-tin solders are shown in Figure 3.6. The maximum joint shear strength is obtained with eutectic composition solder (63% tin-37% lead). Shear strength may decrease up to 30 percent if the joints are aged at room temperature or at moderately elevated temperature for several weeks prior to testing.

Shear strength of soldered joints decreases with increasing temperature, as shown in Figure 3.7 for two solders commonly used in copper plumbing. Many solders remain ductile at cryogenic temperatures, and their strengths increase significantly as the temperature decreases below room temperature.

Creep Strength

THE CREEP STRENGTH of a soldered joint in shear is considerably less than its short-time shear strength, sometimes below 10 percent. The creep shear strengths of copper joints soldered with three solders are shown in Figure 3.8. The 50% tin-50% lead and 95% tin-5% antimony solders have about the same short-time shear strengths, but the tin-antimony solder has much greater long-time creep strength.

Tensile Strength

TYPICAL TENSILE STRENGTHS of soldered butt joints made with five compositions of tin-lead solder are presented in Table 3.27. Soldered joints are much stronger in tension than in shear. Tensile strength increases with increasing tin content up to the eutectic composition. Soldering is not recommended for butt joints in copper because voids in the solder layer will cause premature failure through the solder when the joint is loaded.

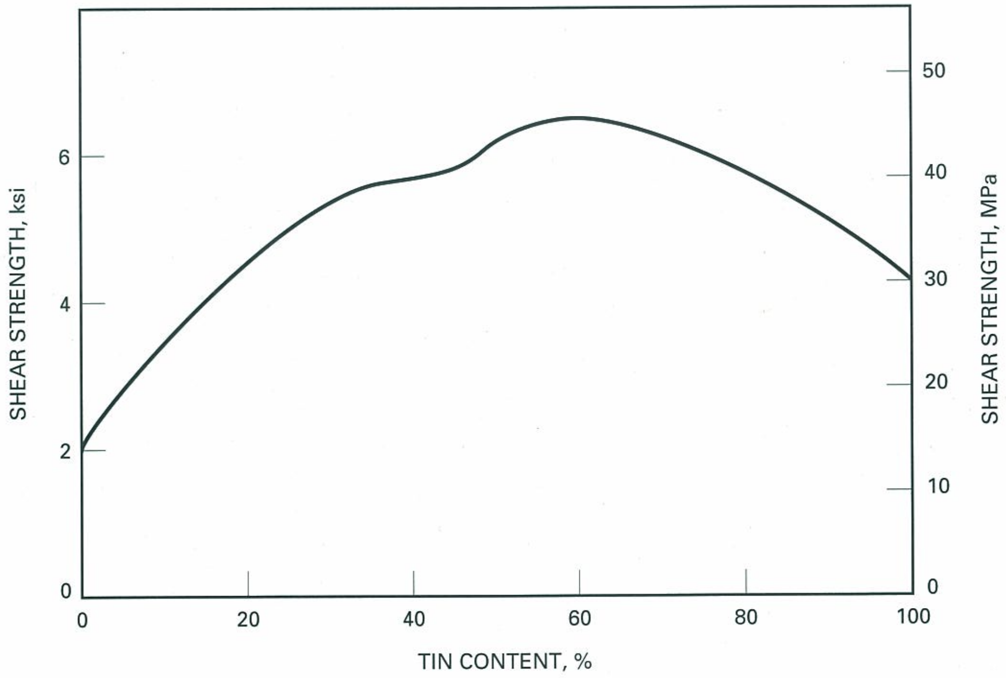


Figure 3.6—Shear Strengths of Copper Joints Soldered with Tin-Lead Solders

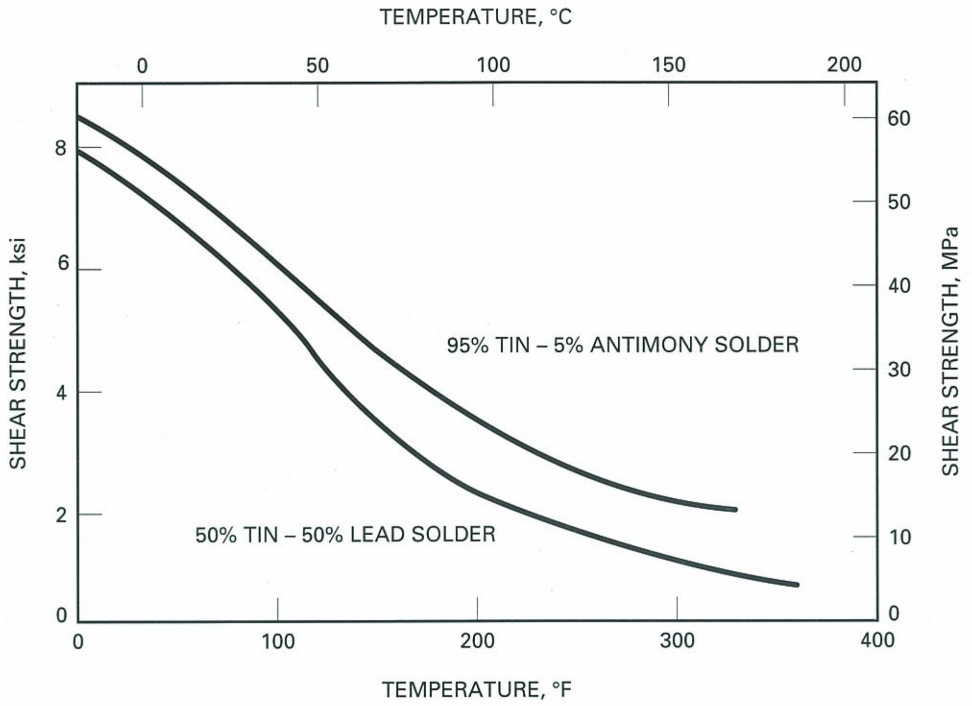


Figure 3.7—Shear Strengths at Elevated Temperatures for Soldered Copper Joints

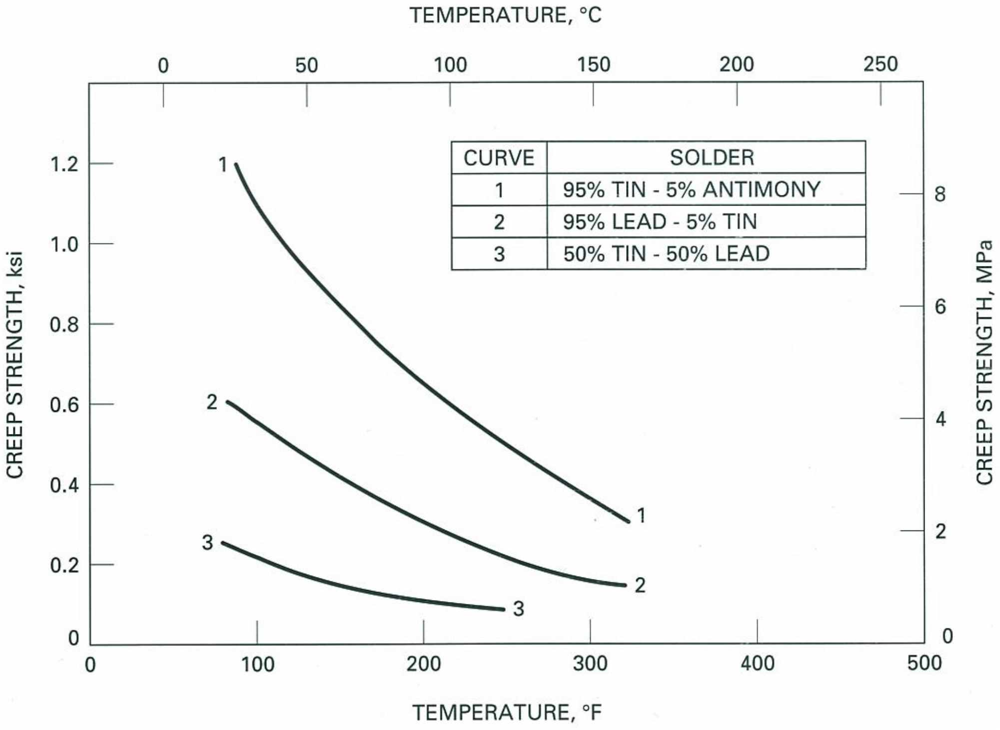


Figure 3.8—Creep Strengths at Elevated Temperatures for Soldered Copper Joints

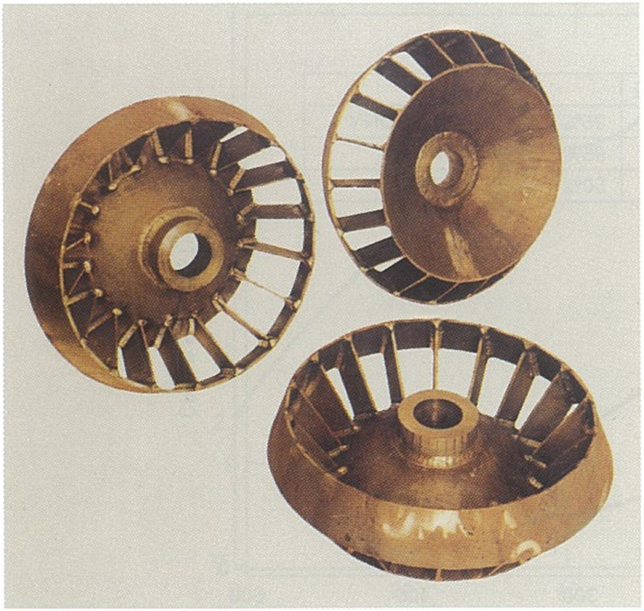
Table 3.27
Tensile Strength of Soldered Copper Butt Joints

Solder Composition, %		Tensile Strength	
Tin	Lead	ksi	MPa
20	80	11.3	77.9
30	70	13.8	95.1
40	60	16.8	115.8
50	50	18.2	125.5
63	37	19.6	135.1

APPLICATIONS

COOLING FANS FOR ELECTRIC MOTORS

COOLING FANS FOR explosion-proof electric motors are fabricated from copper alloys because of their non-magnetic and non-sparking properties (see Figure 3.9).[7] The central hub of each fan is a centrifugally cast tin-bronze alloy that contains 1.5 percent tin and 0.3 percent phosphorus. The conical base, outer ring, and fins are 3/16 in. (4.8 mm) thick C61300 aluminum bronze. Components are assembled and welded with the gas tungsten arc welding (GTAW) process using argon shielding gas and 3/32 in. (2.4 mm) diameter ERCuAl-A2 filler metal. Direct welding current electrode negative is used at 135 amperes.



Courtesy of Ampco Metal, Inc.

Figure 3.9—Cooling Fans for Electric Motors Welded Using the GTAW Process

SEAWATER DISTILLERS FOR SHIPBOARD INSTALLATION

A SUBMERGED TUBE distilling plant that produces 3000 gallons (11 356 L) a day of fresh water aboard a ship is shown in Figure 3.10.[8] This distilling plant is fabricated from ASTM B171M Type 90/10 copper-nickel (C70600) plate and ASTM B111 tube ranging in thickness from 0.1 to 1 in. (2.5 to 25 mm).

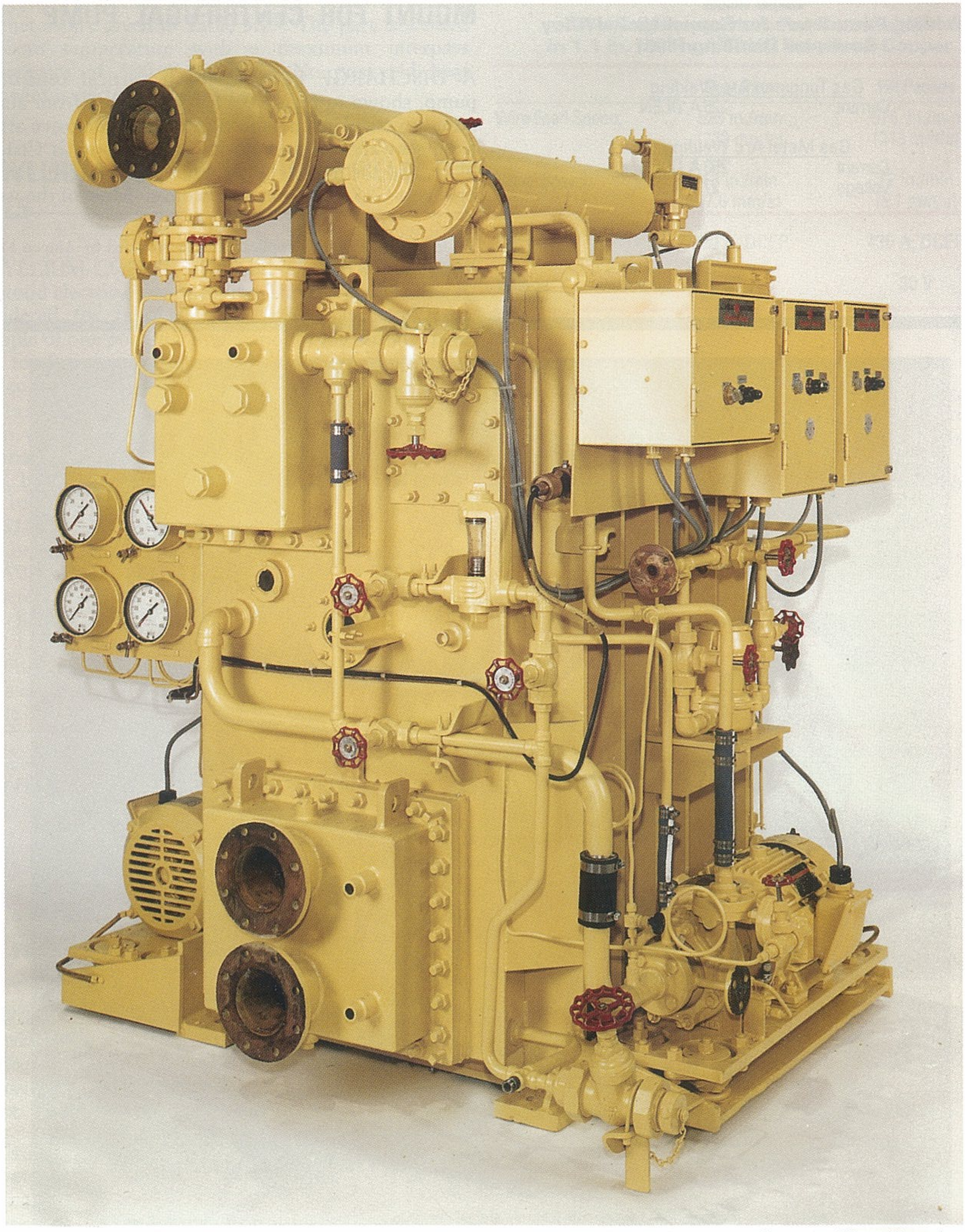
Copper alloy C70600 is used because the excellent seawater corrosion resistance of this alloy gives this design long-term dependability. Copper alloy C70600 is also important for this particular distilling plant, used aboard a minesweeper in which the materials must have low magnetic permeability. This distiller also is economical to operate because it uses waste heat.

The distilling plant is welded with the GMAW and GTAW processes using ERCuNi filler metal and argon shielding gas. Welding parameters are shown in Table 3.28. No preheat is used but welding is restricted to a minimum material temperature of 60 °F (16 °C). Maximum interpass temperature is 300 °F (149 °C). The unit is not postweld heat treated.

---

[7] Information on this application was provided by Ampco Metal, Inc.

[8] Information on this application was provided by Aqua-Chem, Inc.



Courtesy of Aqua-Chem, Inc.

Figure 3.10—Submerged Tube Seawater Distilling Plant Fabricated with Copper-Nickel Alloy

Table 3.28
Welding Parameters for Copper-Nickel Alloy Seawater Distilling Plant

Gas Tungsten Arc Welding	
Current	225 A, DCEN
Gas Metal Arc Welding	
Current	250 A, DCEP
Voltage	27 V

DISCHARGE ELBOW AND MOTOR MOUNT FOR CENTRIFUGAL PUMP

A DISCHARGE ELBOW for a vertical centrifugal pump, shown in Figure 3.11, is fabricated from aluminum bronze plate and castings to resist corrosive attack from seawater.[9] The majority of the elbow is C61300 plate, and the flange rings are temper annealed, centrifugal cast C95200 aluminum bronze. Most of the welds

---

[9] Information on this application was provided by Ampco Metal, Inc.

Courtesy of Ampco Metal, Inc.

Figure 3.11—Pump Discharge Elbow Fabricated with Aluminum Bronze

on this part are GMAW, although the root passes in full penetration joints are deposited with GTAW. Welding parameters are given in Table 3.29. The part is welded at room temperature with a maximum interpass temperature of 500 °F (260 °C). No postweld heat treatment is performed.

BERYLLIUM-COPPER TOROIDAL FIELD COILS

BERYLLIUM-COPPER COMBINES HIGH strength and good electrical conductivity. Therefore, this alloy is considered for fabrication of large conductors. An example of one potential application is for toroidal field coils for fusion reactor research.[10] A concept toroidal field coil is shown in Figure 3.12.

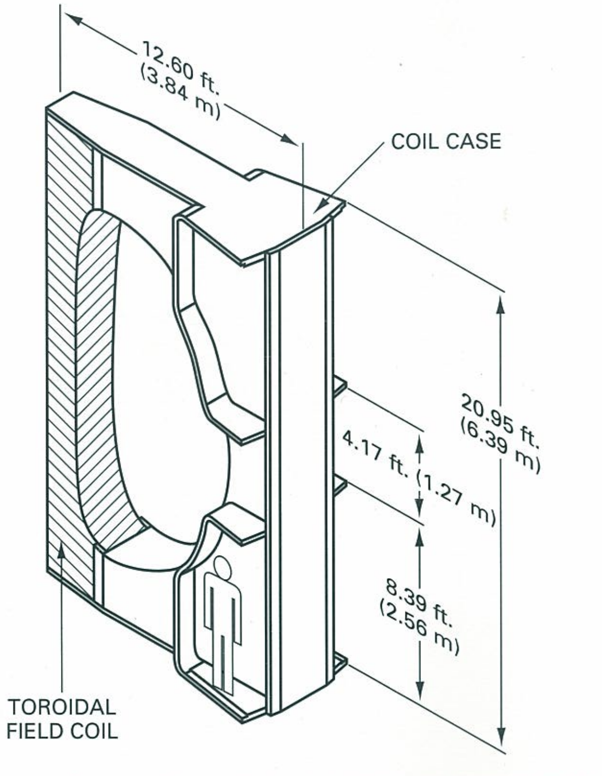
Fabrication of this coil would require butt welding of 1.1 in. (28 mm) thick beryllium-copper plates to form a coil that would be 20 ft (6.1 m) high by 12 ft (3.65 m) wide. Butt welds must have strengths that are equivalent to the base metal. The beryllium-copper alloy C17510, Cu-0.3Be would be used. Butt welds have been produced in double-U-joint preparations using the GMAW process. Filler metal was 0.045-in. (1.14-mm) diameter C17200, Cu-1.9Be alloy and shielding gas was 75% helium-25% argon at a flow rate of 100 ft^3/hr (47.2 L/min). Plates were preheated to 300 °F (149 °C). Welding parameters are given in Table 3.30. Completed welds can be postweld heat treated to develop ultimate tensile strengths of 99 ksi (683 MPa) and yield strengths of 85 ksi (586 MPa). Welding, grinding, and machining of beryllium-copper require special precautions compared to other copper alloys because of greater potential health hazards. Testing of the shop environment is necessary to ensure that controls are adequate to protect workers.

Table 3.29
Welding Parameters for Aluminum Bronze Discharge Elbow

Gas Tungsten Arc Welding	
Filler metal:	3/32 or 1/8 in. (2.4 or 3.2 mm) diam. ERCuAl-A2
Shielding gas:	Helium or argon/helium
Gas flow rate:	35 to 40 ft^3/hr (17 to 19 L/min)
Current:	190 to 220 A, DCEN
Gas Metal Arc Welding	
Filler metal:	1/16 in. (1.6 mm) diameter ERCuAl-A2
Shielding gas:	Argon
Gas flow rate:	45 to 55 ft^3/hr (21 to 26 L/min)
Current:	320 A, DCEP
Voltage:	29 to 32 V

Table 3.30
Welding Parameters For Butt Welds in 1.1 in. (28 mm) Thick Beryllium-Copper

	Root Pass	Fill Passes
Wire Feed Speed:	525 in./min (222 mm/s)	575 in./min (243 mm/s)
Travel Speed:	18 in./min (7.6 mm/s)	12 in./min (5.1 mm/s)
Current:	390 A, DCEP	430 A, DCEP
Voltage:	30 V	30 V



Courtesy of Princeton Plasma Physics Lab and Edison Welding Institute

Figure 3.12—Toroidal Field Coil and Coil Case

---

[10] Information on this application was provided by Princeton University Plasma Physics Laboratory and Edison Welding Institute.

COPPER-NICKEL WELD SURFACING

THE AUTOMATIC GAS tungsten arc welding process with hot wire addition of filler metal is shown in Figure 3.13 being used to clad a carbon steel flange with copper-nickel.[11] The flange is ASTM A285 Grade C steel and is welded to a copper-nickel pipe. This assembly is used on a shipboard turbine condenser. The first layer of GTAW weld cladding is nickel (ERNi) and the second layer is copper-nickel. The copper-nickel is deposited with 1/16 in. (1.6 mm) diameter ERCuNi filler metal and 75% helium-25% argon shielding gas at flow rates of 85 to 95 ft^3/hr (40 to 45 L/min). Preheat temperature is 60 °F (16 °C) minimum and the maximum interpass temperature is 150 °F (66 °C). GTAW current is direct current electrode negative. The welding parameters are listed in Table 3.31.

Courtesy of Westinghouse Electric Corporation, Marine Division

Figure 3.13—GTAW Cladding A Steel Flange with Copper-Nickel

---

[11] Information on this application was provided by Westinghouse Electric Corp., Marine Division.

Table 3.31
Welding Parameters For Hot Wire GTAW Cladding of a Carbon Steel Flange

Arc amperage	340 to 370 A
Arc voltage	14 to 16 V
Hot wire amperage	85 to 105 A (ac)
Wire feed speed	90 to 100 in./min (38 to 42 mm/s)
Travel speed	3.5 to 5.0 in./min (1.5 to 2.1 mm/s)

ALUMINUM BRONZE OVERLAY

IN THIS APPLICATION, aluminum bronze bearing surfaces are applied to a cast steel equalizer crown cushion using the GMAW process.[12] A vital part for an electric mining shovel, the equalizer crown cushion, shown in Figure 3.14, weighs 1030 lb (467 kg). Aluminum bronze bearing surfaces reduce friction and have excellent wear, impact, and galling resistance.

This application uses the manual GMAW process with ERCuAl-A2 filler metal and argon shielding gas. Welding current is 250 A, direct current electrode positive, and welding voltage is 26 V. The surfacing welds are deposited in two passes to a thickness of 0.375 in. (9.5 mm).

---

[12] Information on this application was provided by Ampco Metal, Inc.

Courtesy of Ampco Metal, Inc.

Figure 3.14—Surfacing a Mining Shovel Casting

CONDENSER WATER BOX FABRICATION

THE FABRICATION OF a water box for a shipboard condenser that cools turbine exhaust steam is shown in Figure 3.15.[13] The formed head is ASTM B402 Type 90/10 copper-nickel (C70600), and the flanges are ASTM A285 Grade C carbon steel. The welding process is SMAW using 1/8 and 5/32 in. (3.2 and 4.0 mm) diameter ENiCu-7 electrodes. Typical welding current for 1/8 in. (3.2 mm) diameter electrodes is 90 to 130 A, direct current electrode positive. When 5/32 in. (4.0 mm) diameter electrodes are used, welding current is 120 to 170 A. A minimum of 60 °F (16 °C) preheat is required, and maximum interpass temperature is limited to 150 °F (66 °C).

Courtesy of Westinghouse Electric Corporation, Marine Division

Figure 3.15—Shielded Metal Arc Welding of a Condenser Water Box

---

[13] Information on this application was provided by Westinghouse Electric Corporation, Marine Division.

WELDED COPPER PLUMBING FITTINGS

LARGE-DIAMETER, WELDED PLUMBING fittings (see Figure 3.16) have inherent advantages compared to cast plumbing fittings for some applications.[14] Welded fittings can be made that are lighter weight and can be formed into more configurations than cast fittings. Large diameter, phosphorus-deoxidized copper (C12200) fittings are used for commercial and industrial plumbing systems as well as heating, ventilation, and air-conditioning systems. The fitting shown (see Figure 3.16) was welded with the GTAW process using silicon bronze (ERCuSi-A) filler metal and 50% argon-50% helium shielding gas. Direct current electrode negative was used at 225 to 275 amperes. Welds were made without preheat or postweld heat treatment.

---

[14] Information on this application was provided by Elkhart Products Corporation and Copper Development Association.

Courtesy of Elkhart Products Corp. and Copper Development Association

Figure 3.16—Welded Plumbing Fitting

SUPPLEMENTARY READING LIST

GENERAL

American National Standards Institute. ANSI/ASC Z49.1, *Safety in welding, cutting and allied processes*. (Available from American Welding Society, Miami, Florida) New York: American National Standards Institute, 1988.

American Society For Metals. *Metals handbook*, Vol. 6, 9th Ed. Metals Park, Ohio: American Society for Metals, 1983.

————. "Copper." *Metals handbook*, Vol. 2, 9th Ed., 239-51 and 275-439. Metals Park, Ohio: American Society for Metals, 1979.

American Welding Society. *Brazing handbook*, 4th Ed. Miami, Florida: American Welding Society, 1991.

————. *Soldering manual*, 2nd Ed. Miami, Florida: American Welding Society, 1978.

————. *Welding handbook*, Vol. 2, 8th Ed. Miami, Florida: American Welding Society, 1991.

International Nickel Company. *Guide to the welding of copper-nickel alloys*. New York: International Nickel Company, 1979.

WELDING

Brandon, E. "The weldability of oxygen-free boron deoxidized low phosphorus copper." *Welding Journal* 48(5): 187s-94s, 1969.

Bray, R. S., et al. "Metallographic study of weld solidification in copper." *Welding Journal* 48(5): 181s-5s, 1969.

Dawson, R. J. C."Welding of copper and copper base alloys." Bulletin 287. New York: Welding Research Council, September 1983.

Dimbylow, C. S., and Dawson, R. J. C. "Assessing the weldability of copper alloys." *Welding and Metal Fabrication* 46(9): 461-71, 1978.

Fisher, S. M., et al. "The structural integrity of copper-nickel to steel shielded metal arc weldments." *Welding Journal* 62(3): 37-43, 1983.

Gutierrez, S. H. "Understanding GTA welding of 90/10 copper nickel." *Welding Journal* 70(5): 76-8, 1991.

Hartsell, E. W. "Joining copper and copper alloys." *Welding Journal* 52(2): 89-100, 1973.

Hashimoto, K., et al. “Laser welding copper and copper alloys.” *Journal of Laser Applications* 3(1): 21-5, 1991.

Johnson, L. D. “Some observations on electron beam welding of copper.” *Welding Journal* 49(2): 55s-60s, 1970.

Kelley, T. J. “Ultrasonic welding of Cu-Ni to steel. *Welding Journal* 60(4): 29-31, 1981.

Littleton, J., et al. “Nitrogen porosity in gas shielded arc welding of copper.” *Welding Journal* 53(12): 561s-5s, 1974.

Mustaleski, T. M., McCaw, R. L., and Sims, J. E. “Electron beam welding of nickel-aluminum bronze.” *Welding Journal* 67(7): 53-9, 1988.

Rogerson, J. H. “Significance of welds in copper and cupronickel alloy welds. Their relevance to design and quality standards.” *Welding Review* 3(4): 192-4, 1984.

Ruge, J., Thomas, K., Eckel, C., and Sundaresan, S. “Joining of copper to titanium by friction welding.” *Welding Journal* 66(8): 28-31, 1986.

Sandor, L. W. “Copper-nickel for ship hull constructions—welding and economics.” *Welding Journal* 61(12): 23-30, 1982.

————. “Pulsed HMA spot welding of copper-nickel to steel.” *Welding Journal* 63(6): 35-50, 1984.

Savage, W. F., et al. “Microsegregation in 70Cu-30Ni weld metal.” *Welding Journal* 55(6): 165s-73s, 1976.

————. et al. “Microsegregation in partially heated regions of 70Cu-30Ni weldments.” *Welding Journal* 55(7): 181s-7s, 1976.

Tumuluru, M., and Nippes, E. F. “Weld ductility studies of a tin-modified copper-nickel alloy.” *Welding Journal* 69(5): 197s-203s, 1990.

Wold, K. “Welding of copper and copper alloys.” *Metal Progress* 108(8): 43-7, December 1975.

BRAZING

Belkin, E., and Nagata, P. K. “Hydrogen embrittlement of tough-pitch copper by brazing.” *Welding Journal* 54(2): 54s-62s, 1975.

Chatterjee, S. K., and Mingxi, Z. “Tin-containing brazing alloys.” *Welding Journal* 70 (5): 118s-22s, 1991.

Datta, A., Rabinkin A., and Bose, D. “Rapidly solidified copper-phosphorous base brazing foils.” *Welding Journal* 63 (10): 14-21, 1984.

Gibbay, S. F., Dirnfeld, F., Ramon, J., and Wagner, H. Z. “Mechanism of tough-pitch copper embrittlement by silver brazing alloys.” *Welding Journal* 69 (10): 378s-81s, 1990.

Jones, T. A. and Albright, C. E. “Laser beam brazing of small diameter copper wires to laminated copper circuit boards.” *Welding Journal* 63(12): 34-47, 1984.

McFayden, A. A., Kapoor, R. R., and Eagar, T. W. “Effect of second phase particles on direct brazing of alumina dispersion hardened copper.” *Welding Journal* 69(11): 399s-407s, 1990.

Mottram, D., Wronski, A. S., and Chilton, A. C. “Brazing copper to mild and stainless steel using copper-phosphorus-tin pastes.” *Welding Journal* 65(4): 43-6, 1986.

Munse, W. H. and Alagia, J. A. “Strength of brazed joints in copper alloys.” *Welding Journal* 36(4): 177s-84s, 1957.

SOLDERING

Dirnfeld, S. F. and Ramon, J. J. “Microstructure investigation of copper-tin intermetallics and the influence of layer thickness on shear strength.” *Welding Journal*, 69(10): 373s-7s, 1990.

Ohriner, E. K. “Intermetallic formation in soldered copper-based alloys at 150 to 250 C. *Welding Journal* 66(7): 191s-201s, 1987.

Ramon, J. J., and Dirnfeld, S. F. “A practical way to measure the strength of small soldered joints.” *Welding Journal*, 67(10): 19-21, 1988.

Reichennecker, W. J.“Effect of long term elevated temperature aging on the electrical resistance of soldered copper joints.” *Welding Journal* 62(10): 290s-4s, 1983.

————. “Effect of solder thickness and joint overlap on the electrical resistance of soldered copper joints.” *Welding Journal* 60(5): 199s-201s, 1981.

————. “Electrical conductivity of copper-tin intermetallic compound Cu_3Sn in the temperature range -195 °C to +150 °C.” *Welding Journal* 59(10): 308s-10s, 1980.

Saperstein, Z. P., and Howes, M. A. H. “Mechanical properties of soldered joints in copper alloys.” *Welding Journal* 48 (8): 317s- 27s, 1969.

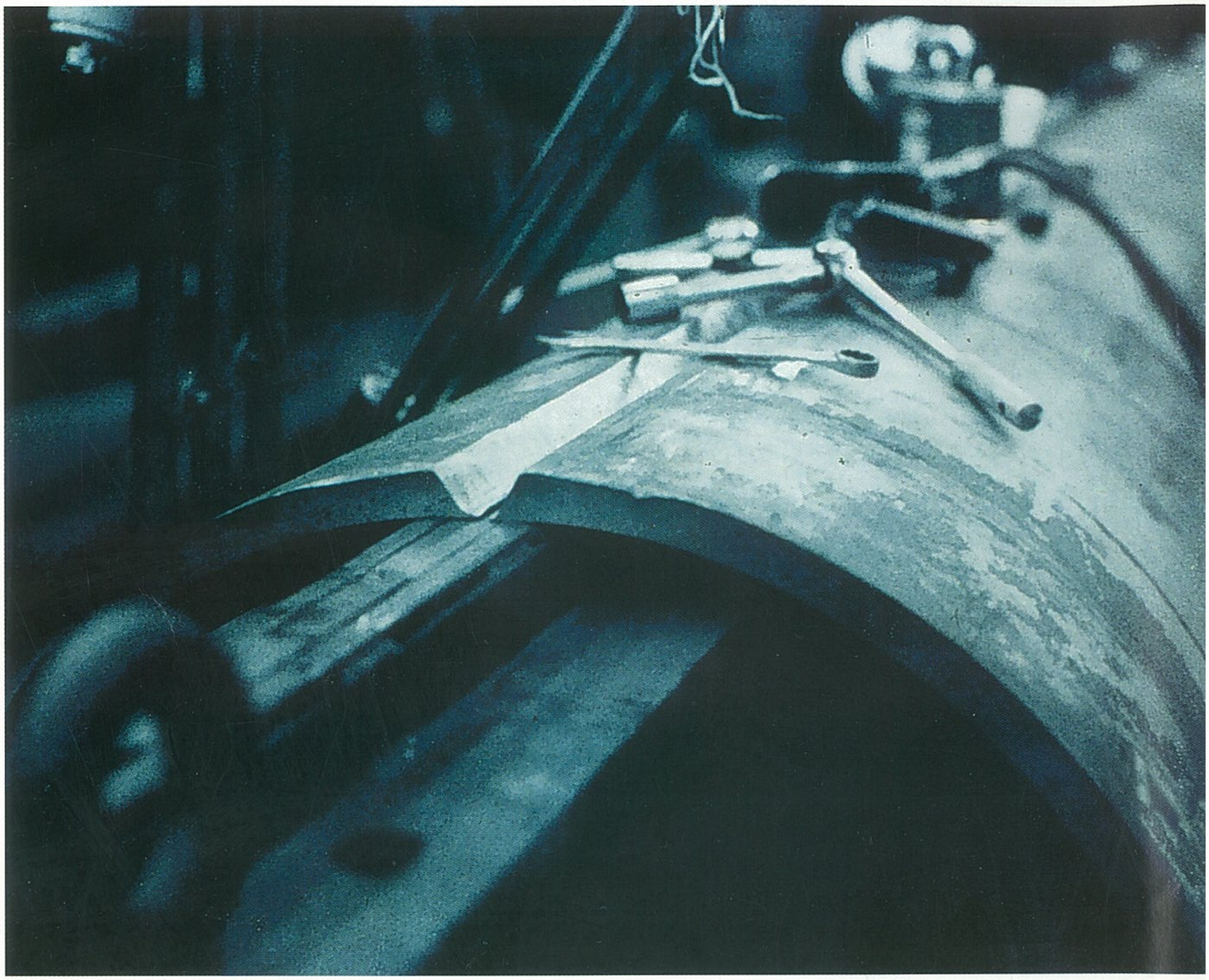
SAFETY AND HEALTH

Ditschun, A. and Sahoo, M. “Production and control of ozone during welding of copper-base alloys.” *Welding Journal* 62(8): 41-6, 1983.

National Institute for Occupational Safety and Health. *Occupational safety and health guidelines for beryllium and its compounds potential human carcinogen.* Washington, D.C.: National Institute for Occupational Safety and Health, 1988.

————. *Occupational health guideline for cadmium fume.* Washington, D.C.: National Institute for Occupational Safety and Health, September 1978.

————. *Occupational health guideline for chromium metal and insoluble chromium salts.* Washington, D.C.: National Institute for Occupational Safety and Health, September 1978.



CDA

Copper Development Association

A1050-72/97