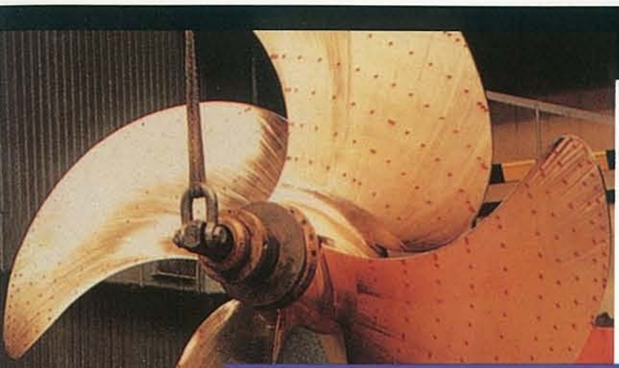
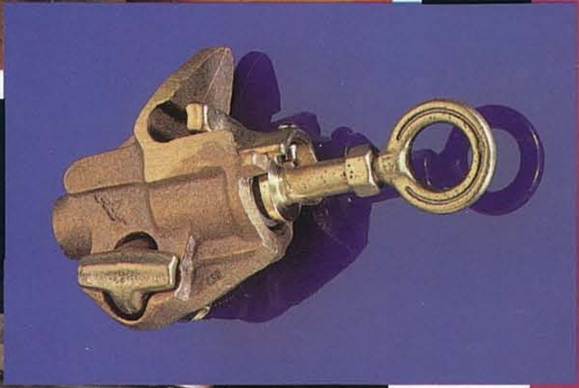
COPPER CASTING ALLOYS

- Alloy Selection Guide
- Properties
- Specifications
- Casting Design





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Non-Ferrous Founders' Society

CDA
Copper Development Association

COPPER CASTING ALLOYS

UNDERSTANDING COPPER CASTING ALLOYS

SELECTING COPPER CASTING ALLOYS

Non-Ferrous Founders' Society
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WORKING WITH COPPER CASTING ALLOYS

SPECIFYING AND BUYING COPPER CASTING ALLOYS

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This Handbook has been prepared for the use of engineers, designers and purchasing managers involved in the selection, design or machining of copper rod alloys. It has been compiled from information supplied by testing, research, manufacturing, standards, and consulting organizations that Copper Development Association Inc. believes to be competent sources for such data. However, CDA assumes no responsibility or liability of any kind in connection with the Handbook or its use by any person or organization and makes no representations or warranties of any kind thereby.

PREFACE

This guide was prepared for individuals who select, specify and buy materials for cast copper alloy products. Its purpose is to help engineers, designers and purchasing agents understand copper alloys so they can choose the most suitable and most economical material to meet their product's requirements.

There have been several excellent texts on copper casting alloys published in recent years,[1, 2] but these were written more for the foundry operator than for designers, engineers and purchasing agents. The collections of technical data on cast copper alloys that were published in the 1960s,[3] 1970s[4] and as recently as 1990[5] are either out of print or have not been widely distributed. As a result, few individuals are fully aware of all the technical, economic and practical advantages that the large family of copper alloys has to offer. The present guide, written specifically for the design community, was prepared to fill this information gap.

Why Specify Cast Copper Alloys?

Cast copper alloys have an extremely broad range of application. They are used in virtually every industrial market category, from ordinary plumbing goods to precision electronic components and state-of-the-art marine and nuclear equipment. Their favorable properties are often available in useful combinations. This is particularly valuable when, as is usually the case, a product must satisfy several requirements simultaneously.

The following properties are the reasons cast copper alloys are most often selected:

- **Excellent Corrosion Resistance.** The ability to withstand corrosive environments is the cast copper alloys' most important and best-known characteristic. The alloys have a natural corrosion resistance, making durability without maintenance an important element of their long-term cost-effectiveness.

  Not surprisingly, water handling equipment of one form or another constitutes the cast alloys' largest single market. Copper alloy castings are also widely used to handle corrosive industrial and process chemicals, and they are well known in the food, beverage and dairy industries. **Figure P-1** shows several aluminum bronze pickling hooks used to immerse coils of steel wire in hot, dilute sulfuric acid.

- **Favorable Mechanical Properties.** Pure copper is soft and ductile, and it is understandably used more often for its high conductivity than for its mechanical strength. Some cast copper alloys, on the other hand, have strengths that rival quenched and tempered steels.

  Almost all copper alloys retain their mechanical properties, including impact toughness, at very low temperatures. Other alloys are used routinely at temperatures as high as 800 F (425 C). No class of engineering materials can match the copper alloys' combination of strength, corrosion resistance and thermal and electrical conductivities over such a broad temperature range.

- **Friction and Wear Properties.** Cast sleeve bearings are an important application for copper alloys, largely because of their excellent tribological properties. For sleeve bearings, no material of comparable strength can match high leaded bronzes in terms of low wear rates against steel. For worm gears, nickel bronzes and tin bronzes are industry standards.

  Equally important, the copper alloys' broad range of mechanical properties enables the designer to match a specific alloy with a bearing's precise operating requirements. Cast sleeve bearings are shown in **Figure P-2**. A comprehensive discussion of copper bearing alloys can be found in the CDA publication, *Cast Bronze Bearings — Alloy Selection and Bearing Design.*

- **Biofouling Resistance.** Copper effectively inhibits algae, barnacles and other marine organisms from attaching themselves to submerged surfaces. Nonfouling behavior is highest in pure copper and high copper alloys, but it is also strong in the alloys used in marine service. Products such as seawater piping, pumps and valves made from copper alloys therefore remain free from biomass buildup and are able to operate continuously without the periodic cleanup needed with steel, rubber or fiber-reinforced plastic products.

- **High Electrical and Thermal Conductivity.** Copper's electrical and thermal conductivities are higher than any other metal's except silver. Even copper alloys with relatively low conductivities compared with pure copper conduct heat and electricity far better than other structural metals such as stainless steels and titanium.

  Unlike most other metals, the thermal conductivity of many copper casting alloys increases with rising temperature. This can improve the efficiency of copper alloy heat exchangers. Electrical conductivity generally decreases with increasing alloy content, but even relatively highly alloyed brasses and bronzes retain sufficient conductivity for use as electrical hardware. For example, the hot-line clamp shown in **Figure P-3** is made from Alloy C84400, a leaded semi-red brass whose electrical conductivity is only 16% that of pure copper. Nevertheless, the alloy has the proper combination of strength and conductivity required for this safety- related application.

Other characteristics of the copper casting alloys can make products simpler and less costly to produce. For example:

- **Good Castability.** All copper alloys can be sand cast. Many compositions can also be specified for permanent mold, plaster, precision and die castings, while continuous casting and centrifugal casting are applicable to virtually all of the copper alloys. With such a wide choice of processes, castability rarely restricts product design.
- **Excellent Machinability and Fabricability.** Almost all castings require some machining; therefore, the copper alloy's machinability should be an important design consideration. High surface finishes and good tolerance control are the norms with these materials. The leaded copper alloys are free-cutting and can be machined at ultrahigh speeds.

  Many unleaded copper alloys can also be machined easily. For example, nickle-aluminum bronze was selected for the motor segment shown in **Figure P-4** in part because it enabled a 50% savings in machining costs compared with stainless steel. Another factor to consider is that many copper alloys are weldable using a variety of techniques. This opens the possibility of economical cast-weld fabrication. Almost all copper alloys can be brazed and soldered.
- **Reasonable Cost.** The copper alloys' predictable castability raises foundry yields, keeping costs low. Copper alloy castings easily compete with stainless steels and nickel-base alloys, which can be difficult to cast and machine.

  Copper's initial metal cost may appear high compared with carbon steel, but when the cost is offset by copper's additional service life and the high value of the fully recyclable casting when it is no longer needed, copper's life cycle cost is very competitive.

The following chapters discuss these important qualities of copper alloys in detail. Where appropriate, the metals are ranked according to their mechanical and physical properties. The intent is to allow the designer to compare alloys and casting processes with the intended product's requirements. By consulting the appropriate tables, it should be possible to narrow the choice to a small number of suitable candidate alloys. Final selection can then be made on the basis of detailed product requirements, availability and cost.

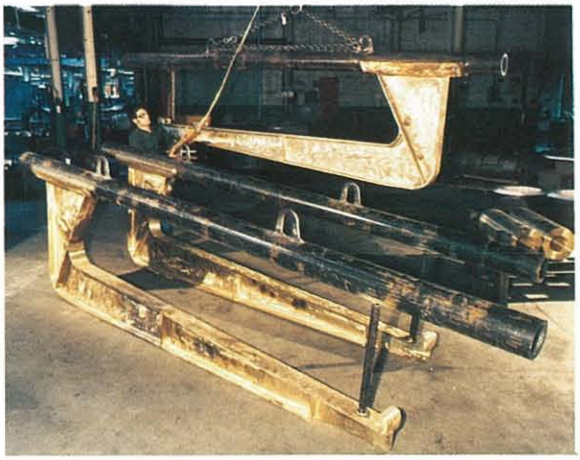


FIGURE P-1
Cast aluminum bronze pickling hooks resist corrosion by hot, dilute sulfuric acid.

FIGURE P-2
Cast sleeve bearings are available in a large variety of copper alloys.

FIGURE P-3
A leaded semi-red brass was selected for this hot line clamp because it offers an economical combination of strength and corrosion resistance with adequate electrical conductivity.

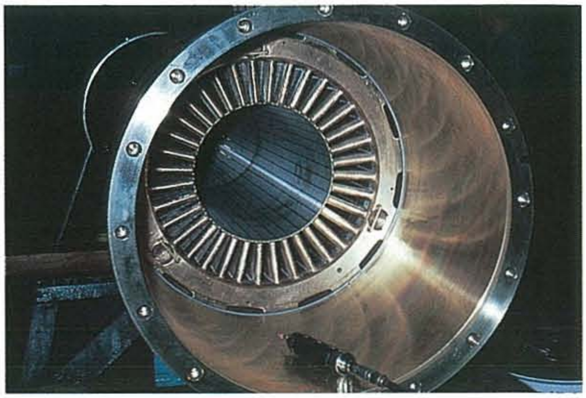
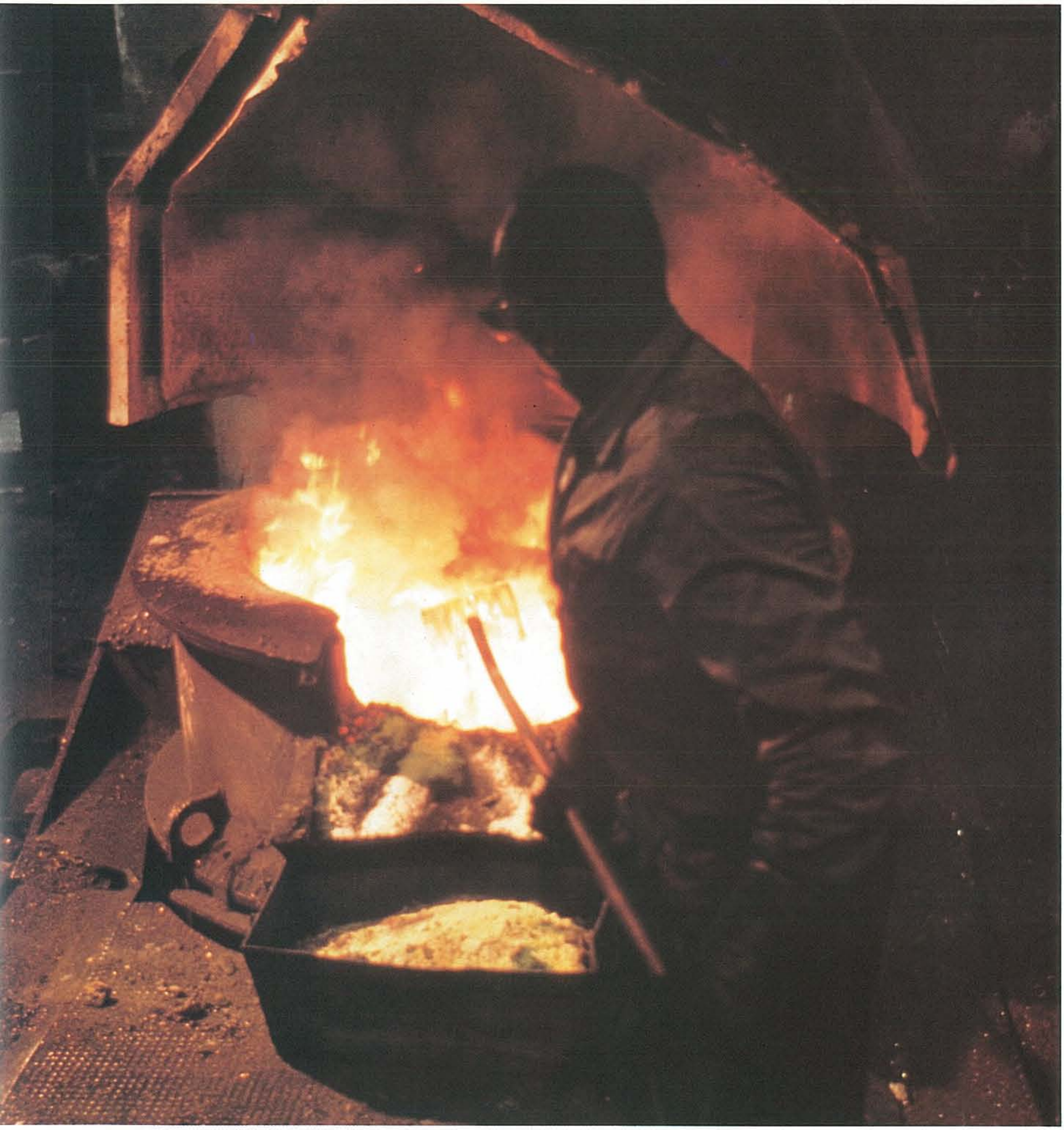


FIGURE P-4
The aluminum bronze chosen for this complex motor segment casting enabled a 50% savings in machining costs compared with stainless steel.

Understanding Copper Casting Alloys



I. CLASSIFYING THE COPPER ALLOYS

Over the years, copper alloys have been identified by individual names and by a variety of numbering systems. Many of these names and numbers are still used, often interchangeably, and because this can be confusing, we will briefly explain how the various identification systems relate to each other. With this as a foundation, we will next describe the families of copper alloys as they are categorized in today's nomenclature. In this chapter, we will also briefly discusses the various metals' metallurgical structures and foundry characteristics, since these are important considerations when deciding how a casting should be produced.

Common Classification Systems

A 1939 American Society for Testing and Materials (ASTM) standard, *Classification of Copper-Base Alloys*, codified 23 distinct alloy families based on general compositional limits. Already-familiar designations such as "Leaded Brass," "Tin Bronze" and "Aluminum Bronze" were associated for the first time with specific composition ranges.

Soon, other ASTM standards added designations for individual alloys within the families. For example, "Leaded Semi-Red Brass 5A" was defined as an alloy containing between 78% and 82% copper, 2.25% to 3.25% tin, 6% to 8% lead and 7% to 10% zinc, with stated limits on impurities. Minimum mechanical properties were also fixed, permitting alloys to be called out in design specifications and construction codes.

Another classification system still in use identifies alloys in terms of their nominal compositions. Thus, a leaded red brass containing 85% copper, 5% tin, 5% lead and 5% zinc is simply called "85-5-5-5," while a leaded tin bronze is somewhat awkwardly designated as 88-6-1½-4½. The system is limited to copper-tin-lead-zinc alloys (always given in that order), but there are some exceptions.

Various other naming and/or numbering systems are used by, for example, ingot suppliers who furnish casting stock to foundries, or designers who, when they specify alloys, commonly call out ASTM or ASME standards or military specifications. None of these systems is obsolete; they are just not in general use in all industries.

The UNS Numbering System

In North America, the accepted designations for cast copper alloys are now part of the Unified Numbering System for Metals and Alloys (UNS), which is managed jointly by the ASTM and the Society of Automotive Engineers (SAE). Under the UNS system, the copper alloys' identifiers take the form of five-digit codes preceded by the letter "C."

The five-digit codes are based on, and supersede, an older three-digit system developed by the U.S. copper and brass industry. The older system was administered by the Copper Development Association (CDA), and alloys are still sometimes identified by their "CDA numbers." The UNS designations for copper alloys are simply two-digit extensions of the CDA numbers. For example, the leaded red brass (85-5-5-5), once known as CDA Copper Alloy No. 836, became UNS C83600.

This selection guide uses UNS numbers for all alloys, but traditional names are included for clarity wherever appropriate. In addition, alloys are described by their *tempers*, which are terms that define metallurgical condition, heat treatment, and/or casting method. The terminology associated with tempers is spelled out in ASTM B 601,[7] and temper designations applicable to cast alloys are listed in **Table 1**, page 8. For convenience, **Table 2**, page 12, lists the alloys by UNS number, common name and conforming specifications.

The UNS alloy list is updated periodically. New alloys may be added on request to CDA, subject to a few simple restrictions, while alloys that are no longer produced are deleted. The alloys described in this handbook are listed in CDA's *Standard Designations for Wrought and Cast Copper and Copper Alloys*, 1992 edition.

The Copper Alloy Families: Classification and Major Uses

Cast copper alloys are assigned UNS numbers from C80000 to C99999. The metals are arranged in a series of eight families drawn from the 18 compositionally related classifications previously identified by the ASTM. These families, some of which include subclassifications, include:

Coppers (C80100–C81200). Coppers are high-purity metals with a minimum designated copper content of 99.3%. They are not intentionally alloyed but may contain traces of silver or deoxidizers. The phosphorus deoxidizer in, for example, C81200 renders this copper somewhat easier to weld by oxyacetylene techniques.

The coppers are soft and ductile and are used almost exclusively for their unsurpassed electrical and thermal conductivities in products such as terminals, connectors and (water-cooled) hot metal handling equipment. **Figure I-1**, page 25, shows a blast furnace tuyere

TABLE 1. Standard Temper Designations for Copper Casting Alloys (Based on ASTM B 601)

Temper Designations	Temper Names
Annealed—O	
O10	Cast and Annealed (Homogenized)
O11	As Cast and Precipitation Heat Treated
As-Manufactured—M	
M01	As Sand Cast
M02	As Centrifugal Cast
M03	As Plaster Cast
M04	As Pressure Die Cast
M05	As Permanent Mold Cast
M06	As Investment Cast
M07	As Continuous Cast
Heat-Treated—TQ	
TQ00	Quench Hardened
TQ30	Quench Hardened and Tempered
TQ50	Quench Hardened and Temper Annealed
Solution Heat Treated and Spinodal Heat Treated—TX	
TX00	Spinodal Hardened (AT)
Solution Heat Treated—TB	
TB00	Solution Heat Treated (A)
Solution Heat Treated and Precipitation Heat Treated—TF	
TF00	Precipitation Hardened (AT)

cast from high conductivity copper. The coppers have very high corrosion resistance, but this is usually a secondary consideration.

High Copper Alloys (C81400-C82800). Next in order of decreasing copper content are alloys with a minimum designated purity of 94% Cu. The high copper alloys are used primarily for their unique combination of high strength and good conductivity. Their corrosion resistance can be better than that of copper itself. Chromium coppers (C81400 and C81500), with a tensile strength of 45 ksi (310 MPa) and a conductivity of 82% IACS (see page 86) (as heat treated), are used in electrical contacts, clamps, welding gear and similar electromechanical hardware. At more than 160 ksi (1,100 MPa), the beryllium coppers have the highest tensile strengths of all the copper alloys. They are used in heavy duty mechanical and electromechanical equipment requiring ultrahigh strength and good electrical and/or thermal conductivity. The resistance welding machine component shown in **Figure I-2**, page 25, was cast in beryllium copper for precisely those reasons.

The high copper alloys' corrosion resistance is as good as or better than that of pure copper. It is adequate for electrical and electronic products used outdoors or in marine environments, which generally do not require extraordinary corrosion protection.

Brasses (C83300–C87900). Brasses are copper alloys in which zinc is the principal alloying addition. Brasses may also contain specified quantities of lead, tin, manganese and silicon. There are five subcategories of cast brasses, including two groups of copper-tin-(lead)-zinc alloys:

- C83300–C83810 and C84200–C84800, the red and leaded red brasses and semi-red and leaded semi-red brasses, respectively;
- copper-zinc-(lead) alloys, C85200–C85800, yellow brasses and leaded yellow brasses;
- manganese bronzes and leaded manganese bronzes, C86100–C86800, also known as high strength and leaded high strength yellow brasses; and,
- copper-silicon alloys, C87300-C87900, which are called silicon brasses or, if they contain more silicon than zinc, silicon bronzes.

The lower the zinc content in the copper-tin-(lead)-zinc alloys, the more copper-like, or "red" they appear. With a few exceptions, red and leaded red brasses contain less than about 8% zinc; semi-red brasses, including the leaded versions, contain between 7% and 17% zinc, while yellow brasses and their leaded counterparts contain as much as 41% zinc. Brasses containing up to 32.5% zinc are also sometimes called "alpha" brasses after the common designation for their single-phase, face-centered cubic crystal structure.

Red and Semi-Red Brasses, Unleaded and Leaded (C83300–C84800). The most important brasses in terms of tonnage poured are the leaded red brass, C83600 (85-5-5-5), and the leaded semi-red brasses, C84400, C84500 and C84800 (81-3-7-9, 78-3-7-12 and 76-3-6-15, respectively). All of these alloys are widely used in water valves, pumps, pipe fittings and plumbing hardware. A typical downstream water meter is shown in **Figure I-3**, page 25.

Yellow Brasses (C85200–C85800). Leaded yellow brasses such as C85400 (67-1-3-29), C85700 (63-1-1-35) and C85800 are relatively low in cost and have excellent castability, high machinability and favorable finishing characteristics. Their corrosion resistance, while reasonably good, is lower than that of the red and semi-red brasses. Typical tensile strengths range from 34 to 55 ksi (234 to 379 MPa).

Leaded yellow brasses are commonly used for mechanical products such as gears and machine components, in which relatively high strength and moderate corrosion resistance must be combined with superior machinability. The yellow brasses are often used for architectural trim and decorative hardware. The relatively narrow solidification range and good high-temperature ductility of the yellow brasses permit some of these alloys to be die cast. The yellow brass door bolt shown in **Figure I-4**, page 52, was pressure die cast to near net shape, thereby avoiding the costly machining and forming operations needed in an alternative manufacturing method. Other die-castable alloys include the structurally similar high strength yellow brasses and the silicon brasses.

High Strength and Leaded High Strength Yellow Brasses (C86100–C86800), or manganese bronzes, are the strongest, as cast, of all the copper alloys. The "all beta" alloys C86200 and C86300 (the alloys' structure is described below) develop typical tensile strengths of 95 and 115 ksi (655 and 793 MPa), respectively, without heat treatment. These alloys are weldable, but should be given a post-weld stress relief. The high strength brasses are used principally for heavy duty mechanical products requiring moderately good corrosion resistance at a reasonable cost. The rolling mill adjusting nut shown in **Figure I-5**, page 52, provides a typical example. The high strength yellow brass alloys have been supplanted to some extent by aluminum bronzes, which offer comparable properties but have better corrosion resistance and weldability.

Silicon Bronzes/Brasses (C87300–C87900) are moderate strength alloys with good corrosion resistance and useful casting characteristics. Their solidification behavior makes alloys in this group amenable to die, permanent mold and investment casting methods. Applications range from bearings and gears to plumbing goods and intricately shaped pump and valve components.

Bronzes. The term "bronze" originally referred to alloys in which tin was the major alloying element. Under the UNS system, the term now applies to a broader class of alloys in which the principal alloying element is neither zinc (which would form brasses) nor nickel (which forms copper-nickels).

There are five subfamilies of bronzes among the cast copper alloys: First listed are the copper-tin alloys, C90200–C91700, or tin bronzes. Next come the copper-tin-lead alloys, which are further broken down into leaded tin bronzes, C92200–C92900, and high leaded tin bronzes, C93100–C94500. Copper-tin-nickel (lead) alloys include the nickel-tin bronze, C94700, and the leaded nickel-tin bronze, C94900. Both of these alloys contain less than 2% lead. Similar alloys with higher nickel contents, C97300–C97800, are classified as copper-nickel-zinc alloys, but are more commonly known as nickel silvers or German silvers. Copper-aluminum-iron and copper-aluminum-iron-nickel alloys, C95200–C95900, are classified as aluminum bronzes and nickel-aluminum bronzes. Manganese bronzes are listed among the brasses because of their high zinc content.

Tin bronzes offer excellent corrosion resistance, reasonably high strength and good wear resistance. Used in sleeve bearings, they wear especially well against steel. Unleaded tin bronze C90300 (88-8-0-4) is used for bearings, pump impellers, piston rings, valve fittings and other mechanical products. The alloy's leaded version, C92300 (87-8-1-4), has similar uses, but is specified when better machinability and/or pressure tightness is needed. Alloy C90500, formerly known as SAE Alloy 62, is hard and strong, and has especially good resistance to seawater corrosion. Used in bearings, it resists pounding well, but lacking lead, it requires reliable lubrication and shaft hardnesses of 300 to 400 HB.

Alloy C93200 is the best-known bronze bearing alloy. Widely available and somewhat less expensive than other bearing alloys, this high leaded tin bronze is also known as "Bearing Bronze." The alloy is recognized for its unsurpassed wear performance against steel journals. It can be used against unhardened and not-perfectly-smooth shafts.

Alloy C93500, another high leaded tin bronze, combines favorable antifriction properties with good load-carrying capacities; it also conforms to slight shaft misalignments. Alloy C93600, a higher lead, lower zinc bronze bearing alloy is claimed to provide faster machining, lower friction and improved corrosion resistance in sulfite media. The higher tin content of alloy C93700 (formerly SAE 64) gives it resistance to corrosion in mild acids, mine waters and paper mill sulfite liquors.

Lead weakens all of these bearing alloys but imparts the ability to tolerate interrupted lubrication. Lead also allows dirt particles to become embeded harmlessly in the bearing's surface, thereby protecting the journal. This is important in off-highway equipment such as the shovel loader shown in **Figure I-6**, page 52. The "premier" bearing alloys, C93800 and C94300 also wear very well with steel and are best known for their ability to conform to slightly misaligned shafts.

Nickel-Tin Bronzes (C94700-C94900). The nickel-tin bronzes are characterized by moderate strength and very good corrosion resistance, especially in aqueous media. One member of this family, C94700, can be age-hardened to typical tensile strengths as high as 75 ksi (517 MPa). Wear resistance is particularly good. Like the tin bronzes, nickel-tin bronzes are used for bearings, but these versatile alloys more frequently find application as valve and pump components, gears, shifter forks and circuit breaker parts.

Nickel Silvers (C97300–C97800). These copper-nickel-tin-lead-zinc alloys offer excellent corrosion resistance, high castability and very good machinability. They have moderate strength. Among their useful attributes is their pleasing silvery luster. Valves, fittings and hardware cast in nickel silvers are used in food and beverage handling equipment and as seals and labyrinth rings in steam turbines.

Aluminum Bronzes (C95200–C95800). These alloys contain between 3% and 12% aluminum. Aluminum strengthens copper and imparts oxidation resistance by forming a tenacious alumina-rich surface film. Iron, silicon, nickel and manganese are added to aluminum bronzes singly or in combination for higher strength and/or corrosion resistance in specific media.

Aluminum bronzes are best known for their high corrosion and oxidation resistance combined with exceptionally good mechanical properties. The alloys are readily fabricated and welded and have been used to produce some of the largest nonferrous cast structures in existence. Aluminum bronze bearings are used in heavily loaded applications.

Alloy C95200, with about 9.5% aluminum, develops a tensile strength of 80 ksi (550 MPa) as cast. Alloys C95400 and C95500, which contain at least 10% aluminum, can be quenched and tempered much like steels to reach tensile strengths of 105 ksi (724 MPa) and 120 ksi (827 MPa), respectively.

Resistance to seawater corrosion is exceptionally high in nickel-aluminum bronzes. Because of its superior resistance to erosion-corrosion and cavitation, nickel-aluminum bronze C95500 is now widely used for propellers and other marine hardware, **Figure I-7**, page 53.

Another nickel-aluminum bronze, C95800, is not heat treated, but nevertheless attains a typical strength of 95 ksi (655 MPa). It should be temper-annealed for service in seawater and other aggressive environments in order to reduce the likelihood of dealuminification corrosion (see page 54). The alloy's very good galling resistance, especially against ferrous metals, has increased its use for bearings and wear rings in hydroelectric turbines. Such bearings must be designed for adequate positive lubrication, and journals must display a minimum hardness of 300 HB.

Copper-Nickel Alloys (C96200–C96900). Sometimes referred to as copper-nickels or cupronickels, these comprise a set of solid-solution alloys containing between 10% and 30% nickel. The alloys also contain small amounts of iron and in some cases niobium (columbium) or beryllium for added strength. Seven standard alloys are currently recognized. Corrosion resistance and strength increase with nickel content, but it is the secondary alloying elements that have an overriding effect on mechanical properties.

Alloy C96200, with nominally 10% nickel, attains a typical tensile strength of about 45 ksi (310 MPa) in the as-cast condition. The 30% nickel grade, C96400, can be oil-quenched from 1,050-1,250 F (565-677 C) to increase its strength and hardness through the precipitation of a complex nickel-columbium-silicon intermetallic compound. Tensile strengths will typically reach 60 ksi (414 MPa). The 30% nickel, beryllium-containing grade, C96600, can be age-hardened to a strength of 110 ksi (758 MPa).

The copper-nickel alloys offer excellent resistance to seawater corrosion. This, combined with their high strength and good fabricability, has found them a wide variety of uses in marine equipment. Typical products include pump components, impellers, valves, tailshaft sleeves, centrifugally cast pipe, fittings and marine products such as the centrifugally cast valve body (Alloy C96400) shown in **Figure I-8**, page 53. The alloys are never leaded, and their machining characteristics resemble those of pure copper.

Leaded Coppers (C98200–C98840). The lead in these alloys is dispersed as discrete globules surrounded by a matrix of pure copper or high-copper alloy. The conductivity of the matrix remains high, being reduced only by whatever other alloying elements may be present. Lead contents range from about 25% in alloy C98200 to as high as 58% in alloy C98840. Between 1% and 5% tin is added to alloys C98820 and C98840 for added strength and hardness. Similarly, alloys C98400 and C98600 contain up to 1.5% silver, while C98800 may contain up to 5.5% silver, balanced against the lead content to adjust the alloy's hardness.

The leaded coppers offer the high corrosion resistance of copper and high copper alloys, along with the favorable lubricity and low friction characteristics of high leaded bronzes.

Metallurgy and Foundry Characteristics

The copper alloy families are based on composition and metallurgical structure. These, in turn, influence or are influenced by the way the metals solidify. Solidification behavior is an important consideration, both in casting design and when selecting a casting process. The following descriptions of the alloys according to their structures and freezing behavior is intended as a brief introduction to a very complex subject. More detailed discussions are available from other sources.[1]

Coppers. Coppers are metallurgically simple materials, containing a single face-centered cubic alpha phase. (Small amounts of oxides may be present in deoxidized grades.) Coppers solidify at a fixed temperature, 1,981 F (1,083 C), but there is usually some undercooling. Freezing begins as a thin chill zone at the mold wall, then follows the freezing point isotherm inward until the entire body has solidified. Cast structures exhibit columnar grain structures oriented perpendicular to the solidification front. Centerline shrinkage cavities can form at isolated "hot spots" and inadequately fed regions of the casting; this must be taken into account when laying out the casting's design.

High Copper Alloys. Like the coppers, the high copper alloys solidify by skin formation followed by columnar grain growth. With a few exceptions, the high copper alloys typically have very narrow freezing ranges and also produce centerline shrinkage in regions that are improperly fed.

The chromium and beryllium coppers develop maximum mechanical properties through age-hardening heat treatments consisting of a solution-annealing step followed by quenching and reheating to an appropriate aging temperature. Conductivity is highest in the aged (maximum strength) or slightly overaged (lower strength but higher ductility) conditions, i.e., when the hardening element has mostly precipitated and the remaining matrix consists of nearly pure copper.

Red and Semi-Red Brasses. These alloys go through an extended solidification range characterized by the growth of tiny tree-like structures known as dendrites, **Figure I-9**, page 53. As the alloys solidify, countless dendrites form and grow more or less uniformly throughout the casting. This leads to a structure made up of small, equiaxed grains.

The dendritic solidification process produces what can best be described as an extended mushy-liquid stage. The metal that freezes first may have a slightly different composition than metal that freezes later on, a phenomenon called microsegregation, or "coring." Coring can sometimes be detrimental to mechanical and/or corrosion properties, but the seriousness of the effect, if any, depends on the alloy and the particular environment.

As the interlocking dendrites grow, they eventually shut off the supply of liquid metal. This produces tiny shrinkage voids, called microporosity, between the arms of the last dendrites to solidify. Microporosity can often be tolerated, but it is obviously detrimental when pressure tightness or high mechanical properties are needed. Porosity in these wide-freezing-range brasses can be avoided by controlling directional solidification, i.e., forcing the freezing front to follow a desired path. This ensures that even the last regions to solidify have access to an adequate supply of liquid metal. It should be noted that the red and semi-red brasses are the best alloys to specify for thin-walled sand castings and that leaded versions produce the best degrees of pressure tightness for reasonably thin sections.

Yellow Brasses. These alloys also solidify by the formation of dendrites, however the tendency to form microporosity and microsegregation is reduced because they tend to solidify over a relatively narrow temperature range when chill-cast.

The microstructure of yellow brasses containing more than 32.5% zinc consists of a mixture of the solid-solution alpha phase and the hard, strong beta phase. In yellow brasses, the amount of beta present depends on the alloys' zinc content; in high strength yellow brasses it depends on zinc and aluminum levels. In both cases, beta content is also influenced by the rate of cooling after solidification. Aluminum is such a strong beta former that alloy C86200, which contains only 4% aluminum in addition to about 25% zinc, has a predominantly beta microstructure. Formation of the beta phase leads to a significant increase in strength at low to moderate temperatures.

Considering their moderately high strength, the yellow brasses are very ductile materials at low and intermediate temperatures. On the other hand, the most important metallurgical effect of the beta phase is that it raises ductility significantly at high temperatures. This improves the alloys' resistance to hot cracking in highly restrained molds, and allows some yellow brasses to be cast by the pressure die and/or permanent mold processes.

Bronzes. Tin increases strength and improves aqueous corrosion resistance. It also increases cost, therefore alloy selection involving tin bronzes may entail a cost-benefits analysis. Tin dramatically expands the freezing range in copper alloys and usually produces significant coring, although this is not necessarily harmful.

Leaded Coppers. These alloys undergo a two-step solidification process. That is, the copper fraction (pure copper or high-copper alloy) freezes over the narrow solidification range typical of such alloys. The lead solidifies only after the casting has cooled some 1,300 Fahrenheit (700 Celsius) degrees. Segregation of lead to the last regions to solidify is therefore a potentially serious problem. Chill-casting and/or using thin sections help trap the lead in a uniform dispersion throughout the structure.

Nickel-Tin Bronzes. The nickel-tin bronzes can be heat treated to produce precipitation hardening. The precipitating phase is a copper-tin intermetallic compound which forms during slow cooling in the mold or during a subsequent aging treatment. Lead is detrimental to the hardening process to the extent that leaded nickel-tin bronzes are not considered heat-treatable.

Nickel Silvers. Despite their complex composition, nickel silvers display simple alpha microstructures. Nickel, tin and zinc impart solid solution hardening, and mechanical properties generally improve in proportion to the concentration of these elements. The nickel silvers are not heat treatable. The alloys' characteristic silver color is produced primarily by nickel, aided to some extent by zinc.

Aluminum Bronzes. These alloys exhibit some of the most interesting metallurgical structures found among all commercial alloys. Aluminum bronzes containing less than about 9.25% aluminum consist mainly of the face-centered cubic alpha structure, although iron- and nickel-rich phases, which contribute strength, will also be present. Higher aluminum concentrations, and/or the addition of silicon or manganese, lead to the formation of the beta phase. Beta transforms into a variety of secondary phases as the casting cools. Standard alloy compositions are carefully balanced to ensure that the resulting complex structures are beneficial to the bronzes' mechanical properties.

Despite their metallurgical complexity, the aluminum bronzes are extraordinarily versatile alloys. They are well suited to sand casting and are often produced by this method. They are also frequently cast centrifugally. On the other hand, the aluminum bronzes are basically short-freezing alloys and this, coupled with their good elevated temperature properties, also makes them good candidates for the permanent mold and die casting processes.

Copper-Nickels. The copper-nickels are metallurgically simple alloys, consisting of a continuous series of solid solutions throughout the copper-nickel system. Copper-rich alloys in the copper-nickel system are known as copper-nickels; nickel-rich compositions in this system are called Monel alloys. The copper-nickels solidify over narrow freezing ranges, although the range extends somewhat with increasing nickel content. Segregation is not a serious problem.

Iron, niobium (columbium) and silicon can produce precipitation hardening in copper-nickels through the formation of silicides; however, precipitation takes place readily as the casting cools, and the alloys are consequently not age-hardenable. On the other hand, beryllium-containing C96600 can be age-hardened in the same manner as can ordinary beryllium-copper alloys.

Effects of Lead

As leaded copper alloys freeze, the lead segregates as microscopic liquid pools which fill and seal the interdendritic microporosity left when the higher-melting constituents solidified, **Figure I-10**, page 53. The lead seals the pores and renders the casting pressure-tight. Lead also makes the alloys free-cutting by promoting the formation of small, easily cleared turnings during machining. This improves high-speed finishing operations. Unless present in high concentrations, lead does not have a strong effect on strength, but it does degrade ductility. Copper alloys containing lead cannot be welded, although they can be brazed and soldered.

TABLE 2. Overview of Copper Casting Alloys

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
	Coppers									
C80100(1,2)	Oxygen-Free Copper	S, C, CL, PM, I, P	99.95(3)	—	—	—	—	—	—	High purity coppers with excellent electrical and thermal conductivities. Deoxidation of C81200 improves its weldability.
C81100(1,2)	High Conductivity Copper	S, C, CL, PM, I, P	99.70(3)	—	—	—	—	—	—	
C81200(1)	High Conductivity Copper	S, C, CL, PM, I, P	99.9(3)	—	—	—	—	—	.045–.065 P	
	High Copper Alloys									
C81400(1,2)	70C	S, C, CL, PM, I, P	98.5 min.(4)	—	—	—	—	—	.02–.10 Be .6–1.0 Cr	Relatively high strength coppers with good electrical and thermal conductivity. Strength generally inversely proportional to conductivities. Used where good combination of strength and conductivity is needed, as in resistance welding electrodes, switch blades and components, dies, clutch rings, brake drums, as well as bearings and bushings. Beryllium coppers have highest strength of all copper alloys, are used in bearings, mechanical products and non-sparking safety tools.
C81500(1,2)	Chromium Copper	S, C, CL, PM, I, P	98.0 min.(4)	.10	.02	.10	—	.10	.15 Si .10 Al .40–1.5 Cr	
C81540(1)	Chromium Copper	S, C, CL, PM, I, P	95.1 min.(4,5)	.10	.02	.10	2.0–3.0(6)	.15	.40–.8 Si .10 Al .10–.6 Cr	
C82000(1,2)	10C	S, C, CL, PM, I, P, D	Rem.(4)	.10	.02	.10	.20	.10	.10 Al .10 Cr .15 Si 2.40–2.70 Co(6) .45–.8 Be	
C82200(1,2)	35C, 53B	S, C, CL, PM, I, P	Rem.(4)	—	—	—	1.0–2.0	—	.35–.80 Be .30 Co	
C82400(1,2)	165C	S, C, CL, PM, I, P, D	Rem.(4)	.10	.02	.10	.20	.20	.20–.65 Co 1.60–1.85 Be .15 Al .10 Cr	
C82500(1,2)	20C	S, C, CL, PM, I, P, D	Rem.(4)	.10	.02	.10	.20	.25	1.90–2.25 Be .35–.70 Co(6) .20–.35 Si .15 Al .10 Cr	
C82510	Increased-Co 20C	S, C, CL, PM, I, P, D	Rem.(4)	.10	.02	.10	.20	.25	1.90–2.15 Be 1.0–1.2 Co(6) .20–.35 Si .15 Al .10 Cr	
C82600(1,2)	245C	S, C, CL, PM, I, P, D	Rem.(4)	.10	.02	.10	.20	.25	2.25–2.55 Be .35–.65 Co .20–.35 Si .15 Al .10 Cr	
C82700(1,2)	Nickel-Beryllium Copper	S, C, CL, PM, I, P	Rem.(4)	.10	.02	.10	1.0–1.5	.25	2.35–2.55 Be .15 Si .15 Al .10 Cr	

\continued on next page

Legend: Applicable Casting Processes

S = Sand
C = Continuous
CL = Centrifugal
D = Die
I = Investment
P = Plaster
PM = Permanent Mold

*** Compositions are subject to minor changes. Consult latest edition of CDA's *Standard Designations for Wrought and Cast Copper and Copper Alloys*.**

Rem. = Remainder

TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
High Copper Alloys \continued										
C82800(1,2)	275C	S, C, CL, PM, I, P, D	Rem.(4)	.10	.02	.10	.20	.25	2.50–2.85 Be .35–.70 Co(6) .20–.35 Si .15 Al .10 Cr	
Copper-Tin-Zinc and Copper-Tin-Zinc-Lead Alloys (Red and Leaded Red Brasses)										
C83300(1,2)	131, Contact Metal	S, C, CL	92.0–94.0(7,8)	1.0–2.0	1.0–2.0	2.0–6.0	—	—	—	High-copper brasses with reasonable electrical conductivity and moderate strength. Used for electrical hardware, including cable connectors.
C83400(1,2)	407.5, Commercial Bronze 90/10, Gilding Metal	S, C, CL	88.0–92.0(7,8)	.20	.50	8.0–12.0	1.0	.25	.25 Sb .08 S .03 P .005 Si .005 Al	
C83450	Nickel-Bearing Leaded Red Brass	S, C, CL	87.0–89.0(7,8)	2.0–3.5	1.5–3.0	5.5–7.5	.8–2.0(9)	.30	.25 Sb .08 S .03 P(10) .005 Al .005 Si	
C83500	Leaded Nickel-Bearing Tin Bronze	S, C, CL	86.0–88.0(7,8)	5.5–6.5	3.5–5.5	1.0–2.5	.50–1.0(9)	.25	.25 Sb .08 S .03 P(10) .005 Al .005 Si	
C83600(1,2)	115, 85-5-5-5, Composition Bronze, Ounce Metal, (SAE 40)	S, C, CL, I	84.0–86.0(7,8)	4.0–6.0	4.0–6.0	4.0–6.0	1.0(9)	.30	.25 Sb .08 S .05 P(10) .005 Al .005 Si	Good corrosion resistance, excellent castability and moderate strength. Lead content ensures pressure tightness. Alloy C83600 is one of the most important cast alloys, widely used for plumbing fittings, other water-service goods. Alloy C83800 has slightly lower strength, but is essentially similar in properties and application.
C83800(1,2)	120, 83-4-6-7, Commercial Red Brass, Hydraulic Bronze	S, C, CL	82.0–83.8(7,8)	3.3–4.2	5.0–7.0	5.0–8.0	1.0(9)	.30	.25 Sb .08 S .03 P(10) .005 Al .005 Si	
C83810	Nickel-Bearing Leaded Red Brass	S, C, CL	Rem.(7,8)	2.0–3.5	4.0–6.0	7.5–9.5	2.0(9)	.50(11)	Sb(11) As(11) .005 Al .10 Si	

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Rem. = Remainder

Legend: Applicable Casting Processes

S = Sand **C = Continuous** **CL = Centrifugal**
D = Die **I = Investment** **P = Plaster**
PM = Permanent Mold

TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
	Copper-Tin-Zinc-Lead Alloys (Leaded Semi-Red Brasses)									
C84200(1,2)	101, 80-5-2½-12½	S, C, CL	78.0–82.0(7,8)	4.0–6.0	2.0–3.0	10.0–16.0	.8(9)	.40	.25 Sb .08 S .05 P(10) .005 Al .005 Si	General purpose alloys for plumbing and hardware goods. Good machinability, pressure tightness. Alloy C84400 is the most popular plumbing alloy in U.S. markets.
C84400(1,2)	123, 81-3-7-9, Valve Composition, 81 Metal	S, C, CL	78.0–82.0(7,8)	2.3–3.5	6.0–8.0	7.0–10.0	1.0(9)	.40	.25 Sb .08 S .02 P(10) .005 Al .005 Si	
C84410		S, C, CL	Rem.(7,8)	3.0–4.5	7.0–9.0	7.0–11.0	1.0(9)	(13)	Sb(13) .01 Al .20 Si .05 Bi	
C84500(1,2)	125, 78 Metal	S, C, CL	77.0–79.0(7,8)	2.0–4.0	6.0–7.5	10.0–14.0	1.0(9)	.40	.25 Sb .08 S .02 P(10) .005 Al .005 Si	
C84800(1,2)	130, 76-3-6-15, 76 Metal	S, C, CL	75.0–77.0(7,8)	2.0–3.0	5.5–7.0	13.0–17.0	1.0(9)	.40	.25 Sb .08 S .02 P(10) .005 Al .005 Si	
	Copper-Zinc and Copper-Zinc-Lead Alloys (Yellow and Leaded Yellow Brasses)									
C85200(1)	400, 72-1-3-24, High Copper Yellow Brass,	S, C, CL	70.0–74.0(7,14)	.7–2.0	1.5–3.8	20.0–27.0	1.0(9)	.6	.20 Sb .05 S .02 P .005 Al .05 Si	Low-cost, low-to-moderate strength, general-purpose casting alloys with good machinability, adequate corrosion resistance for many water-service applications including marine hardware and automotive cooling systems. Some compositions are amenable to permanent mold and die casting processes.
C85400(1,2)	403, 67-1-3-29, Commrcl. No.1 Yellow Brass	S, C, CL, PM, I, P	65.0–70.0(7,19)	.50–1.5	1.5–3.8	24.0–32.0	1.0(9)	.7	.35 Al .05 Si	
C85500(1,2)	60-40 Yellow Brass	S, C, CL	59.0–63.0(7,19)	.20	.20	Rem.	.20(9)	.20	.20 Mn	
C85700(1,2)	405.2, 63-1-1-35, B2, Permanent Mold Brass	S, C, CL, PM, I, P	58.0–64.0(7,14)	.50–1.5	.80–1.5	32.0–40.0	1.0(9)	.7	.8 Al .05 Si	
C85800(1,2)	405.1, Die Casting Yellow Brass	S, C, CL, PM, I, P D	57.0 min.(7,19)	1.5	1.5	31.0–41.0	.50(9)	.50	.05 Sb .25 Mn .05 As .05 S .01 P .55 Al .25 Si	

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Rem. = Remainder

Legend: Applicable Casting Processes

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PM = Permanent Mold

TABLE 2. Overview of Copper Casting Alloys \continued

Manganese Bronze and Leaded Manganese Bronze Alloys (High Strength and Leaded High Strength Yellow Brasses)

			Composition, percent maximum, unless shown as a range or minimum*							
UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Cu	Sn	Pb	Zn	Ni	Fe	Other	Uses, Significant Characteristics
C86100(1,2)	423, 90,000 Tensile Manganese Bronze	S, CL, PM, I, P	66.0–68.0(7,15)	.20	.20	Rem.	—	2.0–4.0	4.5–5.5 Al 2.5–5.5 Mn	Alloys with high mechanical strength, good corrosion resistance and favorable castability. Can be machined, but with the exception of C86400 and C86700, are less readily machined than leaded compositions. Alloy C86300 can attain tensile strengths exceeding 115 ksi (793 MPa). Used for mechanical devices: gears, levers, brackets, valve and pump components for fresh and seawater service. When used for high strength bearings, alloys C86300 and C86400 require hardened shafts.
C86200(1)	423, 95,000 Tensile Manganese Bronze, (SAE 430A)	S, C, CL, PM, I, P, D	60.0–66.0(7,15)	.20	.20	22.0–28.0	1.0(9)	2.0–4.0	3.0–4.9 Al 2.5–5.0 Mn	
C86300(1)	424, 110,000 Tensile Manganese Bronze, (SAE 430B)	S, C, CL, PM, I, P	60.0–66.0(7,15)	.20	.20	22.0–28.0	1.0(9)	2.0–4.0	5.0–7.5 Al 2.5–5.0 Mn	
C86400(1,2)	420, 60,000 Tensile Manganese Bronze	S, C, CL, PM, I, P, D	56.0–62.0(7,15)	.50–1.5	.50–1.5	34.0–42.0	1.0(9)	.40–2.0	.50–1.5 Al .10–1.5 Mn	
C86500(1,2)	421, 65,000 Tensile Manganese Bronze, (SAE 43)	S. C, CL, PM, I, P	55.0–60.0(5,13)	1.0	.40	36.0–42.0	1.0(9)	.40–2.0	.50–1.5 Al .10–1.5 Mn	
C86700(1,2)	422, 80,000 Tensile Manganese Bronze	S, C, CL, PM, I, P	55.0–60.0(7,15)	1.5	.50–1.5	30.0–38.0	1.0(9)	1.0–3.0	1.0–3.0 Al .10–3.5 Mn	
C86800(1,2)	Nickel-Manganese Bronze	S, C, CL, PM, I, P	53.5–57.0(7,15)	1.0	.20	Rem.	2.5–4.0(9)	1.0–2.5	2.0 Al 2.5–4.0 Mn	

Copper-Silicon Alloys (Silicon Bronzes and Silicon Brasses)

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Cu	Sn	Pb	Zn	Ni	Fe	Other	Uses, Significant Characteristics
C87300	95-1-4, Silicon Bronze	S, C, CL, PM, I, P	94.0 min.(4)	—	.20	.25	—	.20	3.5–4.5 Si .80–1.5 Mn	Moderate-to-high strength alloys with good corrosion resistance and favorable casting properties. Used for mechanical products and pump components where combination of strength and corrosion resistance is important. Similar compositions are commonly die and/or permanent mold cast in Europe and the U.K.
C87400(1,2)	500	S, CL, PM, I, P, D	79.0 min.(4)	—	1.0	12.0–16.0	—	—	.80 Al 2.5–4.0 Si	
C87500(1,2)	500	S, CL, PM, I, P, D	79.0 min.(4)	—	.50	12.0–16.0	—	—	.50 Al 3.0–5.0 Si	
C87600(1,2)	500, Low Zinc Silicon Brass	S, CL, PM, I, P, D	88.0 min.(4)	—	.50	4.0–7.0	—	.20	3.5–5.5 Si .25 Mn	
C87610		S, CL, PM, I, P, D	90.0 min.(4)	—	.20	3.0–5.0	—	.20	3.0–5.0 Si .25 Mn	
C87800(1,2)	500, Die Cast Silicon Brass	S, CL, PM, I, P, D	80.0 min.(4)	.25	.15	12.0–16.0	.20(9)	.15	.15 Al 3.8–4.2 Si .15 Mn .01 Mg .05 S .01 P .05 As .05 Sb	

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Rem. = Remainder

Legend: Applicable Casting Processes

S = Sand	**C = Continuous**	**CL = Centrifugal**
D = Die	**I = Investment**	**P = Plaster**
	PM = Permanent Mold	

TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
Copper-Tin Alloys (Tin Bronzes)										
C90200(1,2)	242, 93-7-0-0,	S, C, CL, PM, I, P	91.0–94.0(7,16)	6.0–8.0	.30	.50	.50(9)	.20	.20 Sb .05 S .05 P(10) .005 Al .005 Si	Hard, strong alloys with good corrosion resistance, especially against seawater. As bearings, they are wear resistant and resist pounding well. Moderately machinable. Widely used for gears, worm wheels, bearings, marine fittings, piston rings, and pump components.
C90300(1,2)	225, 88-8-0-4, Navy "G" Bronze, (SAE 620)	S, C, CL, PM, I, P	86.0–89.0(7,16)	7.5–9.0	.30	3.0–5.0	1.0(9)	.20	.20 Sb .05 S .05 P(10) .005 Al .005 Si	
C90500(1,2)	210, 88-10-0-2, Gun Metal, (SAE 62)	S, C, CL, PM, I, P	86.0–89.0(7,25)	9.0–11.0	.30	1.0–3.0	1.0(9)	.20	.20 Sb .05 S .05 P(10) .005 Al .005 Si	
C90700(1,2)	205, 89-11, (SAE 65)	S, C, CL, PM, I, P	88.0–90.0(7,16)	10.0–12.0	.50	.50	.50(9)	.15	.20 Sb .05 S .30 P(10) .005 Al .005 Si	
C90710		S, C, CL, PM, I, P	Rem.(7,16)	10.0–12.0	.25	.05	.10(9)	.10	.20 Sb .05 S .05–1.2 P(10) .005 Al .005 Si	
C90800		S, C, CL, PM, I, P	85.0–89.0(7,16)	11.0–13.0	.25	.25	.50(9)	.15	.20 Sb .05 S .30 P(10) .005 Al .005 Si	
C90810		S, C, CL, PM, I, P	Rem.(7,16)	11.0–13.0	.25	.30	.50(9)	.15	.20 Sb .05 S .15–.8 P(10) .005 Al .005 Si	
C90900(1,2)	199, 87-13-0-0	S, C, CL, PM, I, P	86.0–89.0(7,16)	12.0–14.0	.25	.25	.50(9)	.15	.20 Sb .05 S .05 P(10) .005 Al .005 Si	
C91000(1,2)	197, 85-14-0-1	S, C, CL, PM, I, P	84.0–86.0(7,16)	14.0–16.0	.20	1.5	.80(9)	.10	.20 Sb .05 S .05 P(10) .005 Al .005 Si	
C91100(1,2)	84-16-0-0	S, C, CL, PM, I, P	82.0–85.0(7,16)	15.0–17.0	.25	.25	.50(9)	.25	.20 Sb .05 S 1.0 P(10) .005 Al .005 Si	

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Rem. = Remainder

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TABLE 2. Overview of Copper Casting Alloys \continued

Copper-Tin Alloys \continued (Tin Bronzes)

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
C91300(1,2)	194, 81-19	S, C, CL, PM, I, P	79.0–82.0(7,16)	18.0–20.0	.25	.25	.50(9)	.25	.20 Sb .05 S 1.0 P(10) .005 Al .005 Si	
C91600(1,2)	205N, 88-10½-0-0-1½, Nickel Gear Bronze	S, C, CL, PM, I, P	86.0–89.0(7,16)	9.7–10.8	.25	.25	1.2–2.0(9)	.20	.20 Sb .05 S .30 P(10) .005 Al .005 Si	
C91700(1,2)	86½-12-0-0-1½, Nickel Gear Bronze	S, C, CL, PM, I, P	84.0–87.0(7,16)	11.3–12.5	.25	.25	1.20–2.0(9)	.20	.20 Sb .05 S .30 P(10) .005 Al .005 Si	

Copper-Tin-Lead Alloys (Leaded Tin Bronzes)

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Cu	Sn	Pb	Zn	Ni	Fe	Other	Uses, Significant Characteristics
C92200(1,2)	245, 88-6-1½-4½, Navy "M" Bronze, Steam Bronze, (SAE 622)	S, C, CL, PM, I, P	86.0–90.0(7,8)	5.5–6.5	1.0–2.0	3.0–5.0	1.0(9)	.25	.25 Sb .05 S .05 P(10) .005 Al .005 Si	Lead improves machinability in these tin bronzes but does not materially affect mechanical properties. The alloys are essentially free-cutting versions of the tin bronzes, above, and have similar properties and uses.
C92210	—		86.0–89.0(7,8)	4.5–5.5	1.7–2.5	3.0–4.5	.7–1.0	.25	.25 Sb .05 S .03 P .005 Al .005 Si	
C92300(1,2)	230, 87-8-1-4 Leaded "G" Bronze	S, C, CL, PM, I, P	85.0–89.0(7,8)	7.5–9.0	.30–1.0	2.5–5.0	1.0(9)	.25	.25 Sb .05 S .05 P(10) .005 Al .005 Si	
C92310		S, C, CL, PM, I, P	Rem.(7,8)	7.5–8.5	.30–1.5	3.5–4.5	1.0(9)	—	.03 Mn .005 Al .005 Si	
C92400		S, C, CL, PM, I, P	86.0–89.0(7,8)	9.0–11.0	1.0–2.5	1.0–3.0	1.0(9)	.25	.25 Sb .05 S .05 P(10) .005 Al .005 Si	
C92410		S, C, CL, PM, I, P	Rem.(7,8)	6.0–8.0	2.5–3.5	1.5–3.0	.20(9)	.20	.25 Sb .05 Mn .005 Al .005 Si	

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Legend: Applicable Casting Processes

S = Sand **C = Continuous** **CL = Centrifugal**
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PM = Permanent Mold

TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
	Copper-Tin-Lead Alloys \continued **(Leaded Tin Bronzes)**									
C92500(1,2)	200, 87-11-1-0-1, (SAE 640)	S, C, CL, PM, I, P	85.0–88.0(7)	10.0–12.0	1.0–1.5	.50	.8–1.5(9)	.30	.25 Sb .05 S .30 P(10) .005 Al .005 Si	
C92600(1,2)	215, 87-10-1-2	S, C, CL, PM, I, P	86.0–88.50(7,8)	9.3–10.5	.8–1.5	1.3–2.5	.7(9)	.20	.25 Sb .05 S .03 P(10) .005 Al .005 Si	
C92610		S, C, CL, PM, I, P	Rem.(7,8)	9.5–10.5	.30–1.5	1.7–2.8	1.0(9)	.15	.005 Al .005 Si .03 Mn	
C92700(1,2)	206, 88-10-2-0, (SAE 63)	S, C, CL, PM, I, P	86.0–89.0(7,8)	9.0–11.0	1.0–2.5	.7	1.0(9)	.20	.25 Sb .05 S .25 P(10) .005 Al .005 Si	
C92710		S, C, CL, PM, I, P	Rem.(7,8)	9.0–11.0	4.0–6.0	1.0	2.0(9)	.20	.25 Sb .05 S .10 P(10) .005 Al .005 Si	
C92800(1,2)	295, 79-16-5-0 Ring Metal	S, C, CL, PM, I, P	78.0–82.0(7,8)	15.0–17.0	4.0–6.0	.8	.80(9)	.20	.25 Sb .05 S .05 P(10) .005 Al .005 Si	
C92810		S, C, CL, PM, I, P	78.0–82.0(7)	12.0–14.0	4.0–6.0	.50	.8–1.2(9)	.50	.25 Sb .05 S .05 P(10) .005 Al .005 Si	
C92900(1,2)	84-10-2½-0-3½, Leaded Nickel Tin Bronze	S, C, CL, PM, I, P	82.0–86.0(7)	9.0–11.0	2.0–3.2	.25	2.8–4.0(9)	.20	.25 Sb .05 S .50 P(10) .005 Al .005 Si	

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Rem. = Remainder

Legend: Applicable Casting Processes

S = Sand C = Continuous CL = Centrifugal
D = Die I = Investment P = Plaster
PM = Permanent Mold

TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
Copper-Tin-Lead Alloys (High Leaded Tin Bronzes)										
C93100		S, C, CL, PM, I, P	Rem.(7,15)	6.5–8.5	2.0–5.0	2.0	1.0(9)	.25	.25 Sb .05 S .30 P(10) .005 Al .005 Si	Most commonly used bearing alloys, found in bearings operating at moderate loads and moderate-to-high speeds, as in electric motors and appliances. Alloy C93200 is considered the workhorse alloy of the series. Alloy C93600 has improved machining and anti-seizing properties. C93800 noted for its good corrosion resistance against concentrations of sulfuric acid below 78%. Alloy C94100 is especially good under boundary lubricated conditions.
C93200(1,2)	315, 83-7-7-3, Bearing Bronze, (SAE 660)	S, C, CL, PM, I, P	81.0–85.0(7,15)	6.3–7.5	6.0–8.0	1.0–4.0	1.0(9)	.20	.35 Sb .08 S .15 P(10) .005 Al .005 Si	
C93400(1,2)	311, 84-8-8-0	S, C, CL, PM, I, P	82.0–85.0(7,15)	7.0–9.0	7.0–9.0	.8	1.0(9)	.20	.50 Sb .08 S .50 P(10) .005 Al .005 Si	
C93500(1,2)	326, 85-5-9-1, (SAE 66)	S, C, CL, PM, I, P	83.0–86.0(7,15)	4.3–6.0	8.0–10.0	2.0	1.0(9)	.20	.30 Sb .08 S .05 P(10) .005 Al .005 Si	
C93600		S, C, CL, PM, I, P	79.0–83.0(8)	6.0–8.0	11.0–13.0	1.0	1.0(9)	.20	.55 Sb .08 S .15 P(10) .005 Al .005 Si	
C93700(1,2)	305, 80-10-10, Bushing and Bearing Bronze, (SAE 64)	S, C, CL, PM, I, P	78.0–82.0(15)	9.0–11.0	8.0–11.0	.8	.50(9)	.7(17)	.50 Sb .08 S .10 P(10) .005 Al .005 Si	
C93720		S, C, CL, PM, I, P	83.0 min.(15)	3.5–4.5	7.0–9.0	4.0	.50(9)	.7	.50 Sb .10 P(10)	
C93800(1,2)	319, 78-7-15, Anti-Acid Metal, (SAE 67)	S, C, CL, PM, I, P	75.0–79.0(15)	6.3–7.5	13.0–16.0	.8	1.0(9)	.15	.8 Sb .08 S .05 P(10) .005 Al .005 Si	
C93900(1,2)	79-6-15	S, C, CL, PM, I, P	76.5–79.5(18)	5.0–7.0	14.0–18.0	1.5	.8(9)	.40	.50 Sb .08 S 1.5 P(10) .005 Al .005 Si	
C94000(2)		S, C, CL, PM, I, P	69.0–72.0(19)	12.0–14.0	14.0–16.0	.50	.50–1.0(9)	.25	.50 Sb .08 S(20) .05 P(10) .005 Al .005 Si	
C94100(2)		S, C, CL, PM, I, P	72.0–79.0(19)	4.5–6.5	18.0–22.0	1.0	1.0(9)	.25	.8 Sb .08 S(20) .05 P(10) .005 Al .005 Si	

\continued on next page

Legend: Applicable Casting Processes

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Rem. = Remainder

TABLE 2. Overview of Copper Casting Alloys \continued

Copper-Tin-Lead Alloys \continued (High Leaded Tin Bronzes)

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Cu	Sn	Pb	Zn	Ni	Fe	Other	Uses, Significant Characteristics
C94300(1,2)		S, C, CL, PM, I, P	67.0–72.0(15)	4.5–6.0	23.0–27.0	.8	1.0(9)	.15	.80 Sb .08 S(20) .08 P(10) .005 Al .005 Si	
C94310		S, C, CL, PM, I, P	Rem.(15)	1.50–3.0	27.0–34.0	.50	.25–1.0(9)	.50	.50 Sb .05 P(10)	
C94320		S, C, CL, PM, I, P	Rem.(15)	4.0–7.0	24.0–32.0	—	—	.35	—	
C94330		S, C, CL, PM, I, P	68.5–75.5(15)	3.0–4.0	21.0–25.0	3.0	.50(9)	.7	.50 Sb .10 P(10)	
C94400(1,2)	312, 81-8-11 Phosphor Bronze	S, C, CL, PM, I, P	Rem.(15)	7.0–9.0	9.0–12.0	.8	1.0(9)	.15	.8 Sb .08 S .50 P(10) .005 Al .005 Si	
C94500 (1,2)	321, 73-7-20 Medium Bronze	S, C, CL, PM, I, P	Rem.(15)	6.0–8.0	16.0–22.0	1.2	1.0(9)	.15	.80 Sb .08 S .05 P .005 Al .005 Si	

Copper-Tin-Nickel Alloys (Nickel-Tin Bronzes)

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Cu	Sn	Pb	Zn	Ni	Fe	Other	Uses, Significant Characteristics
C94700(1)	88-5-0-2-5	S, C, CL, PM, I, P	85.0–90.0(19)	4.5–6.0	.10(21)	1.0–2.5	4.5–6.0(9)	.25	.15 Sb .20 Mn .05 S .05 P .005 Al .005 Si	High strength structural castings. Easy to cast, pressure tight. Corrosion and wear resistant. C94700 is heat treatable. Alloys used for bearings, worm gears, valve stems and nuts, impellers, screw conveyors, roller bearing cages, and railway electrification hardware.
C94800(1)	87-5-1-2-5, Leaded Nickel-Tin Bronze	S, C, CL, PM, I, P	84.0–89.0(19)	4.5–6.0	.30–1.0	1.0–2.5	4.5–6.0(9)	.25	.15 Sb .20 Mn .05 S .05 P .005 Al .005 Si	
C94900	Leaded Nickel-Tin Bronze	S, C, CL, PM, I, P	79.0–81.0(16)	4.0–6.0(9)	4.0–6.0	4.0–6.0	4.0–6.0(9)	.30	.25 Sb .10 Mn .08 S .05 P .005 Al .005 Si	

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TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
Copper-Aluminum-Iron and Copper-Aluminum-Iron-Nickel Alloys (Aluminum Bronzes)										
C95200(1,2)	415, 88-3-9, Aluminum Bronze 9A, (SAE 68a)	S, C, CL, PM, I, P	86.0 min.(15)	—	—	—	—	2.5–4.0	8.5–9.5 Al	The aluminum bronzes are characterized by high strength and excellent corrosion resistance. Alloys containing more than 9.5% Al can be heat treated, some to tensile strengths exceeding 120 ksi (827 MPa). Uses include a variety of heavy duty mechanical and structural products including gears, worm drives, valve guides and seats. Excellent heavy duty bearing alloys, but do not tolerate misalignment or dirty lubricants, and generally should be used against hardened steel shafts, with both shaft and bearing machined to fine surface finishes.
C95210		S, C, CL, PM, I, P	86.0 min.(15)	.10	.05	.50	1.0(9)	2.5–4.0	8.5–9.5 Al 1.0 Mn .05 Mg .25 Si	
C95220		S, C, CL, PM, I, P	Rem.(4)	—	—	—	2.5(9)	2.5–4.0	9.5–10.5 Al .50 Mn	
C95300(1,2)	415, 89-1-10, Aluminum Bronze 9B, (SAE 68b)	S, C, CL, PM, I, P	83.0 min.(15)	—	—	—	—	.8–1.5	9.0–11.0 Al	
C95400(1,2)	415, 85-4-11, Aluminum Bronze 9C,	S, C, CL, PM, I, P	83.0 min.(4)	—	—	—	1.5(9)	3.0–5.0	10.0–11.5 Al .50 Mn	
C95410(1,2)		S, C, CL, PM, I, P	83.0 min.(4)	—	—	—	1.5–2.5(9)	3.0–5.0	10.0–11.5 Al .50 Mn	
C95420		S, C, CL, PM, I, P	83.5 min.(4)	—	—	—	.50(9)	3.0–4.3	10.5–12.0 Al .50 Mn	
C95500(1,2)	415, 81-4-4-11, Aluminum Bronze 9D	S, C, CL, PM, I, P	78.0 min.(4)	—	—	—	3.0–5.5(9)	3.0–5.0	10.0–11.5 Al 3.5 Mn	
C95510	Nickel-Aluminum Bronze	S, C, CL, PM, I, P	78.0 min.(22)	.20	—	.30	4.5–5.5(9)	2.0–3.5	9.7–10.9 Al 1.5 Mn	
C95520	Nickel-Aluminum Bronze	S, C, CL, PM, I, P	74.5 min.(4)	.25	.03	.30	4.2–6.0(9)	4.0–5.5	10.5–11.5 Al 1.5 Mn .15 Si .20 Co .05 Cr	
C95600(1,2)	91-2-7, Aluminum-Silicon Bronze	S, C, CL, PM, I, P	88.0 min.(15)	—	—	—	.25(9)	—	6.0–8.0 Al 1.8–3.2 Si	
C95700(1,2)	75-3-8-2-12, Manganese-Aluminum Bronze	S, C, CL, PM, I, P	71.0 min.(4)	—	—	—	1.5–3.0(9)	2.0–4.0	7.0–8.5 Al 11.0–14.0 Mn .10 Si	
C95710	Manganese-Aluminum Bronze	S, C, CL, PM, I, P	71.0 min.(4)	1.0	.05	.50	1.5–3.0(9)	2.0–4.0	7.0–8.5 Al 11.0–14.0 Mn .15 Si .05 P	
C95800(1,2)	415, 81-5-4-9-1,Alpha Nickel-Aluminum Bronze, Propeller Bronze	S, C, CL, PM, I, P	79.0 min.(4)	—	.03	—	4.0–5.0(9,23)	3.5–4.5(23)	8.5–9.5 Al .8–1.5 Mn .10 Si	
C95810	Nickel-Aluminum Bronze	S, C, CL, PM, I, P	79.0 min.(4)	—	.10	.50	4.0–5.0(9,23)	3.5–4.5(23)	8.5–9.5 Al .8–1.5 Mn .05 Mg .10 Si	
C95900		S, C, CL, PM, I, P	Rem.(4)	—	—	—	.50(9)	3.0–5.0	12.0–13.5 Al 1.5 Mn	

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TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
	Copper-Nickel-Iron Alloys (Copper-Nickels)									
C96200(1,2)	90-10 Copper-Nickel	S, C, CL, PM, I, P	Rem.(4)	—	.01	—	9.0–11.0(9)	1.0–1.8	1.5 Mn .50 Si .5–1.0 Nb .10 C .02 S .02 P	Excellent corrosion resistance, especially against seawater. High strength and toughness from low to elevated temperatures. Very widely used in marine applications, as pump and valve components, fittings, flanges, etc. Beryllium-containing alloys can be heat treated to approximately 110 ksi (758 MPa).
C96300(1,2)	80-20 Copper-Nickel	S, C, CL, PM, I, P	Rem.(4)	—	.01	—	18.0–22.0(9)	.50–1.5	.25–1.5 Mn .50 Si .50–1.5 Nb .15 C .02 S .02 P	
C96400(1,2)	70-30 Copper-Nickel	S, C, CL, PM, I, P	Rem.(4)	—	.01	—	28.0–32.0(9)	.25–1.5	1.5 Mn .50 Si .50–1.5 Nb .15 C .02 S .02 P	
C96600(1,2)	717C, Beryllium Copper-Nickel	S, C, CL, PM, I, P	Rem.(4)	—	.01	—	29.0–33.0(9)	.8–1.1	1.0 Mn .15 Si .40–.7 Be	
C96700	Beryllium-Zirconium-Titanium Copper-Nickel	S, C, CL, PM, I, P	Rem.(4)	—	.01	—	29.0–33.0(9)	.40–.70	.40–.70 Mn .15 Si 1.1–1.2 Be .15–.35 Zr .15–.35 Ti	
C96800	Spinodal Alloy	S, C, CL, PM, I, P	Rem.(4)	—	.005	—	9.5–10.5(9)	.50	.05–.30 Mn .05 Si .10–.30 Nb (24)	
C96900	Spinodal Alloy	S, C, CL, PM, I, P	Rem.(4)	7.5–8.5	.02	.50	14.5–15.5(9)	.50	.05–.30 Mn .10 Nb .15 Mg	

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			Cu	Sn	Pb	Zn	Ni	Fe	Other	
	Copper-Nickel-Zinc Alloys (Nickel Silvers)									
C97300(1,2)	56-2-10-20-12, 12% Nickel Silver	S, C, CL, PM, I, P	53.0–58.0(15)	1.5–3.0	8.0–11.0	17.0–25.0	11.0–14.0(9)	1.5	.35 Sb .08 S .05 P .005 Al .50 Mn .15 Si	Moderately strong alloys with very good corrosion resistance and a pleasing silver color. Used in valves, fittings and other components for dairy equipment and as architectural and decorative trim.
C97400(1,2)	59-3-5-17-16, 15% Nickel Silver	S, C, CL, PM, I, P	58.0–61.0(15)	2.5–3.5	4.5–5.5	Rem.	15.5–17.0(9)	1.5	.50 Mn	
C97600(1,2)	64-4-4-8-20, 20% Nickel Silver, Dairy Metal	S, C, CL, PM, I, P	63.0–67.0(25)	3.5–4.5	3.0–5.0	3.0–9.0	19.0–21.5(9)	1.5	.25 Sb .08 S .05 P .005 Al 1.0 Mn .15 Si	
C97800(1,2)	66-5-2-2-25, 25% Nickel Silver	S, C, CL, PM, I, P	64.0–67.0(26)	4.0–5.5	1.0–2.5	1.0–4.0	24.0–27.0(9)	1.5	.20 Sb .08 S .05 P .005 Al 1.0 Mn .15 Si	
	Copper-Lead Alloys (Leaded Coppers)									
C98200	Leaded Copper, 25% SAE 49	S, C	Rem.(4)	.6–2.0	21.0–27.0	.50	.50	.7	.10 P .50 Sb	Ultrahigh lead alloys for special purpose bearings. Alloys have relatively low strength and poor impact properties and generally require reinforcement.
C98400	Leaded Copper, 30%	S, C	Rem.(4)	.50	26.0–33.0	.50	.50	.7	1.5 Ag .10 P .50 Sb	
C98600	Leaded Copper, 35% SAE 480	S, C	60.0–70.0	.50	30.0–40.0	—	—	.35	1.5 Ag	
C98800	Leaded Copper, 40% SAE 481	S, C	56.5–62.5(5)	.25	37.5–42.5(27)	.10	—	.35	5.5 Ag(27) .02 P	
C98820	Leaded Copper, 42%, SAE 484	S, C	Rem.	1.0–5.0	40.0–44.0	—	—	.35	—	
C98840	Leaded Copper, 50%, SAE 485	S, C	Rem.	1.0–5.0	44.0–58.0	—	—	.35	—	

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TABLE 2. Overview of Copper Casting Alloys \continued

UNS Number	Other Designations, Descriptive Names (Former SAE No.)	Applicable Casting Processes (See Legend)	Composition, percent maximum, unless shown as a range or minimum*							Uses, Significant Characteristics
			Cu	Sn	Pb	Zn	Ni	Fe	Other	
	Special Alloys									
C99300[1,2]	Incramet 800	S, C, CL	Rem.[25]	.05	.02	—	13.5–16.5	.40—1.0	10.7–11.5 Al 1.0–2.0 Co .02 Si	Alloys specifically designed for glassmaking molds, but also used for marine hardware.
C99350	Copper-Nickel-Aluminum-Zinc Alloy	S, C, CL	Rem.[25]	—	.15	7.5–9.5	14.5–16.0[9]	1.0 .25 Mn	9.5–10.5 Al	
C99400[1,2]	Non-Dezincification Alloy, NDZ	S, C, CL I, P	Rem.[25]	—	.25	.50–5.0	1.0–3.5	1.0–3.0	.50–2.0 Al .50–2.0 Si .50 Mn	Moderate strength alloys with good resistance to dezincification and dealuminification. Used in various products for marine (especially outboard) and mining equipment.
C99500[1,2]	Copper-Nickel-Aluminum-Zinc-Iron Alloy	S, C, CL	Rem.[25]	—	.25	.50–2.0	3.5–5.5	3.0–5.0	.50–2.0 Al .50–2.0 Si .50 Mn	
C99600	Incramute 1	S, C, CL	Rem.[25]	.10	.02	.20	.20	.20	1.0–2.8 Al .20 Co .10 Si 39.0–45.0 Mn .05 C	Special-purpose alloys with exceptionally high damping capacity.
C99700[1,2]	White Manganese Brass	S, CL, PM, I, P, D	54.0 min.[25]	1.0	2.0	19.0–25.0	4.0–6.0	1.0	.50–3.0 Al 11.0–15.0 Mn	
C99750[1,2]	Copper-Zinc-Manganese Alloy	S, PM, I, P, D	55.0–61.0[25]	.50–2.5	—	17.0–23.0	5.0	1.0	.25–3.0 Al 17.0–23.0 Mn	

Footnotes

(1) Data sheet for this alloy can be found in CDA's *Standards Handbook, Cast Products, Alloy Data/7.*

(2) Alloy has significant commercial importance.

(3) Including Ag, % min.

(4) Cu + Sum of Named Elements, 99.5% min.

(5) Includes Ag.

(6) Ni + Co.

(7) In determining copper min., copper may be calculated as Cu + Ni.

(8) Cu + Sum of Named Elements, 99.3% min.

(9) Including Co.

(10) For continuous castings, P shall be 1.5% max.

(11) Fe + Sb + As shall be .50% max.

(12) Cu + Sum of Named Elements, 99.2% min.

(13) Fe + Sb + As shall be .8% max.

(14) Cu + Sum of Named Elements, 99.1% min.

(15) Cu + Sum of Named Elements, 99.0% min.

(16) Cu + Sum of Named Elements, 99.4% min.

(17) Fe shall be .35% max., when used for steel-backed bearings.

(18) Cu + Sum of Named Elements, 98.9% min.

(19) Cu + Sum of Named Elements, 98.7% min.

(20) For continuous castings, S shall be .25% max.

(21) The mechanical properties of C94700 (heat treated) may not be attainable if the lead content exceeds .01%.

(22) Cu + Sum of Named Elements, 99.8% min.

(23) Fe content shall not exceed Ni content.

(24) The following additional maximum impurity limits shall apply: .10% Al, .001% B, .001% Bi, .005–.15% Mg, .005% P, .0025% S, .02% Sb, 7.5–8.5% Sn, .01% Ti, 1.0% Zn.

(25) Cu + Sum of Named Elements, 99.7% min.

(26) Cu + Sum of Named Elements, 99.6% min.

(27) Pb and Ag may be adjusted to modify the alloy hardness.

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FIGURE I-1
Blast furnace tuyeres are cast in high conductivity copper.

FIGURE I-2
Resistance welding machine components are cast in beryllium copper for maximum strength and high electrical conductivity.

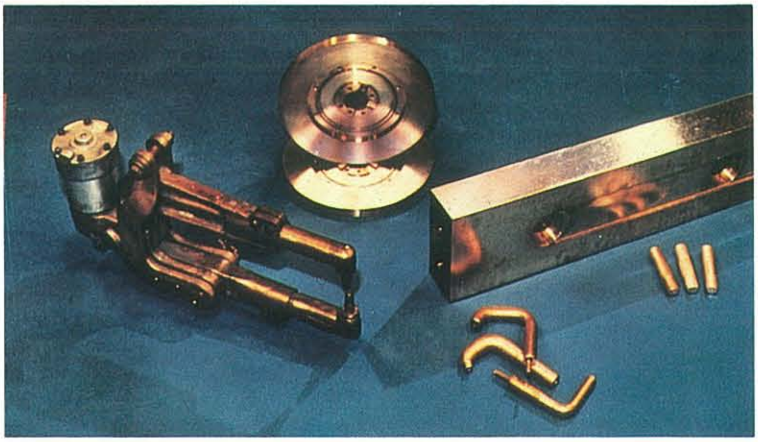

FIGURE I-3
Plumbing goods, such as the water meter shown here, are commonly cast in semi-red brass, an economical alloy with excellent castability and good corrosion resistance.

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys

UNS Number	Casting Process	Temper, (SAE Suffix)(1)	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C80100	S	M01	—	25	—	9	—	—	—	40	—
			—	172	—	62	—	—	—	40	
C81100	S	M01	—	25	—	9	—	—	—	40	—
			—	172	—	62	—	—	—	40	
C81200	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C81400	S	M01	—	30	—	—	—	12	—	35	HR62B
				207	—	—	—	83	—	35	
C81400	S	TF00	—	53	—	—	—	36	—	11	HR69B
			—	365	—	—	—	248	—	11	
C81500	S	TF00	—	51	—	40	—	—	—	17	—
			—	352	—	276	—	—	—	17	
C81540	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C82000	S	M01	—	50	—	—	—	20	—	20	HR55B
			—	345	—	—	—	138	—	20	
C82000	S	011	—	65	—	—	—	37	—	12	—
			—	448	—	—	—	255	—	12	
C82000	S	TB00	—	47	—	—	—	15	—	25	HR40B
			—	324	—	—	—	103	—	25	
C82000	S	TF00	—	96	—	—	—	75	—	6	HR96B
			—	662	—	—	—	517	—	6	
C82200	S	M01	—	50	—	—	—	25	—	20	HR55B
			—	345	—	—	—	172	—	20	
C82200	S	011	—	65	—	—	—	40	—	15	HR75B
			—	448	—	—	—	276	—	15	
C82200	S	TB00	—	45	—	—	—	12	—	30	HR30B
				310	—	—	—	83	—	30	
C82200	S	TF00	—	95	—	—	—	75	—	7	HR96B
			—	655	—	—	—	517	—	7	
C82400	S	011	—	100	—	—	—	80	—	3	HR21C
			—	690	—	—	—	551	—	3	
C82400	S	TB00	—	60	—	—	—	20	—	40	HR59B
			—	414	—	—	—	138	—	40	
C82400	S	TF00	—	155	—	—	—	145	—	1	HR38C
			—	1,068	—	—	—	1,000	—	1	
C82500	S	M01	—	75	—	—	—	40	—	15	HR81B
			—	517	—	—	—	276	—	15	
C82500	S	011	—	120	—	—	—	105	—	2	HR30C
			—	827	—	—	—	724	—	2	
C82500	S	TB00	—	60	—	—	—	25	—	35	HR63B
			—	414	—	—	—	172	—	35	
C82500	S	TF00	—	160	—	—	—	150	—	1	HR43C
			—	1,103	—	—	—	1,034	—	1	
C82510	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C82600	S	M01	—	80	—	—	—	50	—	10	HR86B
			—	552	—	—	—	345	—	10	
C82600	S	011	—	120	—	—	—	105	—	2	HR31C
			—	827	—	—	—	724	—	2	

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand
D = Die
C = Continuous
I = Investment
CL = Centrifugal
P = Plaster
PM = Permanent Mold

Brinell Hardness 10-mm Ball Indicator 500 kg	Brinell Hardness 10-mm Ball Indicator 3,000 kg	Shear Strength	Compressive Strength 0.1% Set	Compressive Strength 1.0% Set	Compressive Strength 10.0% Set	Impact Strength at 68 F (20C) Izod	Impact Strength at 68 F (20C) Charpy V-Notch	Impact Strength at 68 F (20C) Charpy Unnotched	Fatigue Strength	UNS Number
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
44HB	—	—	—	—	—	—	—	—	9	**C80100**
		—	—	—	—	—	—	—	62	
44HB	—	—	—	—	—	—	—	—	9	**C81100**
		—	—	—	—	—	—	—	62	
—	—	—	—	—	—	—	—	—	—	**C81200**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C81400**
		—	—	—						
—	—	—	—	—	—	—	—	—	—	**C81400**
		—	—	—	—	—	—	—	—	
105HB	—	—	—	—	—	3	20	—	15	**C81500**
		—	—	—	—	4	27	—	103	
—	—	—	—	—	—	—	—	—	—	**C81540**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82000**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82000**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82000**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	18	**C82000**
		—	—	—	—	—	—	—	124	
—	—	—	—	—	—	—	—	—	—	**C82200**
		—	—	—	—	—	—	—		
—	—	—	—	—	—	—	—	—	—	**C82200**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82200**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82200**
		—	—	—	—	—	—			
—	—	—	—	—	—	—	—	—	—	**C82400**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82400**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	23	**C82400**
		—	—	—	—	—	—	—	160	
—	—	—	—	—	—	—	—	—	—	**C82500**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82500**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82500**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	24	**C82500**
		—	—	—	—	—	—	—	165	
—	—	—	—	—	—	—	—	—	—	**C82510**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82600**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C82600**
		—	—	—	—	—	—	—	—	

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys \continued

UNS Number	Casting Process	Temper, (SAE Suffix)[1]	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C82600	S	TB00	—	70	—	—	—	30	—	12	HR75B
			—	483	—	—	—	207	—	12	
C82600	S	TF00	—	165	—	—	—	155	—	1	HR45C
			—	1,138	—	—	—	1,069	—	1	
C82700	S	TF00	155	—	—	—	130	—	—	2	HR39C
			1,069	—	—	—	896	—	—	2	
C82800	S	M01	—	80	—	—	—	50	—	10	HR88B
			—	552	—	—	—	345	—	10	
C82800	S	011	—	125	—	—	—	110	—	2	HR31C
			—	862	—	—	—	758	—	2	
C82800	S	TB00	—	80	—	—	—	35	—	10	HR85B
			—	552	—	—	—	241	—	10	
C82800	S	TF00	—	165	—	—	—	155	—	1	HR46C
				1,138	—	—	—	1,069	—	1	
C83300	S	M01	—	32	—	10	—	—	—	35	HR35B
				221	—	69	—	—	—	35	
C83400	S	M01	—	35	—	10	—	—	—	30	HR50F
			—	241	—	69	—	—	—	30	
C83450	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C83500	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C83600	S, CL	M01, M02	30	37	14	17	—	—	20	30	—
		(SAE -A)	205	255	97	117	—	—	20	30	
C83600	C	M07	36	—	19	—	—	—	15	—	—
		(SAE -B)	248	—	131	—	—	—	15	—	
C83600	C	M07	50	—	25	—	—	—	12	—	—
		(SAE -C)	345	—	170	—	—	—	12	—	
C83800	S, CL	M01, M02	30	35	13	16	—	—	20	25	—
		(SAE -A)	207	241	90	110	—	—	20	25	
C83800	C	M07	30	—	15	—	—	—	16	—	—
		(SAE -B)	207	—	103	—	—	—	16	—	
C83810	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C84200	S	M01	28	35	—	14	—	—	15	27	—
			193	241	—	97	—	—	15	27	
C84400	S	M01	29	34	13	15	—	—	18	26	—
			200	234	90	103	—	—	18	26	
C84410	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C84500	S	M01	29	35	13	14	—	—	16	28	—
			200	241	90	97	—	—	16	28	
C84800	S	M01	28	37	12	14	—	—	16	35	—
			193	255	83	97	—	—	16	35	
C85200	S, CL	M01, M02	35	38	12	13	—	—	25	35	—
			241	262	83	90	—	—	25	35	
C85400	S, CL	M01, M02	30	34	11	12	—	—	20	35	—
			207	234	76	83	—	—	20	35	
C85500	S	M01	55	60	—	23	—	—	25	40	HR55B
			379	414	—	159	—	—	25	40	

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand	C = Continuous	CL = Centrifugal
D = Die	I = Investment	P = Plaster
	PM = Permanent Mold	

Brinell Hardness 10-mm Ball Indicator		Shear Strength	Compressive Strength			Impact Strength at 68 F (20C)			Fatigue Strength	UNS Number
500 kg	3,000 kg		0.1% Set	1.0% Set	10.0% Set	Izod	Charpy V-Notch	Charpy Unnotched		
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
—	—	—	—	—	—	—	—	—	—	C82600
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C82600
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C82700
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C82800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C82800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C82800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C82800
		—	—	—	—	—	—	—	—	
35HB	—	—	—	—	—	—	—	—	—	C83300
		—	—	—	—	—	—	—		
—	—	—	—	—	—	—	—	—	—	C83400
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C83450
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C83500
		—	—	—	—	—	—	—	—	
60HB	—	—	14	—	38	10	11	—	11	C83600
		—	97	—	262	14	15	—	76	
—	—	—	—	—	—	—	—	—	—	C83600
		—	—	—	—	—	—	—	—	
—	—	—	—		—	—	—	—	—	C83600
		—	—	—	—	—	—	—	—	
60HB	—	—	12	—	29	8	—	—	—	C83800
		—	83	—	200	11	—	—	—	
—	—	—	—	—	—	—	—	—	—	C83800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C83810
		—	—	—	—	—	—	—	—	
60HB	—	—	—	—	—	—	—	—	—	C84200
		—	—	—	—	—	—	—	—	
55HB	—	—	—	—	—	8	—	—	—	C84400
		—	—	—	—	11	—	—	—	
—	—	—	—	—	—	—	—	—	—	C84410
		—	—	—	—	—	—	—	—	
55HB	—	—	—	—	—	—	—	—	—	C84500
		—	—	—	—	—	—	—	—	
55HB	—	—	13	16	34	—	12	—	—	C84500
		—	90	110	234	—	16	—	—	
45HB	—	—	9	—	30	—	—	—	—	C85200
		—	62	—	207	—	—	—	—	
50HB	—	—	9	—	28	—	—	—	—	C85400
		—	62	—	193	—	—	—	—	
85HB	—	—	—	—	—	—	—	—	—	C85500
		—	—	—	—	—	—	—	—	

UNS Number	Casting Process	Temper, (SAE Suffix)[1]	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C85700	S, CL	M01, M02	40	50	14	18	—	—	15	40	—
			276	345	97	124	—	—	15	40	
C85800	D	M04	—	55	—	—	—	30	—	15	HR55B
			—	379	—	—	—	207	—	15	
C86100	S	M01	90	95	—	—	45	50	18	20	—
			621	655	—	—	310	345	18	20	
C86200	S, CL, C	M01, M02, M07	90	95	—	—	45	48	18	20	—
			621	655	—	—	310	331	18	20	
C86300	S	M01	—	119	—	—	—	67	—	18	—
			—	821	—	—	—	462	—	18	
C86300	S, CL	M01, M02	110	—	—	—	60	—	12	—	—
		(SAE -A)	758	—	—	—	414	—	12	—	—
C86300	C	M07	110	—	—	—	62	—	14	—	—
		(SAE -B)	758	—	—	—	427	—	14	—	
C86400	S	M01	60	65	—	—	20	25	15	20	—
			414	448	—	—	138	172	15	20	
C86500	S, CL	M01, M02	65	71	27	29	25	28	20	30	—
		(SAE -A)	448	490	187	200	172	193	20	30	
C86500	C	M07	70	—	—	—	25	—	25	—	—
		(SAE -B)	483	—	—	—	172	—	25	—	
C86700	S	M01	80	85	32	42	—	—	15	20	HR80B
			552	586	221	290	—	—	15	20	
C86800	S	M01	78	82	35	38	—	—	18	22	—
			538	565	241	262	—	—	18	22	
C87300	S, CL	M01, M02	45	55	18	25	—	—	20	30	—
			310	379	124	172	—	—	20	30	
C87400	S, CL	M01, M02	50	55	21	24	—	—	18	30	—
			345	379	145	165	—	—	18	30	
C87500	S, CL	M01, M02	60	67	24	30	—	—	16	21	—
			414	462	165	207	—	—	16	21	
C87600	S	M01	60	66	30	32	—	—	16	20	HR76B
			414	455	207	221	—	—	16	20	
C87610	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C87800	D	M04	—	85	—	—	—	50	—	25	HR85B
			—	586	—	—	—	345	—	25	
C90200	S	M01	—	38	—	16	—	—	—	30	—
			—	124	—	110	—	—	—	30	
C90300	S, CL	M01, M02	40	45	18	21	—	—	—	30	—
			276	310	124	145	—	—	—	30	
C90300	C	M07	44	—	22	—	—	—	18	—	—
		(SAE -B)	303	—	152	—	—	—	18	—	
C90500	S, CL	M01, M02	40	45	18	22	—	—	20	25	—
		(SAE -A)	276	310	124	152	—	—	20	25	
C90500	C	M07	44	—	25	—	—	—	10	—	—
		(SAE -B)	303	—	172	—	—	—	10	—	
C90700	S	M01	35	44	18	22	—	—	10	20	—
		(SAE -A)	241	303	124	152	—	—	10	20	
C90700	CL, PM	M02, M05	—	55	—	30	—	—	—	16	—
			—	379	—	207	—	—	—	16	

Legend: Casting Processes

S = Sand
C = Continuous
CL = Centrifugal
D = Die
I = Investment
P = Plaster
PM = Permanent Mold

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Brinell Hardness 10-mm Ball Indicator			Compressive Strength			Impact Strength at 68 F (20C)				
500 kg	3,000 kg	Shear Strength	0.1% Set	1.0% Set	10.0% Set	Izod	Charpy V-Notch	Charpy Unnotched	Fatigue Strength	UNS Number
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
75HB	—	—	—	—	—	—	—	—	—	**C85700**
		—	—	—	—	—	—	—		
102HB	—	—	—	—	—	—	—	40	—	**C85800**
		—	—	—	—	—	—	54	—	
—	180HB	—	50	—	—	12	—	—	—	**C86100**
		—	345	—	—	16	—	—	—	
—	180HB	—	50	—	—	12	—	—	—	**C86200**
		—	345	—	—	16	—	—	—	
—	225HB	—	60	—	97	15	12	—	25	**C86300**
		—	414	—	669	20	16	—	172	
—	—	—	—	—	—	—	—	—	—	**C86300**
			—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C86300**
		—	—	—	—	—	—	—	—	
90HB	105HB	—	22	—	87	30	25	—	—	**C86400**
		—	152	—	600	41	34	—	—	
100HB	130HB	—	24	35	79	—	32	—	20	**C86500**
		—	166	241	545	—	43	—	138	
—	—	—	—	—	—	—	—	—	—	**C86500**
		—	—	—	—	—	—	—	—	
—	155HB	—	—	—	—	—	—	—	—	**C86700**
		—	—	—	—	—	—	—	—	
—	80HB	—	—	—	—	—	—	—	—	**C86800**
		—	—	—	—	—	—	—	—	
85HB	—	28	18	—	60	33	—	—	—	**C87300**
		193	124	—	414	45	—	—	—	
70HB	100HB	—	—	—	—	—	40	—	—	**C87400**
		—	—	—	—	—	54	—	—	
115HB	134HB	—	27	—	75	—	32	—	22	**C87500**
		—	186	—	517	—	43	—	152	
110HB	135HB	—	—	—	60	—	—	—	—	**C87600**
		—	—	—	414	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C87610**
			—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	70	—	**C87800**
		—	—	—	—	—	—	95	—	
70HB	—	—	—	—	—	—	—	—	25	**C90200**
		—	—	—	—	—	—	—	172	
70HB	—	—	13	—	—	—	14	—	—	**C90300**
		—	90	—	—	—	19	—	—	
—	—	—	—	—	—	—	—	—	—	**C90300**
		—	—	—	—	—	—	—	—	
75HB	—	—	—	40	—	10	—	—	13	**C90500**
		—	—	276	—	13	—	—	90	
—	—	—	—	—	—	—	—	—	—	**C90500**
		—	—	—	—	—	—	—	—	
80HB	—	—	—	—	—	—	—	—	25	**C90700**
		—	—	—	—	—	—	—	172	
—	—	—	—	—	—	—	—	—	—	**C90700**
		—	—	—	—	—	—	—	—	

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys \continued

UNS Number	Casting Process	Temper, (SAE Suffix)(1)	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C90700	C	M07	40	—	25	—	—	—	—	10	—
		(SAE -B)	276	—	172	—	—	—	10	—	
C90710	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C90800	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C90810	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C90900	S	M01	—	40	—	20	—	—	—	15	—
			—	276	—	138	—	—	—	15	
C91000	S	M01	30	32	—	25	—	—	1	2	—
			207	221	—	172	—	—	1	2	
C91100	S	M01	—	35	—	25	—	—	—	2	—
			—	241	—	172	—	—	—	2	
C91300	S	M01	—	35	—	30	—	—	—	0.5	—
			—	241	—	207	—	—	—	0.5	
C91600	S	M01	35	44	17	22	—	—	10	16	—
			241	303	117	152	—	—	10	16	
C91600	CL, PM	M02, M05	45	60	25	32	—	—	10	16	—
			310	414	172	221	—	—	10	16	
C91700	S	M01	35	44	17	22	—	—	10	16	—
			241	303	117	152	—	—	10	16	
C91700	CL, PM	M02, M05	50	60	28	32	—	—	12	16	—
			345	414	193	221	—	—	12	16	
C92200	S, CL	M01, M02	34	40	16	20	—	—	24	30	—
		(SAE -A)	234	276	110	138	—	—	24	30	
C92200	C	M07	38	—	19	—	—	—	18	—	—
		(SAE -B)	262	—	131	—	—	—	18	—	
C92300	S, CL	M01, M02	36	40	16	20	—	—	18	25	—
		(SAE -A)	248	276	110	138	—	—	18	25	
C92300	C	M07	40	—	19	—	—	—	16	—	—
		(SAE -B)	276	—	131	—	—	—	16	—	
C92310	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C92400	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C92410	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C92500	S	M01	35	44	18	20	—	—	10	20	—
		(SAE -A)	241	303	124	138	—	—	10	20	
C92500	C	M07	40	—	24	—	—	—	10	—	—
		(SAE -B)	276	—	166	—	—	—	10	—	
C92600	S	M01	40	44	18	20	—	—	20	30	HR78F
			276	303	124	138	—	—	20	30	
C92610	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C92700	S	M01	35	42	18	21	—	—	10	20	—
		(SAE -A)	241	290	124	145	—	—	10	20	
C92700	C	M07	38	—	20	—	—	—	8	—	—
		(SAE -B)	262	—	138	—	—	—	8	—	

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand	C = Continuous	CL = Centrifugal
D = Die	I = Investment	P = Plaster
	PM = Permanent Mold	

Brinell Hardness 10-mm Ball Indicator		Shear Strength	Compressive Strength			Impact Strength at 68 F (20C)			Fatigue Strength	UNS Number
500 kg	3,000 kg		0.1% Set	1.0% Set	10.0% Set	Izod	Charpy V-Notch	Charpy Unnotched		
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
—	—	—	—	—	—	—	—	—	—	C90700
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C90710
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C90800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C90810
		—	—	—	—	—	—	—	—	
90HB	—	—	—	—	—	—	—	—	—	C90900
		—	—	—	—	—	—	—	—	
105HB	—	—	—	—	—	—	—	—	—	C91000
		—	—	—	—	—	—	—	—	
—	135HB	—	—	—	—	—	—	—	—	C91100
		—	—	—	—	—	—	—	—	
—	170HB	—	—	—	—	—	—	—	—	C91300
	160HB(2)	—	—	—	—	—	—	—	—	
85HB	—	—	—	—	—	—	—	—	—	C91600
65HB(2)		—	—	—	—	—	—	—	—	
106HB	—	—	—	—	—	—	—	—	—	C91600
95HB(2)		—	—	—	—	—	—	—	—	
85HB	—	—	—	—	—	—	—	—	—	C91700
65HB(2)		—	—	—	—	—	—	—		
106HB	—	—	—	—	—	—	—	—	—	C91700
95HB(2)		—	—	—	—	—	—	—	—	
65HB	—	—	15	20	38	—	19	—	11	C92200
		—	103	140	262	—	26	—	76	
—	—	—	—	—	—	—	—	—	—	C92200
		—	—	—	—	—	—	—	—	
70HB	—	—	10	—	35	12	—	—	—	C92300
		—	69	—	241	16	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92300
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92310
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92400
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92410
		—	—	—	—	—	—	—	—	
80HB	—	—	—	—	—	—	—	—	—	C92500
	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92500
		—	—	—	—	—	—	—	—	
70HB	—	—	12	—	40	7	—	—	—	C92600
		—	83	—	276	9	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92610
		—	—	—	—	—	—	—	—	
77HB	—	—	—	—	—	—	—	—	—	C92700
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92700
		—	—	—	—	—	—	—	—	

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys \continued

UNS Number	Casting Process	Temper, (SAE Suffix)(1)	Tensile Strength		Yield Strength 0.5% Extension		Yield Strength 0.2% Offset		% Elongation		Rockwell Hardness
			Minimum	Typical	Minimum	Typical	Minimum	Typical	Minimum	Typical	
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C92710	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C92800	S	M01	—	40	—	30	—	—	—	1	HR80B
			—	276	—	207	—	—	—	1	
C92810	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C92900	S, PM, C	M01, M05, M07	45	47	25	26	—	—	8	20	—
			310	324	172	179	—	—	8	20	
C93100	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C93200	S, CL	M01, M02	30	35	14	18	—	—	15	20	—
		(SAE -A)	207	241	97	124	—	—	15	20	
C93200	C	M07	35	—	20	—	—	—	10	—	—
		(SAE -B)	241	—	138	—	—	—	10	—	—
C93400	S	M01	25	32	12	16	—	—	8	20	—
			172	221	83	110	—	—	8	20	
C93500	S, CL	M01, M02	28	32	12	16	—	—	15	20	—
		(SAE -A)	193	221	83	110	—	—	15	20	
C93500	C	M07	30	—	16	—	—	—	12	—	—
		(SAE -B)	207	—	110	—	—	—	12	—	
C93600	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C93700	S, CL	M01, M02	30	35	12	18	—	16	15	20	—
		(SAE -A)	207	241	83	124	—	110	15	20	
C93700	C	M07	35	—	20	—	—	—	6	—	—
		(SAE -B)	241	—	138	—	—	—	6	—	
C93700	C	M07	40	—	25	—	—	—	6	—	—
		(SAE -C)	276	—	172	—	—	—	6	—	
C93720	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C93800	S, CL	M01, M02	26	30	14	16	—	—	12	18	—
			179	207	97	110	—	—	12	18	
C93800	CL	M02	—	33	—	20	—	—	—	12	—
		(SAE -A)	—	228	—	138	—	—	—	12	
C93800	C	M07	25	—	16	—	—	—	5	—	—
		(SAE -B)	172	—	110	—	—	—	5	—	
C93900	C	M07	25	32	16	22	—	—	5	7	—
			172	221	110	152	—	—	5	7	
C94000	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C94100	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C94300	S	M01	24	27	—	13	—	—	10	15	—
			166	186	—	90	—	—	10	15	
C94300	S, CL	M01, M02	21	—	—	—	—	—	10	—	—
		(SAE -A)	145	—	—	—	—	—	10	—	
C94300	C	M07	21	—	15	—	—	—	7	—	—
		(SAE -B)	145	—	103	—	—	—	7	—	
C94310	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	

Legend: Casting Processes

S = Sand	C = Continuous	CL = Centrifugal
D = Die	I = Investment	P = Plaster
	PM = Permanent Mold	

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Brinell Hardness 10-mm Ball Indicator			Compressive Strength			Impact Strength at 68 F (20C)				
500 kg	3,000 kg	Shear Strength	0.1% Set	1.0% Set	10.0% Set	Izod	Charpy V-Notch	Charpy Unnotched	Fatigue Strength	UNS Number
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
—	—	—	—	—	—	—	—	—	—	C92710
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C92810
		—	—	—	—	—	—	—	—	
80HB	—	—	—	—	50	12	—	—	—	C92900
75HB(2)		—	—	—	345	16	—	—	—	
—	—	—	—	—	—	—	—	—	—	C93100
		—	—	—	—	—	—	—	—	
65HB	—	—	—	—	46	6	—	—	16	C93200
		—	—	—	317	8	—	—	110	
—	—	—	—	—	—	—	—	—	—	C93200
		—	—	—	—	—	—	—	—	
60HB	—	—	—	—	48	5	—	—	15	C93400
		—	—	—	331	7	—	—	103	
60HB	—	—	13	—	—	—	8	—	—	C93500
		—	90	—	—	—	11	—	—	
—	—	—	—	—	—	—	—	—	—	C93500
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C93600
		—	—	—	—	—	—	—	—	
60HB	—	18	13	—	47	5	11	—	13	C93700
		124	90	—	324	7	15	—	90	
—	—	—	—	—	—	—	—	—	—	C93700
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C93700
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C93720
		—	—	—	—	—	—	—	—	
55HB	—	15	12	—	38	5	—	—	10	C93800
		103	83	—	262	7	—	—	69	
—	—	—	19	—	—	—	—	—	—	C93800
		—	131	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C93800
		—	—	—	—	—	—	—	—	
63HB	—	—	—	—	—	—	—	—	—	C93900
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C94000
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C94100
		—	—	—	—	—	—	—	—	
48HB	—	—	11	—	23	5	—	—	—	C94300
		—	76	—	159	7	—	—		
—	—	—	—	—	—	—	—	—	—	C94300
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C94300
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C94310
		—	—	—	—	—	—	—	—	

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys \continued

UNS Number	Casting Process	Temper, (SAE Suffix)(1)	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C94320	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C94330	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C94400	S	M01	—	32	—	16	—	—	—	18	—
			—	221	—	110	—	—	—	18	
C94500	S	M01	—	25	—	12	—	—	—	12	—
			—	172	—	83	—	—	—	12	
C94700	S, C	M01, M07	45	50	20	23	—	—	25	35	—
		(SAE -A)	310	345	138	159	—	—	25	35	
C94700	S, C	TX00	75	85	50	60	—	—	5	10	—
		(SAE -B)	517	586	345	414	—	—	5	10	
C94800	S, C	M01, M07	40	45	20	23	—	—	20	35	—
			276	310	138	159	—	—	20	35	
C94800	S	TX00	—	60	—	30	—	—	—	8	—
			—	414	—	207	—	—	—	8	
C94900	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95200	S, CL	M01, M02	65	80	25	27	—	—	20	35	HR64B
		(SAE -A)	448	552	172	186	—	—	20	35	
C95200	C	M07	68	—	26	—	—	—	20	—	—
		(SAE -B)	469	—	179	—	—	—	20	—	
C95210	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95220	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95300	S, CL	M01, M02	65	75	25	27	—	—	20	25	HR67B
		(SAE -A)	448	517	172	186	—	—	20	25	
C95300	C	M07	70	—	26	—	—	—	25	—	—
		(SAE -B)	483	—	179	—	—	—	25	—	
C95300	S, CL, C	TQ50	80	85	40	42	—	—	12	15	HR81B
		(SAE -C)	552	586	276	290	—	—	12	15	
C95400	S, CL	M01, M02	75	85	30	35	—	—	12	18	—
		(SAE -A)	517	586	207	241	—	—	12	18	
C95400	C	M07	85	—	32	—	—	—	12	—	—
		(SAE -B)	586	—	221	—	—	—	12	—	
C95400	S, CL	TQ50	90	105	45	54	—	—	6	8	—
		(SAE -C)	621	724	310	372	—	—	6	8	
C95400	C	TQ50	95	—	45	—	—	—	10	—	—
		(SAE -D)	655	—	310	—	—	—	10		—
C95410	S	M01	—	85	—	35	—	—	—	18	—
			—	586	—	241	—	—	—	18	
C95410	S	TQ50	—	105	—	54	—	—	—	8	—
			—	724	—	372	—	—	—	8	
C95420	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95500	S, CL	M01, M02	90	100	40	44	—	—	6	12	HR87B
		(SAE -A)	621	690	276	303	—	—	6	12	
C95500	C	M07	95	—	42	—	—	—	10	—	—
		(SAE -B)	665	—	290	—	—	—	10	—	

Legend: Casting Processes

S = Sand　C = Continuous　CL = Centrifugal
D = Die　I = Investment　P = Plaster
PM = Permanent Mold

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Brinell Hardness 10-mm Ball Indicator		Shear Strength	Compressive Strength			Impact Strength at 68 F (20C)			Fatigue Strength	UNS Number
500 kg	3,000 kg		0.1% Set	1.0% Set	10.0% Set	Izod	Charpy V-Notch	Charpy Unnotched		
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
—	—	—	—	—	—	—	—	—	—	**C94320**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C94330**
		—	—	—	—	—	—	—	—	
55HB	—	16	—	—	44	5	—	—	11	**C94400**
		110	—	—	303	7	—	—	76	
50HB	—	13	—	—	36	4	—	—	10	**C94500**
		90	—	—	248	5	—	—	69	
85HB	—	38	—	—	—	85	—	—	14	**C94700**
		262	—	—	—	115	—	—	97	
—	180HB	65	—	—	—	110	—	—	14	**C94700**
		448	—	—	—	149	—	—	97	
80HB	—	—	—	—	—	—	—	—	12	**C94800**
		—	—	—	—	—	—	—	83	
120HB	—	—	—	—	—	—	—	—	12	**C94800**
		—	—	—	—	—	—	—	83	
—	—	—	—	—	—	—	—	—	—	**C94900**
		—	—	—	—	—	—	—	—	
—	125HB	40	27	—	70	30	30	20(4)	22	**C95200**
		276	186	—	483	41	41	27(4)	152	
—	—	—	—	—	—	—	—	—	—	**C95200**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C95210**
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C95220**
		—	—	—	—	—	—	—	—	
—	140HB	41	20	—	83	28(5)	23(6)	—	22	**C95300**
		283	138	—	572	38(5)	31(6)	—	152	
—	—	—	—	—	—	—	—	—	—	**C95300**
		—	—	—	—	—	—	—	—	
—	174HB	46	35	—	90	—	—	27(4)	27	**C95300**
		317	241	—	—	621		37(4)	186	
—	170HB	47	—	—	100	16	—	11(4)	28	**C95400**
		324	—	—	690	22	—	15(4)	193	
—	—	—	—	—	—	—	—	—	—	**C95400**
		—	—	—	—	—	—	—	—	
—	195HB	50	—	—	120	11	—	7(4)	35	**C95400**
		345	—	—	827	15(4)	—	9	241	
—	—	—	—	—	—	—	—	—	—	**C95400**
		—	—	—	—	—	—	—	—	
—	170HB	47	—	—	100	—	—	—	—	**C95410**
		324	—	—	690	—	—	—	—	
—	195HB	50	—	—	120	—	—	—	—	**C95410**
		345	—	—	827	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	**C95420**
		—	—	—	—	—	—	—	—	
—	195HB	48	—	—	120	13	—	10(4)	31	**C95500**
		331	—	—	827	18	—	14(4)	214	
—	—	—	—	—	—	—	—	—	—	**C95500**
		—	—	—	—	—	—	—	—	

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys \continued

UNS Number	Casting Process	Temper, (SAE Suffix)[1]	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi	ksi	ksi	ksi	ksi	ksi	in 2 inches	in 2 inches	
			MPa	MPa	MPa	MPa	MPa	MPa	in 51 mm	in 51 mm	
C95500	S, CL	TQ50	110	120	60	68	—	—	5	10	HR96B
		(SAE -C)	758	827	414	469	—	—	5	10	
C95510	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95520	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95600	S	M01	60	75	28	34	—	—	10	18	—
			414	517	193	234	—	—	10	18	
C95700	S	M01	90	95	40	45	—	—	20	26	—
			621	655	276	310	—	—	20	26	
C95710	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—		
C95800	S, CL	M01, M02	85	95	35	38	—	—	15	25	—
		(SAE -A)	586	655	241	262	—	—	15	25	
C95800	C	M07	90	—	38	—	—	—	18	—	—
		(SAE -B)	621	—	262	—	—	—	18	—	
C95810	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C95900	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C96200	S	M01	45	—	25	—	—	—	20	—	—
			310	—	172	—	—	—	20	—	
C96300	S	M01	75	—	55	—	—	—	10	—	—
			517	—	379	—	—	—	10	—	
C96400	S	M01	60	68	32	37	—	—	20	28	—
			414	469	221	255	—	—	20	28	
C96600	S	TB00	—	75	—	38	—	—	—	12	HR74B
			—	517	—	262	—	—	—	12	
C96600	S	TF00	—	120	—	75	—	—	—	12	HR24C
			—	827	—	517	—	—	—	12	
C96700	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C96800	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C96900	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C97300	S	M01	30	35	15	17	—	—	8	20	—
			207	241	103	117	—	—	8	20	
C97400	S	M01	30	38	16	17	—	—	8	20	—
			207	262	110	117	—	—	8	20	—
C97600	S	M01	40	45	17	24	—	—	10	20	—
			276	310	117	165	—	—	10	20	
C97800	S	M01	50	55	22	30	—	—	10	15	—
			345	379	152	207	—	—	10	15	
C98200	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C98400	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C98600	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand **C = Continuous** **CL = Centrifugal**
D = Die **I = Investment** **P = Plaster**
PM = Permanent Mold

Brinell Hardness 10-mm Ball Indicator		Shear Strength	Compressive Strength			Impact Strength at 68 F (20C)			Fatigue Strength	UNS Number
500 kg	3,000 kg		0.1% Set	1.0% Set	10.0% Set	Izod	Charpy V-Notch	Charpy Unnotched		
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
—	230HB	70	—	—	150	15		—	38	C95500
		483	—	—	1,034	20		—	262	
—	—	—	—	—	—	—	—	—	—	C95510
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C95520
		—	—	—	—	—	—	—	—	
—	140HB	—	—	—	—	—	—	—	—	C95600
		—	—	—	—	—	—	—	—	
—	180HB	—	—	—	150	20	30	—	33	C95700
		—	—	—	1,034	27	41	—	228	
—	—	—	—	—	—	—	—	—	—	C95710
		—	—	—	—	—	—	—	—	
—	159HB	58	—	—	100	20	16	10(6)	31	C95800
		400	—	—	690	27	22	14(6)	214	
—	—	—	—	—	—	—	—	—	—	C95800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C95810
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C95900
		—	—	—	—	—	—	—	—	
—	—	—	—	—	37	—	100	—	13	C96200
		—	—	—	255	—	136	—	90	
150HB	—	—	—	—	—	—	—	—	—	C96300
		—	—	—	—	—	—	—	—	
140HB	—	—	—	—	—	—	78	—	18	C96400
		—	—	—	—	—	106	—	124	
—	—	—	—	—	—	—	—	—	—	C96600
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C96600
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C96700
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C96800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C96900
		—	—	—	—	—	—	—	—	
55HB	—	—	—	—	—	—	—	—	—	C97300
		—	—	—	—	—	—	—	—	
70HB	—	—	—	—	—	—	—	—	—	C97400
		—	—	—	—	—	—	—	—	
80HB	—	—	—	30	57	—	11	—	16	C97600
		—	—	207	393	—	15	—	110	
—	130HB	—	—	—		—	—	—	—	C97800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C98200
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C98400
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C98600
		—	—	—	—	—	—	—	—	

TABLE 3. Typical Mechanical Properties of Copper Casting Alloys \continued

UNS Number	Casting Process	Temper, (SAE Suffix)[1]	Tensile Strength Minimum	Tensile Strength Typical	Yield Strength 0.5% Extension Minimum	Yield Strength 0.5% Extension Typical	Yield Strength 0.2% Offset Minimum	Yield Strength 0.2% Offset Typical	% Elongation Minimum	% Elongation Typical	Rockwell Hardness
			ksi MPa	ksi MPa	ksi MPa	ksi MPa	ksi MPa	ksi MPa	in 2 inches in 51 mm	in 2 inches in 51 mm	
C98800	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—		
C98820	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—		
C98840	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C99300	S	M01	—	95	—	55	—	—	—	2	—
			—	655	—	379	—	—	—	2	
C99350	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—		
C99400	S	M01	60	66	30	34	—	—	20	25	—
			414	455	207	234	—	—	20	25	
C99400	S	TF00	—	79	—	54	—	—	—	—	—
			—	545	—	372	—	—	—	—	
C99500	S	M01	70	—	40	—	—	—	12	—	—
			483	—	276	—	—	—	12	—	
C99500	S	TF00	—	86	—	62	—	—	—	8	—
			—	593	—	427	—	—	—	8	
C99600	—	—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	
C99700	S	M01	—	55	—	25	—	—	—	25	—
			—	379	—	172	—	—	—	25	
C99700	D	M04	—	65	—	27	—	—	—	15	—
				448	—	186	—	—	—	15	
C99750	S	M01	—	65	—	32	—	—	—	30	HR77B
			—	448	—	221	—	—	—	30	
C99750	S	TQ50	—	75	—	40	—	—	—	20	HR82B
			—	517	—	276	—	—	—	20	

Footnotes

[1] SAE Suffix

For alloys listed under SAE J462, suffix symbols may be specified to distinguish between two or more sets of mechanical properties, heat treatment, conditions, etc., as applicable.

Most commonly used method of casting is shown for each alloy. However, unless the purchaser specifies the method of casting or the mechanical properties by supplement to the UNS Number, the supplier may use any method which will develop the properties indicated. These suffixes are shown in the shaded areas below the temper designations.

See Society of Automotive Engineers Inc., *SAE Handbook, Vol. 1, Materials,* Warrendale, PA, 1989.

[2] Minimum value

[3] As cast and spinodal hardened

[4] Charpy Keyhole

[5] As cast and annealed

[6] Charpy Keyhole, properties as cast and annealed

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand
D = Die
C = Continuous
I = Investment
CL = Centrifugal
P = Plaster
PM = Permanent Mold

Brinell Hardness 10-mm Ball Indicator 500 kg	Brinell Hardness 10-mm Ball Indicator 3,000 kg	Shear Strength	Compressive Strength 0.1% Set	Compressive Strength 1.0% Set	Compressive Strength 10.0% Set	Impact Strength at 68 F (20C) Izod	Impact Strength at 68 F (20C) Charpy V-Notch	Impact Strength at 68 F (20C) Charpy Unnotched	Fatigue Strength	UNS Number
		ksi	ksi	ksi	ksi	ft-lb	ft-lb	ft-lb	ksi	
		MPa	MPa	MPa	MPa	J	J	J	MPa	
—	—	—	—	—	—	—	—	—	—	C98800
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C98820
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C98840
		—	—	—	—	—	—	—	—	
—	200HB	—	—	—	—	—	4	—	—	C99300
		—	—	—	—	—	5	—	—	
—	—	—	—	—	—	—	—	—	—	C99350
		—	—	—	—	—	—	—	—	
—	125HB	48	—	—	—	—	—	—	—	C99400
		331	—	—	—	—	—	—	—	
—	170HB	—	—	—	—	—	—	—	—	C99400
		—	—	—	—	—	—	—	—	
145HB	50HB	—	—	—	—	—	—	—	—	C99500
		—	—	—	—	—	—	—	—	
—	196HB	—	—	—	—	—	—	—	—	C99500
		—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	C99600
		—	—	—	—	—	—	—	—	
—	110HB	—	—	—	—	—	—	—	—	C99700
		—	—	—	—	—	—	—	—	
—	125HB	—	—	—	—	—	—	—	—	C99700
		—	—	—	—	—	—	—	—	
110HB	—	—	28	38	72	—	75	—	19	C99750
		—	193	262	496	—	102	—	131	
119HB	—	—	—	—	—	—	—	—	—	C99750
		—	—	—	—	—	—	—	—	

TABLE 4. Physical Properties of Copper Casting Alloys

UNS Number	Melting Point Solidus	Melting Point Liquidus	Density	Coefficient of Thermal Expansion			Specific Heat	Thermal Conductivity	Electrical Conductivity	Electrical Resistivity	Elastic Modulus
	° F	° F	lb/in³ at 68 F	68–212 F, 10⁻⁶ per °F	68–392 F, 10⁻⁶ per °F	68–572 F, 10⁻⁶ per °F	Btu/lb/° F at 68 F	Btu/ft²/ft/h/° F at 68 F	% IACS at 68 F	ohms-cmil/ft at 68 F	ksi
	° C	° C	g/cm³ at 20 C	20–100 C, 10⁻⁶ per °C	20–200 C, 10⁻⁶ per °C	20–300 C, 10⁻⁶ per °C	J/kg • °K at 293 K	W/m • °K at 293 K	Megmho/cm at 20 C	nΩ • m at 20 C	MPa
C80100	1,981	1,948	0.323	—	—	9.4	0.092	226	100	10.4	17,000
	1,083	1,064	8.94	—	—	16.9	385	391	0.580	17.2	117,000
C81100	1,981	1,948	0.323	—	—	9.4	0.090	200	92	11.3	17,000
	1,083	1,064	8.94	—	—	16.9	377	346	0.534	18.7	117,000
C81200	—	—	0.323	—	—	9.4	—	—	—	—	—
	—	—	8.94	—	—	16.9	—	—	—	—	—
C81400	2,000	1,950	0.318	—	—	10.0	0.093	150	60	17.3	16,000
	1,093	1,066	8.80	—	—	18.0	389	259	0.348	28.7	110,000
C81500	1,985	1,967	0.319	—	—	9.5	0.09	182	82	12.6	16,500
	1,085	1,075	8.82	—	—	17.1	377	315	0.476	21.0	114,000
C81540	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C82000	1,990	1,780	0.311	—	—	9.9	0.10	150	45	23.1	17,000
	1,088	971	8.62	—	—	17.8	419	259	0.260	38.5	117,000
C82200	2,040	1,900	0.316	—	9.0	—	0.10	106	45	23.0	16,500
	1,116	1,038	8.75	—	16.2	—	419	183	0.261	38.3	114,000
C82400	1,825	1,650	0.304	—	9.4	—	0.10	76.9	25	41.8	18,500
	996	899	8.41	—	16.9	—	419	133	0.144	69.4	128,000
C82500	1,800	1,575	0.302	—	9.4	—	0.10	74.9	20	51.6	18,500
	982	857	8.35	—	16.9	—	419	130	0.116	86.2	128,000
C82510	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C82600	1,750	1,575	0.302	—	9.4	—	0.10	73.0	19	54.7	19,000
	954	857	8.35	—	16.9	—	419	126	0.110	90.9	131,000
C82700	1,750	1,575	0.292	—	9.4	—	0.10	74.9	20	52.3	19,100
	954	857	8.09	—	16.9	—	419	130	0.115	87.0	132,000
C82800	1,710	1,625	0.294	—	9.4	—	0.10	70.8	18	57.8	19,300
	932	885	8.14	—	16.9	—	419	123	0.104	96.2	133,000
C83300	1,940	1,886	0.318	—	—	—	0.09	—	32	32.3	15,000
	1,060	1,030	8.80	—	—	—	377	—	0.186	53.8	103,000
C83400	1,910	1,870	0.318	—	—	10.0	0.09	109	44	23.5	15,000
	1,043	1,021	8.80	—	—	18.0	377	188	0.256	39.1	103,000
C83450	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C83500	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C83600	1,850	1,570	0.318	—	10.0	—	0.09	41.6	15	69.1	13,500
	1,010	854	8.83	—	18.0	—	377	72.0	0.087	114.9	93,100
C83800	1,840	1,550	0.312	—	10.0	—	0.09	41.8	15	69.1	13,300
	1,004	843	8.64	—	18.0	—	377	72.4	0.087	114.9	91,700
C83810	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C84200	1,820	1,540	0.311	—	10.0	—	0.09	41.8	16	63.3	14,000
	993	838	8.61	—	18.0	—	377	72.4	0.095	105.3	96,500
C84400	1,840	1,549	0.314	—	—	10.0	0.09	41.8	16	63.3	13,000
	1,004	843	8.69	—	—	18.0	377	72.4	0.095	105.3	89,600
C84410	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C84500	1,790	1,540	0.312	—	—	10.0	0.09	41.6	16	62.7	14,000
	977	838	8.64	—	—	18.0	377	72.0	0.096	104.2	96,500
C84800	1,750	1,530	0.310	—	10.0	—	0.09	41.6	16	63.3	15,000
	954	832	8.58	—	18.0	—	377	72.0	0.095	105.3	103,000
C85200	1,725	1,700	0.307	11.5	—	—	0.09	48.5	18	57.8	11,000
	941	927	8.50	20.8	—	—	377	83.9	0.104	96.2	75,800

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 4. Physical Properties of Copper Casting Alloys \continued

UNS Number	Melting Point Solidus	Melting Point Liquidus	Density	Coefficient of Thermal Expansion			Specific Heat	Thermal Conductivity	Electrical Conductivity	Electrical Resistivity	Elastic Modulus
	° F	° F	lb/in^3 at 68 F	68–212 F, 10^{-6} per °F	68–392 F, 10^{-6} per °F	68–572 F, 10^{-6} per °F	Btu/lb/° F at 68 F	Btu/ft^2/ft/h/° F at 68 F	% IACS at 68 F	ohms-cmil/ft at 68 F	ksi
	° C	° C	g/cm^3 at 20 C	20–100 C, 10^{-6} per °C	20–200 C, 10^{-6} per °C	20–300 C, 10^{-6} per °C	J/kg • °K at 293 K	W/m • °K at 293 K	Megmho/cm at 20 C	nΩ • m at 20 C	MPa
C85400	1,725	1,700	0.305	11.1	—	—	0.09	50.8	20	53.2	12,000
	941	927	8.44	20.0	—	—	377	87.9	0.113	88.5	82,700
C85500	1,652	1,634	0.304	11.8	—	—	0.09	67.0	26	39.8	15,000
	900	890	8.41	21.3	—	—	377	116	0.151	66.2	103,000
C85700	1,725	1,675	0.304	—	—	12.0	0.09	48.5	22	47.0	14,000
	941	913	8.41	—	—	21.6	377	83.9	0.128	78.1	96,500
C85800	1,650	1,600	0.305	—	—	—	0.09	48.5	20	51.9	15,000
	899	871	8.44	—	—	—	377	83.9	0.116	86.2	103,000
C86100	1,725	1,650	0.288	—	—	12.0	0.09	20.5	8	136.7	15,000
	941	899	7.97	—	—	21.6	377	35.5	0.044	227.3	103,000
C86200	1,725	1,650	0.288	—	—	12.0	0.09	20.5	8	136.7	15,000
	941	899	7.97	—	—	21.6	377	35.5	0.044	227.3	103,000
C86300	1,693	1,625	0.283	—	—	12.0	0.09	20.5	8	130.8	14,200
	923	885	7.83	—	—	21.6	377	35.5	0.046	217.4	97,900
C86400	1,616	1,583	0.301	—	11.0	—	0.09	51.0	19	54.2	14,000
	880	862	8.33	—	19.8	—	377	88.3	0.111	90.1	96,500
C86500	1,616	1,583	0.301	11.3	—	—	0.09	49.6	22	47.0	15,000
	880	862	8.33	20.4	—	—	377	85.8	0.128	78.1	103,000
C86700	1,616	1,583	0.301	—	11.0	—	0.09	—	17	62.0	15,000
	880	862	8.33	—	19.8	—	377	—	0.097	103.1	103,000
C86800	1,652	1,616	0.290	—	—	—	0.09	—	9	115.7	15,000
	900	880	8.03	—	—	—	377	—	0.052	192.3	103,000
C87300	1,780	1,580	0.302	—	—	10.9	0.09	16.4	6	171.9	15,000
	971	860	8.36	—	—	19.6	377	28.4	0.035	285.7	103,000
C87400	1,680	1,510	0.300	—	—	10.9	0.09	16.0	7	154.2	15,400
	916	821	8.30	—	—	19.6	377	27.7	0.039	256.4	106,000
C87500	1,680	1,510	0.299	—	—	10.9	0.09	16.0	7	154.2	15,400
	916	821	8.28	—	—	19.6	377	27.7	0.039	256.4	106,000
C87600	1,780	1,580	0.300	—	—	—	0.09	16.4	6	132.2	17,000
	971	860	8.30	—	—	—	377	28.4	0.035	230.1	117,000
C87610	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C87800	1,680	1,510	0.300	—	—	10.9	0.09	16.0	7	154.2	20,000
	916	821	8.30	—	—	19.6	377	27.7	0.039	256.4	138,000
C90200	1,915	1,608	0.318	—	—	10.1	0.09	36.0	13	80.2	16,000
	1,046	876	8.80	—	—	18.2	377	62.3	0.075	133.3	110,000
C90300	1,832	1,570	0.318	—	10.0	—	0.09	43.2	12	87.2	14,000
	1,000	854	8.80	—	18.0	—	377	74.8	0.069	144.9	96,500
C90500	1,830	1,570	0.315	—	—	11.0	0.09	43.2	11	94.0	15,000
	999	854	8.72	—	—	19.8	377	74.8	0.064	156.3	103,000
C90700	1,830	1,528	0.317	—	10.2	—	0.09	40.8	10	107.4	15,000
	999	831	8.77	—	18.4	—	377	70.6	0.056	178.6	103,000
C90710	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C90800	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C90810	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C90900	1,792	1,505	—	—	—	—	0.09	—	—	—	16,000
	978	818	—	—	—	—	377	—	—	—	110,000
C91000	1,760	1,505	—	—	—	—	0.09	—	9	111.4	16,000
	960	818	—	—	—	—	377	—	0.054	185.2	110,000
C91100	1,742	1,505	—	—	—	—	0.09	—	8	122.8	15,000
	950	818	—	—	—	—	377	—	0.049	204.1	103,000

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 4. Physical Properties of Copper Casting Alloys \continued

UNS Number	Melting Point Solidus	Melting Point Liquidus	Density	Coefficient of Thermal Expansion			Specific Heat	Thermal Conductivity	Electrical Conductivity	Electrical Resistivity	Elastic Modulus
	° F	° F	lb/in^3 at 68 F	68–212 F, 10^{-6} per °F	68–392 F, 10^{-6} per °F	68–572 F, 10^{-6} per °F	Btu/lb/° F at 68 F	Btu/ft^2/ft/h/° F at 68 F	% IACS at 68 F	ohms-cmil/ft at 68 F	ksi
	° C	° C	g/cm^3 at 20 C	20–100 C, 10^{-6} per °C	20–200 C, 10^{-6} per °C	20–300 C, 10^{-6} per °C	J/kg • °K at 293 K	W/m • °K at 293 K	Megmho/cm at 20 C	nΩ • m at 20 C	MPa
C91300	1,632	1,505	—	—	—	—	0.09	—	7	150.4	16,000
	889	818	—	—	—	—	377	—	0.040	250.0	110,000
C91600	1,887	1,575	0.320	—	9.0	—	0.09	40.8	10	103.7	16,000
	1,031	857	8.87	—	16.2	—	377	70.6	0.058	172.4	110,000
C91700	1,859	1,563	0.316	—	9.0	—	0.09	40.8	10	103.7	15,000
	1,015	851	8.75	—	16.2	—	377	70.6	0.058	172.4	103,000
C92200	1,810	1,518	0.312	—	—	10.0	0.09	40.2	14	72.5	14,000
	988	826	8.64	—	—	18.0	377	69.6	0.083	120.5	96,500
C92300	1,830	1,570	0.317	—	10.0	—	0.09	43.2	12	85.9	14,000
	999	854	8.77	—	18.0	—	377	74.8	0.070	142.9	96,500
C92310	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C92400	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C92410	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C92500	—	—	0.317	—	—	—	0.09	—	—	—	16,000
	—	—	8.77	—	—	—	377	—	—	—	110,000
C92600	1,800	1,550	0.315	—	10.0	—	0.09	—	9	115.7	15,000
	982	843	8.73	—	18.0	—	377	—	0.052	192.3	103,000
C92610	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C92700	1,800	1,550	0.317	—	10.0	—	0.09	27.2	11	94.0	16,000
	982	843	8.78	—	18.0	—	377	47.0	0.064	156.3	110,000
C92710	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C92800	1,751	1,505	—	—	—	—	0.09	—	—	—	16,000
	955	818	—	—	—	—	377	—	—	—	110,000
C92810	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C92900	1,887	1,575	0.320	—	9.5	—	0.09	33.6	9	113.5	14,000
	1,031	857	8.87	—	17.1	—	377	58.2	0.053	188.7	96,500
C93100	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C93200	1,790	1,570	0.322	10.0	—	—	0.09	33.6	12	85.9	14,500
	977	854	8.91	18.0	—	—	377	58.2	0.070	142.9	100,000
C93400	—	—	0.320	—	10.0	—	0.09	33.6	12	85.9	11,000
	—	—	8.87	—	18.0	—	377	58.2	0.070	142.9	75,800
C93500	1,830	1,570	0.320	—	9.9	—	0.09	40.7	15	68.4	14,500
	999	854	8.87	—	17.8	—	377	70.4	0.088	113.6	100,000
C93600	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C93700	1,705	1,403	0.320	—	10.3	—	0.09	27.1	10	102.0	11,000
	929	762	8.87	—	18.5	—	377	46.9	0.059	169.5	75,800
C93720	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C93800	1,730	1,570	0.334	—	10.3	—	0.09	30.2	11	91.1	10,500
	943	854	9.25	—	18.5	—	377	52.3	0.066	151.5	72,400
C93900	1,730	1,570	0.334	—	10.3	—	0.09	30.2	11	91.1	11,000
	943	854	9.25	—	18.5	—	377	52.3	0.066	151.5	75,800
C94000	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C94100	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 4. Physical Properties of Copper Casting Alloys \continued

UNS Number	Melting Point Solidus	Melting Point Liquidus	Density	Coefficient of Thermal Expansion			Specific Heat	Thermal Conductivity	Electrical Conductivity	Electrical Resistivity	Elastic Modulus
	° F	° F	lb/in³ at 68 F	68–212 F, 10⁻⁶ per °F	68–392 F, 10⁻⁶ per °F	68–572 F, 10⁻⁶ per °F	Btu/lb/° F at 68 F	Btu/ft²/ft/h/° F at 68 F	% IACS at 68 F	ohms-cmil/ft at 68 F	ksi
	° C	° C	g/cm³ at 20 C	20–100 C, 10⁻⁶ per °C	20–200 C, 10⁻⁶ per °C	20–300 C, 10⁻⁶ per °C	J/kg • °K at 293 K	W/m • ° K at 293 K	Megmho/cm at 20 C	nΩ • m at 20 C	MPa
C94300	—	—	0.336	—	—	—	0.09	36.2	9	113.5	10,500
	—	—	9.31	—	—	—	377	62.7	0.053	188.7	72,400
C94310	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C94320	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C94330	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C94400	1,725	1,450	0.320	—	10.3	—	0.09	30.2	10	103.7	11,000
	941	788	8.87	—	18.5	—	377	52.3	0.058	172.4	75,800
C94500	1,475	1,725	0.340	—	10.3	—	0.09	30.2	10	103.7	10,500
	802	941	9.40	—	18.5	—	377	52.3	0.058	172.4	72,400
C94700	1,660	1,880	0.320	—	10.9	—	0.09	31.2	—	—	15,000
	904	1,027	8.87	—	19.6	—	377	54.0	—	—	103,000
C94800	1,660	1,800	0.320	—	—	10.9	0.09	22.3	12	85.9	15,000
	904	1,027	8.87	—	—	19.6	377	38.6	0.070	142.9	103,000
C94900	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95200	1,913	1,907	0.276	—	—	9.0	0.09	29.1	11	94.0	15,000
	1,045	1,042	7.64	—	—	16.2	377	50.4	0.064	156.3	103,000
C95210	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95220	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95300	1,913	1,904	0.272	—	—	9.0	0.09	36.3	13	80.2	16,000
	1,045	1,040	7.53	—	—	16.2	377	62.8	0.075	133.3	110,000
C95400	1,900	1,880	0.269	—	—	9.0	0.10	33.9	13	80.2	15,500
	1,038	1,027	7.45	—	—	16.2	419	58.7	0.075	133.3	107,000
C95410	1,900	1,880	0.269	—	—	9.0	0.10	33.9	13	80.2	15,500
	1,038	1,027	7.45	—	—	16.2	419	58.7	0.075	133.3	107,000
C95420	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95500	1,930	1,900	0.272	—	—	9.0	0.10	24.2	8	122.8	16,000
	1,054	1,038	7.53	—	—	16.2	419	41.9	0.049	204.1	110,000
C95510	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95520	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95600	1,840	1,800	0.278	—	—	9.2	0.10	22.3	8	122.8	15,000
	1,004	982	7.69	—	—	16.6	419	38.6	0.049	204.1	103,000
C95700	1,814	1,742	0.272	—	—	9.8	0.105	7.0	3	334.2	18,000
	990	950	7.53	—	—	17.6	440	12.1	0.018	555.6	124,000
C95710	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95800	1,940	1,910	0.276	—	—	9.0	0.105	20.8	7	146.7	16,500
	1,060	1,043	7.64	—	—	16.2	440	36.0	0.041	243.9	114,000
C95810	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C95900	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C96200	2,100	2,010	0.323	—	—	9.5	0.09	26.1	11	94.0	18,000
	1,149	1,099	8.94	—	—	17.1	377	45.2	0.064	156.3	124,000
C96300	2,190	2,100	0.323	—	—	9.1	0.09	21.3	6	167.1	20,000
	1,199	1,149	8.94	—	—	16.4	377	36.8	0.036	277.8	138,000

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 4. Physical Properties of Copper Casting Alloys \continued

UNS Number	Melting Point Solidus	Melting Point Liquidus	Density	Coefficient of Thermal Expansion			Specific Heat	Thermal Conductivity	Electrical Conductivity	Electrical Resistivity	Elastic Modulus
	°F	°F	lb/in^3 at 68 F	68–212 F, 10^{-6} per °F	68–392 F, 10^{-6} per °F	68–572 F, 10^{-6} per °F	Btu/lb/°F at 68 F	Btu/ft^2/ft/h/°F at 68 F	% IACS at 68 F	ohms-cmil/ft at 68 F	ksi
	°C	°C	g/cm^3 at 20 C	20–100 C, 10^{-6} per °C	20–200 C, 10^{-6} per °C	20–300 C, 10^{-6} per °C	J/kg • °K at 293 K	W/m • °K at 293 K	Megmho/cm at 20 C	nΩ • m at 20 C	MPa
C96400	2,260	2,140	0.323	—	—	9.0	0.09	16.4	5	214.8	21,000
	1,238	1,171	8.94	—	—	16.2	377	28.5	0.028	357.1	145,000
C96600	2,160	2,010	0.318	—	—	9.0	0.09	17.4	4	240.6	22,000
	1,182	1,099	8.80	—	—	16.2	377	30.1	0.025	400.0	152,000
C96700	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C96800	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C96900	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C97300	1,904	1,850	0.321	—	—	9.0	0.09	16.5	6	182.3	16,000
	1,040	1,010	8.89	—	—	16.2	377	28.6	0.033	303.0	110,000
C97400	2,012	1,958	0.320		—	9.2	0.09	15.8	6	188.0	16,000
	1,100	1,070	8.86	—	—	16.6	377	27.3	0.032	312.5	110,000
C97600	2,089	2,027	0.321	—	—	9.3	0.09	13.0	5	207.4	19,000
	1,143	1,108	8.88	—	—	16.7	377	31.4	0.029	344.8	131,000
C97800	2,156	2,084	0.320	—	—	9.7	0.09	14.7	4	231.4	19,000
	1,180	1,140	8.85	—	—	17.5	377	25.4	0.026	384.6	131,000
C98200	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C98400	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C98600	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C98800	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C98820	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C98840	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C99300	1,970	1,955	0.275	—	—	9.2	0.10	25.4	9	115.7	18,000
	1,077	1,068	7.61	—	—	16.6	419	43.9	0.052	192.3	124,000
C99350	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C99400	—	—	0.300	—	—	—	—	—	12	85.9	19,300
	—	—	8.30	—	—	—	—	—	0.070	142.9	133,000
C99500	—	—	0.300	—	—	8.3	—	—	10	71.0	19,000
	—	—	8.30	—	—	14.9	—	—	0.057	116.4	131,000
C99600	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—
C99700	1,655	1,615	0.296	—	—	—	—	—	3	353.8	16,500
	902	879	8.19	—	—	—	—	—	0.017	588.2	114,000
C99750	1,550	1,505	0.290	—	13.5	—	0.09	—	2	501.3	17,000
	843	818	8.03	—	24.3	—	377	—	0.012	838.3	117,000

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 5. Conforming Specifications for Copper Casting Alloys \continued

UNS Number	Type	Conforming Specifications
	Coppers	
C80100	Ingot	Federal QQ-C-521
C81100		
C81200		
	High Copper Alloys	
C81400	Sand	ASTM B 770
C81500		
C81540		
C82000	Sand	ASTM B 770, Federal QQ-C-390
C82200	Sand	ASTM B 770
C82400	Centrifugal	Federal QQ-C-390
	Sand	Federal QQ-C-390; ASTM B 770
	Valves	Federal WW-V-1967
C82500	Centrifugal	Federal QQ-C-390; AMS 4511
	Investment	AMS 4511, 4890; Military MIL-C-22087
	Precision	Military MIL-C-11866
	Sand	Federal QQ-C-390; AMS 4511; ASTM B 770
C82510	Sand	ASTM B 770
C82600	Sand	Federal QQ-C-390; ASTM B 770
	Valves	Federal WW-V-1967
C82700	Sand	Federal QQ-C-390
	Valves	WW-V-1967
C82800	Sand	Federal QQ-C-390; ASTM B 770
	Valves	WW-V-1967
	Copper-Tin-Zinc and Copper-Tin-Zinc-Lead Alloys (Red and Leaded Red Brasses)	
C83300	Ingot	Ingot No. 131
C83400	Rotating Bands	Military MIL-B-46066
C83450	Ingot	ASTM B 30
	Sand	ASTM B 584, B 763
C83500	Ingot	Ingot No. 251
C83600	Centrifugal	AMS 4855; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Fittings	ASME B 16.15, B16.18, B 16.23, B 16.26, B 16.32, SB 62; ASTM B 62; Federal WW-P-460, WW-T-725
	Flanges	ASME B 16.24, SB 62; ASTM B 62
	Ingot	ASTM B 30; Ingot No.115
	Precision	MIL-C-11866
	Sand	AMS 4855; ASME SB 62; ASTM B 62, B 584; Federal QQ-C-390; SAE J461, J462
	Unions	Federal WW-U-516
	Valves	MIL-V-18436
C83800	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Fittings	ASME B 16.15, B 16.18, B 16.23, B 16.32; ASTM B 584
	Ingot	ASTM B 30; Ingot No. 120
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Unions	Federal WW-U-516
	Valves	Federal WW-V-1967
C83810		
	Copper-Tin-Zinc-Lead Alloys (Leaded Semi-Red Brasses)	
C84200	Continuous	ASTM B 505; Federal QQ-C-390
	Fittings	Federal WW-P-460
C84400	Centrifugal	ASTM B 271; Federal QQ-C-390
	Continuous	ASTM B 505; Federal QQ-C-390
	Fittings	ASME B 16.15, B 16.18, B 16.23, B 16.24, B 16.26, B 16.32; ASTM B 584; Federal WW-T-725
	Ingot	ASTM B 30; Ingot No. 123
	Sand	ASTM B 584, B 763; Federal QQ-C-390
	Unions	Federal WW-U-516
C84410		
C84500	Ingot	Ingot No. 125
C84800	Centrifugal	ASTM B 271; Federal QQ-C-390
	Continuous	ASTM B 505, Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No.130
	Sand	ASTM B 584, B 763; Federal QQ-C-390
	Copper-Zinc and Copper-Zinc-Lead Alloys (Yellow and Leaded Yellow Brasses)	
C85200	Centrifugal	ASTM B 271; SAE J461, J462
	Continuous	SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 400
	Sand	ASTM B 584, B 763; Federal QQ-C-390
	Valves	Federal WW-V-1967
C85400	Centrifugal	ASTM B 271; SAE J461, J462
	Continuous	SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 403
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C85500	Centrifugal	Federal QQ-C-390
	Sand	Federal QQ-C-390
	Valves	Federal WW-V-1967
C85700	Centrifugal	ASTM B 271; Federal QQ-C-390
	Die	ASTM B 176
	Ingot	ASTM B 30, Ingot No. 405.2
	Sand	ASTM B 584, B 763; Federal QQ-C-390
C85800	Die	ASTM B 176; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 405.1

TABLE 5. Conforming Specifications for Copper Casting Alloys \continued

Manganese Bronze and Leaded Manganese Bronze Alloys (High Strength and Leaded High Strength Yellow Brasses)

UNS Number	Type	Conforming Specifications
C86100	Centrifugal	Federal QQ-C-390
	Ingot	Ingot No. 423
	Sand	Federal QQ-C-390
	Valves	Federal WW-V-1967
C86200	Centrifugal	AMS 4862; ASTM B 271; Federal QQ-C-390; SAE J461, 462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Federal QQ-C-523; Ingot No. 423
	Precision	Military MIL-C-11866
	Sand	AMS 4862; ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C86300	Centrifugal	AMS 4862; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30; Federal QQ-C-523; Ingot No. 424
	Precision	Military MIL-C-11866,
	Sand	AMS 4862; ASTM B 22, B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C86400	Centrifugal	ASTM B 271
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30; Federal QQ-C-523; Ingot No. 420
	Sand	ASTM B 584, B 763; Federal QQ-C-390
	Valves	Federal WW-V-1967
C86500	Centrifugal	AMS 4860; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505
	Die	ASTM B 176
	Ingot	ASTM B 30; Federal QQ-C-523; Ingot No. 421
	Sand	AMS 4860, ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C86700	Centrifugal	ASTM B 271
	Ingot	ASTM B 30
	Sand	ASTM B 584, B 763
C86800	Sand	Federal QQ-C-390
	Valves	Federal WW-V-1967

Copper-Silicon Alloys (Silicon Bronzes and Silicon Brasses)

UNS Number	Type	Conforming Specifications
C87300	Centrifugal	ASTM B 271; SAE J461, J462
	Ingot	ASTM B 30, Ingot No. 530A
	Precision	Military MIL-C-11866
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C87400	Centrifugal	ASTM B 271
	Ingot	ASTM B 30; Ingot No. 500B
	Sand	ASTM B 584, B 763; Federal QQ-C-390
	Valves	Federal WW-V-1967
C87500	Centrifugal	ASTM B 271; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 500C
	Permanent	ASTM B 806
	Sand	ASTM B 584, B 763; Federal QQ-C-390
C87600	Ingot	ASTM B 30; Ingot No. 500D
	Sand	ASTM B 584, B 763
C87610	Ingot	Ingot No. 500E
	Sand	ASTM B 584, B 763
C87800	Die	ASTM B 176, SAE J461, J462
	Ingot	ASTM B 30, Ingot No. 500F
	Permanent	ASTM B 806

Copper-Tin Alloys (Tin Bronzes)

UNS Number	Type	Conforming Specifications
C90200	Ingot	Ingot No. 242
C90300	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 225
	Precision	Military MIL-C-11866
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C90500	Centrifugal	AMS 4845; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 210
	Sand	AMS 4845; ASTM B 22, B 584, B 763; Federal QQ-C-390; SAE J461, J462
C90700	Centrifugal	ASTM B 427; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 205
	Sand	ASTM B 427; SAE J461, J462
C90710		
C90800	Centrifugal	ASTM B 427
	Ingot	ASTM B 30
	Sand	ASTM B 427
C90810		
C90900		
C91000	Centrifugal	Federal QQ-C-390
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No. 197
	Sand	Federal QQ-C-390
C91100	Sand	ASTM B 22

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TABLE 5. Conforming Specifications for Copper Casting Alloys \continued

Copper-Tin Alloys \continued (Tin Bronzes)

UNS Number	Type	Conforming Specifications
C91300	Centrifugal	AMS 7322; Federal QQ-C-390
	Continuous	AMS 7322; ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No. 194
	Sand	AMS 7322; ASTM B 22; Federal QQ-C-390
C91600	Centrifugal	ASTM B 427; Federal QQ-C-390
	Continuous	Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No. 205N
	Sand	ASTM B 427
C91700	Centrifugal	ASTM B 427
	Ingot	ASTM B 30
	Sand	ASTM B 427

Copper-Tin-Lead Alloys (Leaded Tin Bronzes)

UNS Number	Type	Conforming Specifications
C92200	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Fittings	ASME B 16.24, SB 61; ASTM B 61; Federal WW-P-460; WW-T-725
	Flanges	ASME SB 61; ASTM B 61; Federal WW-P-460
	Ingot	ASTM B 30; Ingot No. 245
	Sand	ASME SB 584, SB 61; ASTM B 584, B 61; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967; Military Mil-V-17547
C92300	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30, Ingot No. 230
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461
C92310		
C92400	Ingot	Ingot No. 220
C92410		
C92500	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 200N
	Sand	SAE J461, J462
	Valves	Federal WW-V-1967
C92600	Ingot	Ingot No. 215
	Sand	ASTM B 584
C92610		
C92700	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 206
	Sand	SAE J461, J462
C92710		
C92800	Continuous	ASTM B 505
	Ingot	ASTM B 30
C92810		
C92900	Centrifugal	ASTM B 427
	Continuous	ASTM B 505; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 206N
	Sand	ASTM B 427; SAE J461, J462

Copper-Tin-Lead Alloys (High Leaded Tin Bronzes)

UNS Number	Type	Conforming Specifications
C93100		
C93200	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 315
	Permanent Mold	SAE J461, J462
	Sand	ASTM B 585, B 763; Federal QQ-C-390; SAE J461, J462
C93400	Centrifugal	Federal QQ-C-390
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No. 310
	Sand	Federal QQ-C-390;
C93500	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, 462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 326
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
C93600	Sand	Federal QQ-C-390
C93700	Bearings	AMS 4827
	Centrifugal	AMS 4842; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 305
	Sand	AMS 4842; ASME SB 584; ASTM B 22, B 584, B 763; Federal QQ-C-390; SAE J461, J462
C93720		
C93800	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 319
	Permanent Mold	SAE J461, J462
	Sand	ASTM B 584, B 66, B 763; Federal QQ-C-390; SAE J461, J462
C93900	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30
C94000	Centrifugal	Federal QQ-C-390
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30;
	Sand	Federal QQ-C-390
C94100	Centrifugal	Federal QQ-C-390
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No. 325
	Sand	ASTM B 67; Federal QQ-C-390
C94300	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 322
	Sand	ASTM B 584, B 66, B 763; Federal QQ-C-390; SAE J461, J462

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TABLE 5. Conforming Specifications for Copper Casting Alloys \continued

Copper-Tin-Lead Alloys \continued (High Leaded Tin Bronzes)

UNS Number	Type	Conforming Specifications
C94310		
C94320		
C94330		
C94400	Ingot	ASTM B 30
	Sand	ASTM B 66
C94500	Ingot	ASTM B 30; Ingot No. 321
	Sand	ASTM B 66

Copper-Tin-Nickel Alloys (Nickel-Tin Bronzes)

UNS Number	Type	Conforming Specifications
C94700	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C94800	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30
	Sand	ASTM B 584, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C94900	Ingot	ASTM B 30
	Sand	ASTM B 584, B 763

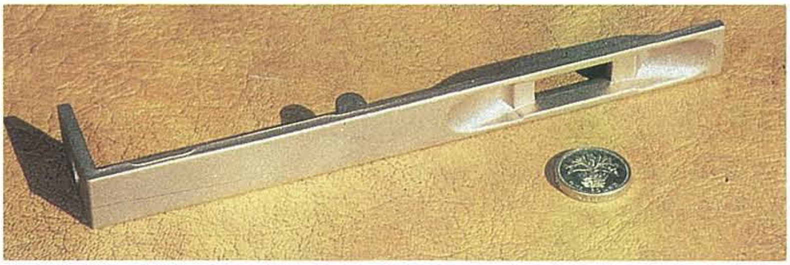
Copper-Aluminum-Iron and Copper-Aluminum-Iron-Nickel Alloys (Aluminum Bronzes)

UNS Number	Type	Conforming Specifications
C95200	Centrifugal	ASME SB 271; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASME SB 505; ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Flanges	ASME B 16.24, SB 148; ASTM B 148
	Ingot	ASTM B 30; Ingot No. 415A
	Sand	ASME SB 148; ASTM B 148, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C95210		
C95220		
C95300	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 415B
	Permanent	ASTM B 806
	Precision	Military MIL-C-11866
	Sand	ASTM B 148, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	WW-V-1967
C95400	Centrifugal	ASME SB 271; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 415C
	Permanent	ASTM B 806
	Precision	Military MIL-C-11866
	Sand	ASME SB 48; ASTM B 148, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C95410	Ingot	Ingot 415 C + Ni
	Precision	ASTM B 806
	Sand	ASTM B 148, B 763
C95420	Centrifugal	AMS 4870, 4871, 4873; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Sand	AMS 4870, 4871, 4873; Federal QQ-C-390; SAE J461, J462
C95500	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 415D
	Precision	ASTM B 806
	Sand	ASTM B 148, B 763; Federal QQ-C-390; SAE J461, J462
	Valves	Federal WW-V-1967
C95510	Centrifugal	AMS 4880; ASTM B 271; Federal QQ-C-390; SAE J461, J462
C95520	Centrifugal	AMS 4881; ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505
	Sand	AMS 4881; Federal QQ-C-390; SAE J461, J462
C95600	Ingot	ASTM B 30; Ingot No. 415E
	Sand	ASTM B 148, B 763
C95700	Centrifugal	Federal QQ-C-390
	Ingot	ASTM B 30; Ingot No. 415F
	Sand	ASTM B 148; Federal QQ-C-390
C95710		
C95800	Centrifugal	ASTM B 271; Federal QQ-C-390; SAE J461, J462
	Continuous	ASTM B 505; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 415G
	Precision	ASTM B 806
	Sand	ASTM B 148, B 763; Federal QQ-C-390; Military MIL-B-24480, SAE J461, J462
	Valves	Federal WW-V-1967
C95810		
C95900	Sand	ASTM B 148

TABLE 5. Conforming Specifications for Copper Casting Alloys \continued

UNS Number	Type	Conforming Specifications
	Copper-Nickel-Iron Alloys (Copper-Nickels)	
C96200	Centrifugal	ASTM B 369; Federal QQ-C-390; SAE J461, J462
	Ingot	ASTM B 30
	Sand	ASTM B 369; Federal QQ-C-390; SAE J461, 462
	Valves	Military MIL-V-18436
C96300		
C96400	Centrifugal	ASTM B 369; Federal QQ-C-390
	Continuous	ASTM B 505; Federal QQ-C-390
	Ingot	ASTM B 30
	Sand	ASTM B 369; Federal QQ-C-390
	Valves	Federal WW-V-1967
C96600		
C96700	Sand	ASTM B 770
C96800	Ingot	ASTM B 30
C96900		
	Copper-Nickel-Zinc Alloys (Nickel Silvers)	
C97300	Centrifugal	ASTM B 271
	Continuous	ASTM B 505; SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 410
	Sand	ASTM B 584, B 763
C97400	Ingot	Ingot No. 411
C97600	Centrifugal	ASTM B 271
	Continuous	ASTM B 505, SAE J461, J462
	Ingot	ASTM B 30; Ingot No. 412
	Sand	ASME SB 584; ASTM B 584, B 763; Military MIL-C-17112
	Valves	Military MIL-V-18436
C97800	Centrifugal	ASTM B 271
	Continuous	ASTM B 505
	Ingot	ASTM B 30; Ingot No. 413B
	Sand	ASTM B 584, B 763
	Valves	Military MIL-V-18436
	Copper-Lead Alloys (Leaded Coppers)	
C98200	Bearings	AMS 4824
C98400	Bearings	AMS 4820
C98600		
C98800		
C98820		
C98840		
	Special Alloys	
C99300		
C99350		
C99400	Sand	ASTM B 763
C99500	Sand	ASTM B 763
C99600		
C99700	Die	ASTM B 176
C99750	Die	ASTM B 176

FIGURE I-4
By pressure die casting this door bolt in a yellow brass, the manufacturer eliminated several expensive machine and finishing operations.



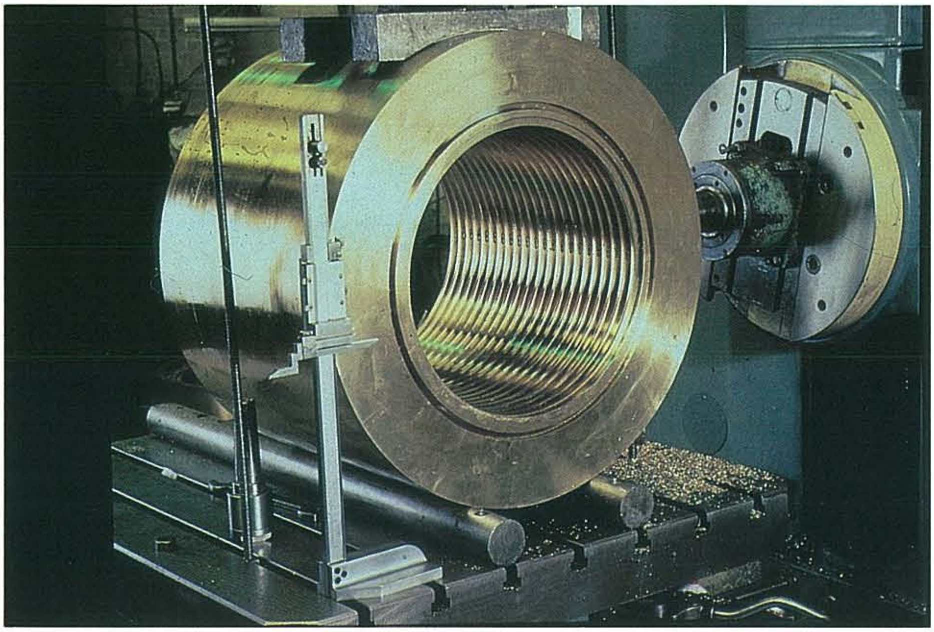


FIGURE I-5
High strength yellow brass was selected for this rolling mill adjusting nut. Also known as manganese bronzes and high-tensile brasses, these alloys are the strongest, as cast of the copper-base materials.

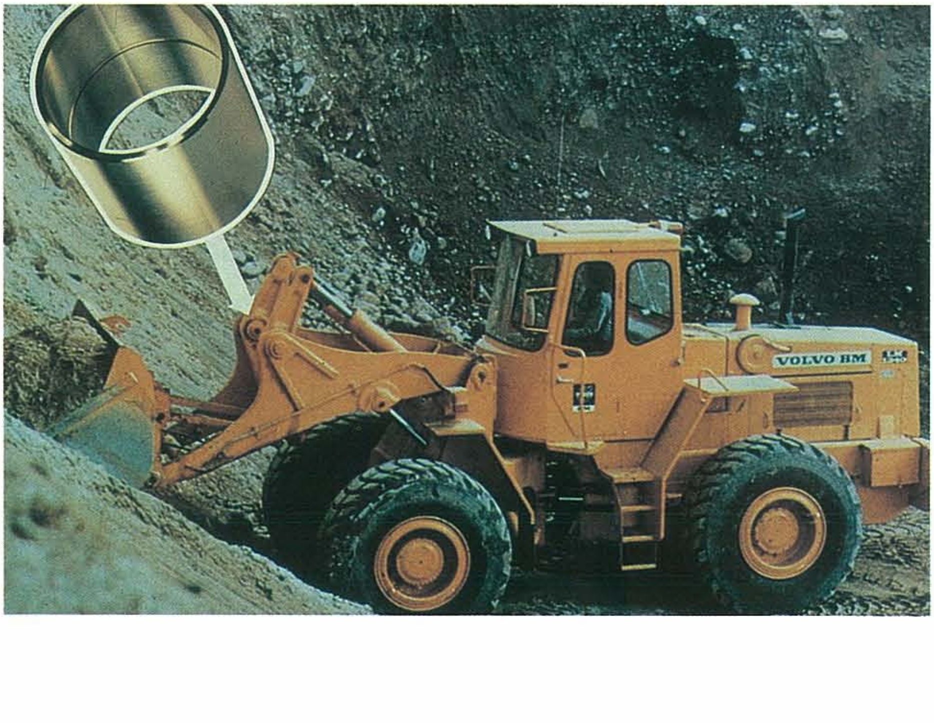


FIGURE I-6
The leaded bronze sleeve bearings used in this shovel loader (inset) can accommodate dirty or contaminated lubricants. It also continues to function if lubrication is temporarily interrupted.

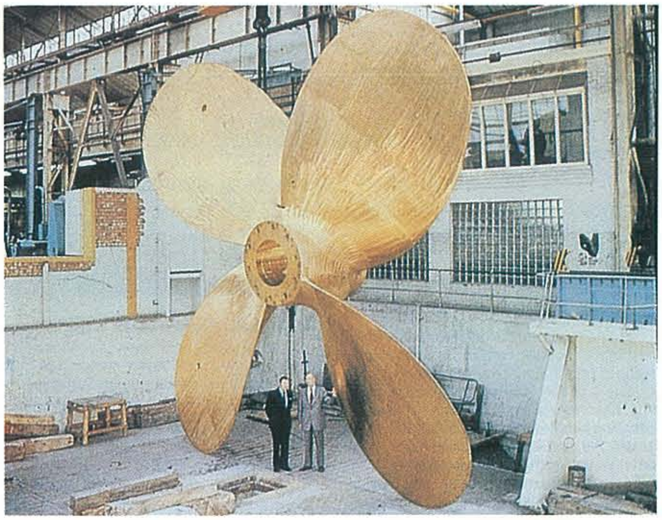


FIGURE I-7
Because of its excellent resistance to erosion-corrosion and cavitation attack, nickel-aluminum bronze has become the standard propeller alloy.

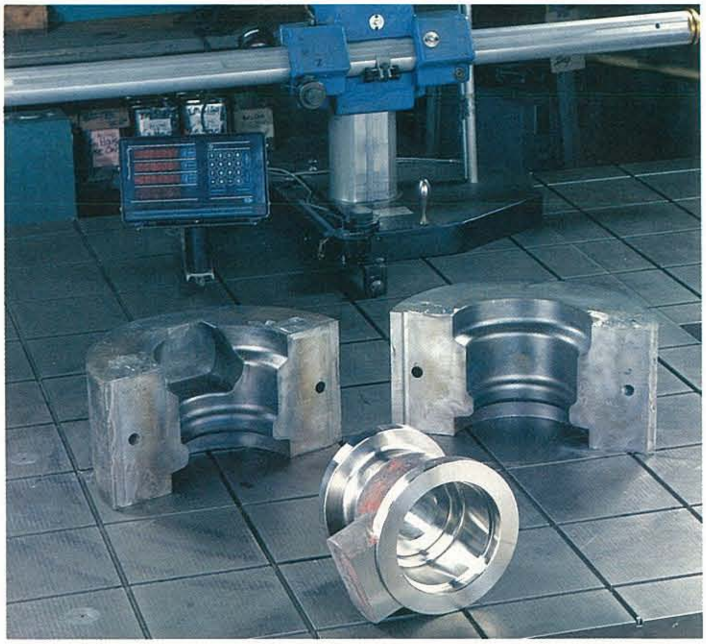


FIGURE I-8
Centrifugally cast copper-nickel valve, with split casting dies. Copper-nickel alloys have exceptional resistance to corrosion in seawater.

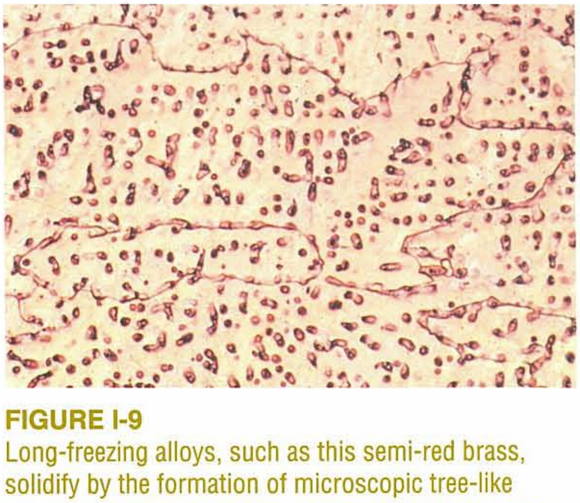


FIGURE I-9
Long-freezing alloys, such as this semi-red brass, solidify by the formation of microscopic tree-like structures called dendrites, traces of which are seen here. Residual microporosity is minimized by mold design, although some porosity is often tolerable.

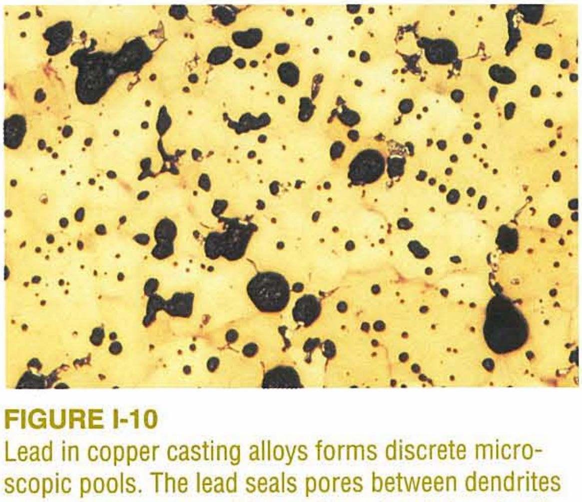
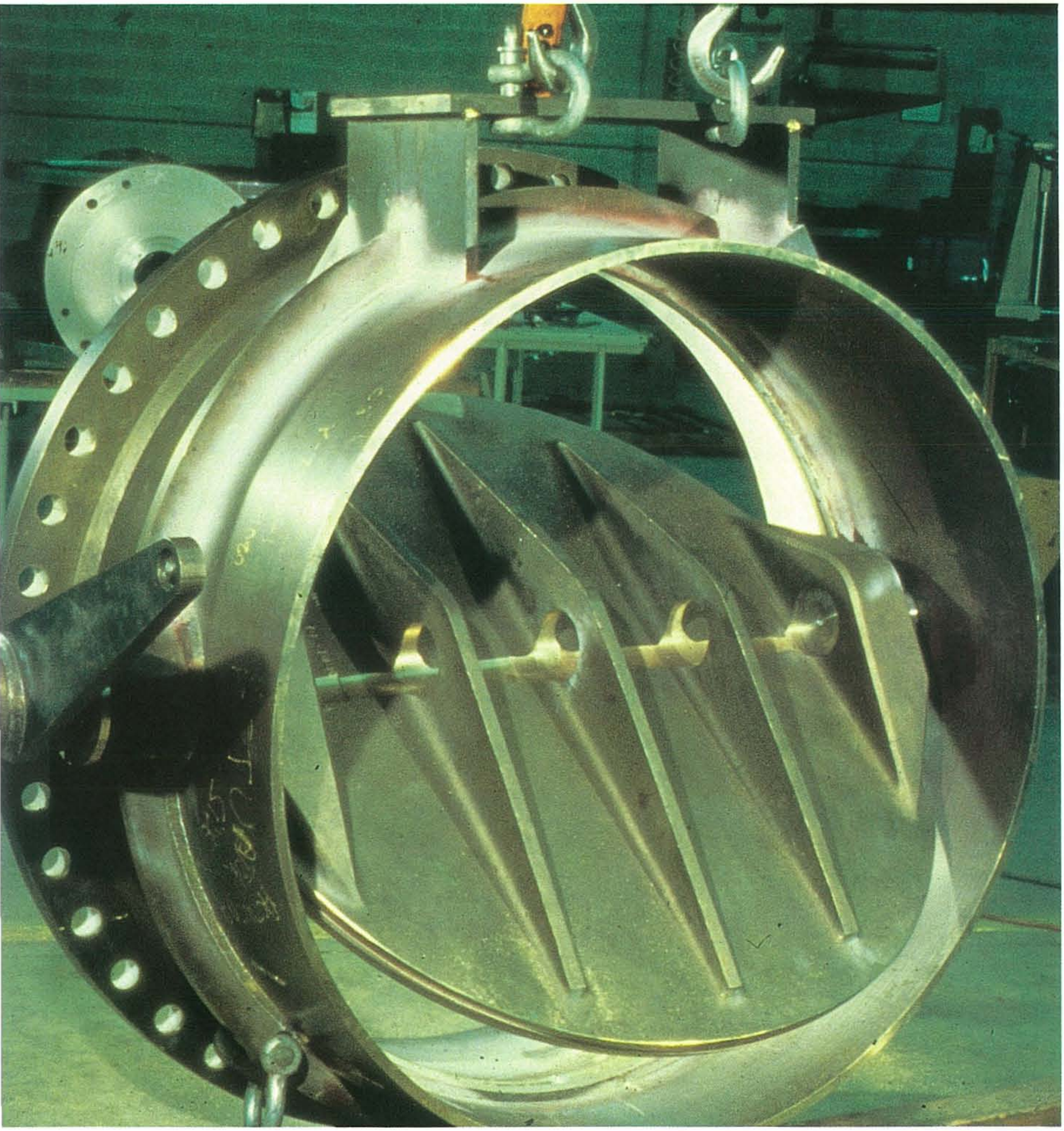


FIGURE I-10
Lead in copper casting alloys forms discrete microscopic pools. The lead seals pores between dendrites to produce pressure-tight castings. Lead also significantly improves machinability.

Selecting Copper Casting Alloys



II. SELECTING COPPER ALLOYS FOR CORROSION RESISTANCE

Forms of Corrosion in Copper Alloys

Copper is classified as one of the noble metals, along with silver, gold and platinum. While not as chemically inert as the other noble metals, copper is well known for its ability to shield itself from corrosion by forming protective, tightly adhering corrosion product films. The films are usually made up of oxides or hydroxides unless strong anions are present in the environment, in which case the films' structures become more complex. The attractive green patina found on bronze statuary and old copper roofing is a familiar example of this self-protecting behavior.

Alloying can increase copper's corrosion resistance significantly, although effects vary with individual elements and particular environments. The very existence of copper alloys cast at least as early as 5,000 B.C. and of bronzes salvaged from ships that sank more than 1,500 years ago is strong evidence for the copper alloys' inherent corrosion resistance. Despite its nobility, however, copper can be susceptible to several types of corrosion, and before discussing the selection of copper alloys for various environments, it may be helpful to review the more common of these forms of attack.

General Corrosion. As its name implies, general corrosion involves a more or less uniform wasting away of metal surfaces. Attack converts the metal to a corrosion product which may or may not adhere to the surface. Dense, adherent corrosion products such as the minerals in patina block or retard the access of corrodant, usually oxygen, to the metal's surface. Once a protective corrosion product forms, the rate of corrosion quickly diminishes to a value governed by the transport of ionic species through the film. At some point, corrosion may effectively cease altogether.

If the corrosion product swells and spalls away from the corroding surface, fresh metal will be continuously exposed and corrosion will proceed at a rapid rate. The rusting of steel and the exfoliation of heat treated aluminum alloys are familiar examples of this phenomenon. Copper alloys do not normally generate exfoliative corrosion products, although there are some exceptions.

The copper alloys' behavior in marine environments also depends on the tendency for copper to form a tightly adhering, protective corrosion product film. Although some corrosion does occur in seawater, the rate at which it proceeds is quickly and significantly reduced as the protective film forms. The composition and properties of the film depend on the metal composition and on the nature of the environment as the film forms. The film thickness has been found to range between 2,800 Å and 4,400 Å in a 90-10 copper-nickel.

Films consist mainly of cuprous oxide, Cu_2O, but may also contain cuprous hydroxychloride, $Cu_2(OH)_3Cl$ and cupric oxide, CuO, plus oxides and hydroxychlorides of the particular alloy's constituents. The corrosion product film begins to form immediately upon immersion; the rate of film formation, i.e., the corrosion rate, will already decrease to one-tenth of its original rate 10 minutes later, see **Figure II-1**, page 61. The protective film continues to thicken at a decreasing rate until steady state is approached, normally several months to years after immersion.

The benign aspect of general corrosion is that it proceeds at a constant rate so long as the environment doesn't change. If a stable environment can be assured, the life of the product can be calculated. This has led to the common practice of incorporating "corrosion allowances"—extra metal beyond that needed for strength—in corrosion-sensitive products such as cast pipe and fittings.

Pitting Corrosion. In this case, the corrosion process is concentrated in very small areas, leaving the remainder of the exposed surface virtually corrosion-free. Pitting begins with the breakdown of the protective, or passive, surface film through the action of chlorides or other highly oxidizing species in the environment. Penetration rates in the pits themselves can exceed the rate of general corrosion by several orders of magnitude.

Copper alloys are not very susceptible to pitting corrosion, although attack can occur in some fresh and marine waters in coppers, red brasses, and tin, silicon and aluminum bronzes.[3] Evidence suggests that pits in copper alloys begin to broaden after reaching a certain depth, leaving a roughened but otherwise intact surface. That is, pits in copper alloys do not "drill" into the surface as they characteristically do in stainless steels and aluminum alloys.

Crevice Corrosion. As its name implies, crevice corrosion occurs in regions that are not fully exposed to the corroding environment. Typical examples include metal-to-gasket interfaces, crevices under fastener heads and areas underlying debris deposits. Crevice corrosion is usually not observable until considerable damage has occurred.

Attack begins because the exposed surface, away from the crevice, sees higher oxygen concentrations than the surfaces within the crevice. The exposed surface therefore becomes cathodically polarized to the crevice, which becomes the anode. The small anode/large cathode area ratio that generally results leads to rapid attack in the hidden areas. As with pitting, chlorides accelerate the rate of attack.

Crevice corrosion is not a serious problem among the copper alloys, although yellow brasses and manganese bronzes can corrode in this fashion. Aluminum bronzes, tin bronzes, red- and semi-red brasses and copper-nickel alloys are less likely to be attacked. In all, copper alloys are notably superior to the stainless steels in their resistance to crevice corrosion.

Dealloying or "Parting" Corrosion. Some copper alloys corrode by the selective removal of one of the alloy's constituents, leaving behind a spongy mass of nearly pure copper. Dealloying occurs in seawater and in stagnant, neutral or slightly acidic fresh waters, often under sediments or biomass deposits. Corrosion apparently proceeds by the dissolution of the entire alloy followed by the cathodic redeposition of the more noble copper. Two forms of attack are known: *plug-type* dealloying occurs in localized areas and proceeds relatively rapidly; *layer-type* dealloying is typically spread over larger areas and is somewhat less aggressive.

All brasses are potentially vulnerable to dezincification. The beta phase found in high zinc brasses is especially susceptible to this form of attack. Dealloying in brasses can be reduced significantly by the addition of phosphorus and/or tin. Arsenic and antimony strongly reduce susceptibility in the alpha phase. These alloying elements are utilized in the dezincification-resistant silicon brasses C87800 and C87900. The elements do not retard dezincification of the zinc-rich beta phase, therefore high beta brasses should not be specified for seawater or oxidizing acidic environments.

An analogous form of dealloying known as dealuminification is found in some aluminum bronzes. Alloys with relatively high aluminum contents, such as C95300 and C95400, can contain substantial amounts of the γ_2 phase when in the as-cast condition. The elevated nickel and iron contents of nickel-aluminum bronzes C95500 and C95800 also cause this phase to appear. The presence of γ_2 is detrimental to corrosion resistance, particularly with regard to dealuminification.

The corrosion resistance of alloys C95300 and C95500 can be improved by heat treatment, a process which removes γ_2 from the microstructure and at the same time increases the alloys' strength. In the case of Alloy C95800, the temper anneal heat treatment is applied to improve dealuminification resistance, especially when the alloy is to be used in seawater.

Dealuminification in the aluminum and nickel-aluminum bronzes can be avoided by applying cathodic protection (CP), usually by electrically coupling the alloys with less noble metals. Steel ship hulls, for example, provide adequate CP to protect C95500 propellers, even when these have not been heat treated.

Another copper alloy can also provide CP, but this is not always possible. For example, aluminum bronzes C95200-C95400 are slightly anodic to (less noble than) nickel-aluminum bronzes, but the potential difference between the two alloys is not sufficient to prevent dealuminification of nickel-aluminum bronze C95000 when the two are coupled in seawater.

Aluminum-silicon bronze (C95600), as well as manganese-nickel-aluminum bronze (C95700), contain little or no γ_2 and they are therefore less susceptible to dealuminification than C95500 and C95800. Heat treatment is not essential; however, the seawater corrosion resistance of these alloys does improve somewhat after the alloys are temper annealed.

Erosion-Corrosion, Cavitation. In quiescent or slowly moving waters, the copper alloys' protective corrosion-product films are able to replenish themselves faster than they can dissolve, with the result that film thickness and corrosion rates remain essentially constant. When flow velocity is permitted to increase, it eventually reaches a point where the film is removed faster than it can regenerate. This flow rate is called the critical velocity, and it is marked by an abrupt rise in the corrosion rate.

Estimates for critical flow velocities for several of the cast copper alloys are given in **Table 6**, page 61. When using these limiting values, designers should be aware that the numbers refer to smooth flow conditions, and that turbulence around obstructions, at sharp changes in flow direction and over rough cast surfaces may result in velocities that are considerably higher than bulk flow rates would suggest.

Nickel-aluminum bronzes are known for their good resistance to erosion-corrosion, but the degree of resistance depends on the alloys' metallurgical condition. Alloy C95500, for example, exhibits very good resistance to erosion-corrosion in the as-cast condition and good resistance to dealuminification when heat treated.

For the reasons discussed above, the alloy does not require heat treatment to improve its dealuminification resistance when used in ship propellers.

Alloy C95800, an accepted alloy for seawater pump components, behaves similarly, i.e., it has good erosion-corrosion resistance as cast and good dealuminification resistance after heat treatment. However, it is known that erosion-corrosion resistance deteriorates as a result of the temper anneal heat treatment. Therefore, if velocity resistance is important, the alloy should be used in the as-cast condition; if there also is a possibility that dealuminification might occur (as in seawater), the alloy should be protected by an effective CP system.

Severe forms of erosion-corrosion occur when the fluid contains abrasive particles (abrasion corrosion) or when terminal velocities are extremely high (impingement attack). High differential pressures can give rise to vapor generation and cavitation, the mode of attack sometimes observed on the low-pressure side of impellers and ship propellers.

Ordinary erosion-corrosion can usually be avoided by selecting a more corrosion-resistant material, but abrasion-corrosion, impingement and cavitation can only be overcome by using alloys that combine better corrosion resistance with higher strength and hardness.

Galvanic Corrosion. A galvanic couple is formed when two dissimilar metals are electrically connected in the presence of a corrosive medium, or electrolyte. The couple acts as a battery, causing one metal (the more active anode) to corrode more rapidly, while reducing corrosion at the other (the less active cathode). The behavior of metals in galvanic couples depends on the difference in their electrochemical potentials, the properties of the electrolyte and on the galvanic circuit's electrical resistance, i.e., how intimately the metals are connected.

The propensity for galvanic corrosion is described by a galvanic series, which lists the common metals in order of their electrochemical behavior in a particular medium. A galvanic series for seawater exposure (there are many others) is shown in **Figure II-2**, page 62. The farther apart metals lie on the series, the greater the possibility that galvanic corrosion can occur when the metals are joined. Metals that are close to each other in the series normally do not present a problem; therefore, copper alloys do not affect each other nor are they seriously affected by coupling to nickel-base alloys and passive stainless steels. Copper alloys do accelerate attack in less noble metals such as aluminum and mild steel.

The rate of galvanic attack depends very strongly on the anode/cathode area ratio. For example, a small brass fitting may cause no serious damage to a large steel housing because the galvanic corrosion on the steel will be spread over a large area. Galvanic corrosion can be controlled by taking advantage of the area ratio. It can be eliminated entirely by insulating the two metals from each other.

Stress-Corrosion Cracking (SCC). Also known as environmentally assisted cracking, SCC occurs only in the simultaneous presence of a susceptible material, a suitably aggressive environment and a sufficiently high tensile stress. Failure is usually in the form of a network of cracks oriented perpendicular to the applied (or residual) stress vector. Cracking may be intergranular or transgranular depending on the alloy and the attacking medium.

Almost all metals exhibit SCC in some environment, however, susceptibility is typically very specific to the attacking species, and corrodants that readily crack one class of materials may have no effect on another. Chlorides are notorious for causing SCC in stainless steels, for example, but will not crack the copper alloys. Conversely, copper alloys can exhibit SCC in aqueous solutions of ammonium ions, nitrites, mercury compounds, and moist atmospheres containing sulfur dioxide, media which are not known to crack the steels.

SCC susceptibility varies considerably among the copper alloy families. Brasses are most vulnerable to failure in the media listed above; tin-bronzes, red brasses and aluminum bronzes are less sensitive to attack in these environments, and pure copper and copper-nickels are essentially immune.

Selecting Alloys for Corrosive Environments

When corrosion resistance is the principal design criterion, the obvious metal to use is the one that provides the desired service life (highest acceptable corrosion rate) at the lowest cost. When a longer minimum service life is required, or when there is uncertainty regarding corrosion conditions over time, the simplest options are to provide a corrosion allowance in the form of excess wall thickness and/or use of a more corrosion-resistant alloy.

Corrosion allowances are only safe to use when corrosion rates can be predicted with a high degree of reliability. They are perfectly acceptable for situations involving general corrosion or mild erosion-corrosion under nonvarying environmental conditions.

Corrosion allowances are less useful when pitting, plug-type dealloying, severe cavitation or stress corrosion cracking can occur, since the rate of penetration under these conditions is nearly impossible to predict. Using a more resistant alloy often—but not always—entails higher costs. In this regard, it should be noted that copper alloys are considerably less expensive than exotic materials such as titanium and nickel-base alloys, yet their performance may be more than adequate to meet the demands of the corrosive environment.

It is often the case that several design criteria must be satisfied at the same time. Alloy selection then becomes a matter of choosing the material with the best overall combination of the required properties. For example, a marine winch bearing would require good corrosion resistance combined with high strength. In this case, an aluminum bronze would be a good candidate because it is both strong and corrosion-resistant.

It is not possible to define a specific alloy for a particular application in a publication such as this. The following chapters therefore suggest selections from groups of alloys that should be nominally acceptable for given situations. The final choice can then be made after testing candidate alloys under simulated service conditions.

Atmospheric Exposure. All copper alloys resist corrosion in clean, dry air. Exposed outdoors, they slowly tarnish to successively darker shades of brown, varying in color with alloy composition. Carbon dioxide, chlorine, sulfur compounds and oxygen dissolved in rainwater may eventually give rise to a gray-green patina. Corrosion rates corresponding to patina formation—an excellent example of a protective corrosion—range from 0.00008 to 0.00012 in/y (0.002 to 0.003 mm/y).[8]

Exposed indoors, high strength yellow brasses (C86100-C86800), nickel silvers and aluminum bronzes tend to retain their brightness quite well. The cast copper-nickels, which are nearly identical in composition to the wrought coinage alloys used throughout the world, are also highly tarnish resistant.

Copper, brasses and tin bronzes gradually lose their luster unless shielded from the atmosphere. Protective lacquers containing corrosion inhibitors can retain the bright colors of newly polished metal for many years. A number of modern polymeric coatings are also effective outdoors.

After sufficient time for protective film formation, atmospheric corrosion rates for copper alloys usually decrease to inconsequential levels. Corrosion rates for copper, aluminum bronze and 70-30 copper-nickel range between 0.000013 and 0.000051 in/y (0.05 and 0.2 μm/y) after 20 years in rural desert areas, and reach only 0.000011, 0.000051 and 0.00001 in/y (0.43, 0.20 and 0.48 μm/y), respectively, in northern rural areas. Industrial pollutants, especially when combined with the marine atmospheres of seacoast locations, increase the rate of corrosion several-fold, but only to a quite tolerable 0.00066 in/y (2.6 μm/y).[9]

High zinc brasses are less resistant to atmospheric corrosion, and may suffer superficial dezincification under acid rain conditions. Sulfur dioxide, the principal industrial pollutant, is detrimental to many copper alloys; however, nickel-tin bronzes and aluminum bronzes can be recommended where high atmospheric concentrations of SO_2 prevail.[8]

Industrial atmospheres occasionally give rise to stress corrosion cracking in cast alloys, but the phenomenon is rare and data are therefore sparse. The behavior of cold-worked copper alloys suggests increasing resistance to SCC in industrial/near-seacoast atmospheres in the order: 70-30 brass (approximately equivalent to C85800) < leaded duplex brass < admiralty brass (similar to C85400) < aluminum brass (similar to C86500) < aluminum bronze (similar to C95200).[10] In part because of their lower levels of residual stresses and less severe loading, castings are generally less susceptible to SCC than wrought materials.

Moist ammoniacal atmospheres can produce stress corrosion cracking in copper alloys, although susceptibility varies widely with alloy composition. Again, brasses exhibit the highest susceptibility, followed by aluminum bronzes, pure copper and 90-10 copper-nickel. High nickel (70-30) copper-nickels are regarded as being virtually immune to SCC failure in this environment.[11, 12]

Copper alloys oxidize slowly in air at elevated temperatures. Oxidation resistance is improved considerably by alloying, which changes the composition and properties of the oxide film. Tenacious mixed-oxide films give aluminum bronzes (including nickel- and manganese-containing varieties), high strength bronzes and beryllium coppers particularly good resistance to oxidation. Nickel, as in copper-nickel alloys, retards the oxidation of copper at high temperatures by as much as a factor of three.[13] Brasses are not notably oxidation resistant at elevated temperatures, and for this and other reasons, they are not commonly used above about 572 F (300 C).

Steam. Corrosion resistance in steam is normally a less critical design factor than stress-rupture and creep strength requirements at the service temperature. From a corrosion standpoint, leaded red brass, C83600, leaded semi-red brass, C84400, and high strength yellow brasses and silicon bronzes are all suitable for steam service. The metals' creep strengths (which decrease in the same order) fix the limits of their allowable service conditions.

Aluminum bronzes C95400 and C95500, as well as manganese-aluminum bronze, C95700, are recommended for steam service at temperatures up to 800 F (427 C). Small additions of tin or silver, used to prevent intergranular stress corrosion cracking in wrought aluminum bronzes,[14] are not necessary in cast versions of these alloys. The aluminum bronzes' high hardness helps protect against impingement corrosion, which can occur under wet steam conditions. The leaded tin bronze, C92700, is also widely used in steam fittings.

Fresh Waters. The corrosion behavior of copper alloys in clean, fresh water is similar to that in air. Unless conditions favor dezincification or flow velocities are very high, virtually any copper alloy can be used. Red brass, C83600, and semi-red brass, C84400, are the most popular alloys for cast plumbing hardware in North America.

Higher zinc yellow brasses also give good service, but these alloys may dezincify under conditions involving an acidic pH, stagnation or crevices such as those formed under sediments. Dezincification is less of a problem in tin-bearing brasses (C85200, C85400, C85700) or brasses that are inhibited against dezincification by additions of arsenic or antimony (C87800, C87900).

Some potable waters can attack the lead contained in plumbing fixtures made from alloys such as C83600 and C84400, but this is by no means a universal problem. Moderately hard and harder waters, for example, quickly cause the formation of an insoluble calcareous film that almost immediately blocks any further corrosion of the lead.

Under more aggressive conditions, lead from the fixtures' surfaces can leach into the water. (Since only surface lead is affected by the leaching action, the process is inherently self-limiting.) Therefore, in very soft, aggressive waters, where water remaining in a fixture could exceed the Environmental Protection Agency's action levels for lead after an overnight dwell, designers might opt for a reduced-lead or lead-free alloy. The unleaded silicon brasses, C87600 and C87800 among other alloys, have been proposed as possible alternatives to leaded alloys for such situations.

It should be noted that surface lead can be removed from even highly leaded alloys by a simple chemical treatment with an acidified solution of sodium acetate. This treatment effectively renders the alloys "lead-free" from a corrosion standpoint, yet it has no harmful effect on structure or properties.

Tin bronzes and aluminum bronzes have excellent corrosion resistance in fresh water. These alloys are considerably stronger than the red or semi-red brasses, and are better suited to industrial applications than to domestic plumbing. Typical uses include pump components for handling acidic mine waters and chemical process streams.

Waters containing sulfides, nitrates, cyanides, amines or mercury or ammonia compounds are corrosive to copper alloys. Tin bronzes, aluminum bronzes and copper-nickels are more resistant to these species than coppers and brasses, and these alloys can be used if conditions are well understood. If there is any doubt about performance, it is good practice to conduct simulated or accelerated service tests before committing an alloy to a new application.

Seawater. Copper, the original marine metal, is quite resistant to attack by seawater. This property is shared by most of the cast copper alloys, which find a large market in marine service applications. Pure copper is far too weak for mechanical applications in marine service, and today's workhorse alloys are the strong, corrosion-resistant copper-nickels and aluminum bronzes.

The copper-nickel alloys have exceptional seawater corrosion resistance. With minimum tensile strengths (as sand cast) ranging between 45 and 75 ksi (310 and 517 MPa), depending on alloy type, they have gained wide acceptance in both cast and wrought forms.

Alloy C96200, a 90-10 copper-nickel alloy, offers good corrosion performance at a cost between that of the tin bronzes and the higher nickel alloys. As with other copper-nickels, the alloy's corrosion rate in seawater decreases steadily during exposure, eventually approaching steady-state behavior at 0.04 to 0.05 mpy (1.0 to 1.3 x 10^{-3} mm/y), **Figure II-3**, page 61.

Alloy C96400, with 30% nickel, is better able to tolerate polluted waters and high velocity flow than the 90-10 alloy. The alloy contains a small amount of columbium (niobium) to improve its weldability. It is, in fact, the most weldable alloy in the cast copper-nickel series and is consequently a good candidate for products in which weld-cast fabrication is a manufacturing option. The alloy's higher nickel content makes it about 30% stronger than the 90-10 composition, but it also adds significant cost. Higher initial cost can often be amortized over a longer service life, however, resulting in a lower life cycle cost. This is especially true for maintenance-prone items such as valve components and pump bodies.

With a tensile strength of 75 ksi (517 MPa), the 80-20 alloy, C96300, is the strongest of the conventional cast copper-nickels. It is used primarily for centrifugally cast tailshaft sleeves. Stronger still is alloy C96600, a beryllium-modified 70-30 composition that can be age-hardened to a yield strength of 75 ksi (517 MPa) and a tensile strength of 120 ksi (827 MPa). At maximum strength, the alloy's hardness reaches HR24C. The presence of beryllium oxide in the alloy's protective corrosion-product film enhances corrosion and oxidation resistance.

C96600 is used for highly stressed and/or unattended products such as submerged pressure housings, pump and valve bodies, line fittings, low-tide hardware, submersible gimbal assemblies and release mechanisms. Like all copper alloys, the high strength copper-nickels can be soldered and brazed, but their weldability can only be rated as fair.

The aluminum bronzes' resistance to seawater corrosion is almost equivalent to the best copper-nickels. As a class, however, the aluminum bronzes are considerably stronger than the copper-nickels. They tend also to cost a bit less, and they are readily weldable.

As a rule, mechanical properties improve with alloy content, and aluminum bronzes are no exception. The alpha (single-phase) 9% aluminum bronze, C95200, develops a minimum tensile strength of 65 ksi (448 MPa) in the as-sand-cast condition. The 10% aluminum bronze, C95300, and the 11% aluminum, 4% nickel aluminum bronze, C95500, which respond to heat treatment, reach tensile strengths of 80 and 110 ksi (551 and 758 MPa), respectively.

Aluminum-silicon bronze, C95600, manganese-aluminum bronze, C95700 and nickel-aluminum bronze, C95800 do not respond to heat treatment, yet they attain appreciable strength levels (60-90 ksi, 413-620 MPa) in the as-cast condition. Typical applications include severe-duty, corrosion-resistant products such as pumps, valves, heat exchanger components and propeller hubs, as well as seawater pipe and fittings for use under high flow rate conditions. Alloy C95800 is regarded as the most cost-effective propeller alloy for commercial vessels.

For less demanding applications, both leaded and unleaded tin bronzes can be considered. These alloys perform very well in seawater but are not often used for marine products because of their modest mechanical properties. On the other hand, red brasses such as C83600 give very good service under moderate operating conditions and can be used very cost-effectively in pumps, valves and general utility products.

Seawater causes dezincification and selective attack of the beta phase in high zinc brasses, including the semi-red brasses. These should only be used with caution in marine applications. Yellow brasses, leaded or unleaded, should not be specified for wetted or submerged applications. High strength yellow brasses are not generally recommended for the same reason, although an alloy similar to C86500 is successfully used for underwater fittings in the U.K.

Desalination. Copper alloys are standard materials for all stages of flash-evaporative desalination equipment. They are also used extensively for supply and service water lines in reverse osmosis systems. In one evaporative desalination unit, alpha aluminum bronze, 90-10 copper-nickel and 70-30 copper-nickel exhibited corrosion rates between as little as 0.0003 and 0.001 in/y (0.0076 and 0.025 mm/y) after 29 months' service. The range in corrosion rates in this instance reflects the severity of the service conditions at various locations in the plant.[14]

Industrial and Process Chemicals. Copper alloys are widely used in the process industries. Properly selected for the given environment, they can be more cost-effective than stainless steels, significantly less expensive than titanium or nickel-base alloys, and cheaper and more reliable in the long run than organic-lined, carbon steel components.

Copper alloy families that display good corrosion resistance in seawater are usually durable in corrosive process streams, as well. That is, red and semi-red brasses, tin and nickel-tin bronzes, aluminum bronzes and copper-nickel alloys are generally good candidates for industrial chemical service. Because chemical service environments can vary so widely, however, it is always best to test candidate alloys before committing a casting to use. A few general principles may help in making the initial alloy selection(s):[4, 8]

- Tin bronzes, silicon bronzes, nickel silver, copper, aluminum bronzes and low zinc brasses can safely be used in contact with concentrated or dilute acids and alkalis, hot or cold, providing the medium does not contain air or other oxidants (nitric acid, dichromates, chlorine and ferric salts), complexing agents such as cyanides, ammonia, chlorides (when hot) and amines, or compounds that react directly with copper. The latter include sulfur, hydrogen sulfide, silver salts, mercury and its compounds, and acetylene.
- Yellow brasses and other high-zinc alloys are prone to dezincification and should not be used with dilute or concentrated acids or acid salts, both organic and inorganic. The high zinc alloys should never be used in dilute or concentrated alkalis, neutral chloride or sulfate solutions or mild oxidizing agents such as calcium hypochlorite, hydrogen peroxide and sodium nitrate.
- Nonoxidizing acetic, hydrochloric and phosphoric acids are relatively benign toward all copper alloys except the high zinc alloys. Tin bronzes, aluminum bronzes, nickel silver, copper and silicon bronzes can be recommended; however, hot and concentrated hydrochloric acid may become aggressive toward alloys which resist attack when the acid is cold and dilute. Nitric, chromic and other oxidizing acids must be avoided in all cases.
- Alkalis are best handled with 70-30 copper-nickel alloys, although high tin bronzes, nickel silver, silicon bronzes and most other alloys except high zinc brasses are safe to use with dilute bases. Aluminum bronzes are susceptible to dealuminification in hot dilute hydroxides, but this tendency is markedly reduced in aluminum bronzes containing tin. Ammonium hydroxide, substituted ammonium compounds, amines and cyanides should never be used in contact with copper alloys as these species cause rapid corrosion through the formation of highly soluble complex ions. Aerated solutions of ammonium compounds and nitrites can cause stress corrosion cracking if the exposed copper alloy is under an applied or residual tensile stress.
- Neutral salt solutions can usually be handled safely by most copper alloys, although corrosion rates vary among alloy types. Chlorides are more corrosive than sulfates and carbonates, especially in aerated solutions; however, copper-nickels and aluminum bronzes are the preferred materials for use in evaporative desalination plants because of their extremely low corrosion rates in these highly saline environments. Basic salts behave like hydroxides, but less aggressively, although high zinc brasses are not recommended. Mercury salts (and the metal itself) are highly corrosive to copper alloys and will, in addition, provoke stress corrosion cracking when tensile stresses are present.
- Dry gases, including ammonia and chlorine, do not attack copper and copper alloys, but these gases are corrosive when moist. All copper alloys are attacked by moist chlorine; however, chlorinated water can be handled by high tin bronze, aluminum bronze, silicon bronze, nickel silver and copper itself. High zinc brasses are attacked by moist carbon dioxide.
- Organic compounds are generally innocuous toward copper alloys. Exceptions include hot, moist, chlorinated hydrocarbons and aerated organic acids. Moist acetylene forms explosive compounds in contact with copper, although alloys containing less than 65% copper are safe in this regard.
- A number of foodstuffs and beverages are routinely handled in copper alloys, the best-known examples being the use of copper alloy in breweries and distilleries, and nickel silver fittings, valves and fixtures in dairy equipment. It should be noted that copper is an absolutely essential trace nutrient, and its presence in foodstuffs in low concentrations is not hazardous. Copper can impart an objectionable metallic taste if present in sufficiently high concentrations, and it is for this reason that direct contact between copper alloys and acidic foodstuffs should be avoided. An electroplated tin coating provides a good contact barrier. Leaded copper alloys should be used with caution when there is concern that lead may be leached into foods or beverages.

Table 7, page 73, lists the resistance of cast copper alloys to a selection of common industrial and process chemicals. The data are necessarily general in nature and should only be used as a guide. The best assurance of alloy performance can be gained by conducting simulated service tests of candidate alloys before making the final alloy selection.

TABLE 6. Velocity Guidelines for Copper Alloys in Pumps and Propellers Operating in Seawater

UNS Number	Peripheral Velocity feet/second	Peripheral Velocity meters/second
C83600	<30	<9.1
C87600	<30	<9.1
C90300	<45	<13.7
C92200	<45	<13.7
C95200	<75	<22.8
C86500	<75	<22.8
C95500	>75	>22.8
C95700	>75	>22.8
C95800	>75	>22.8

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

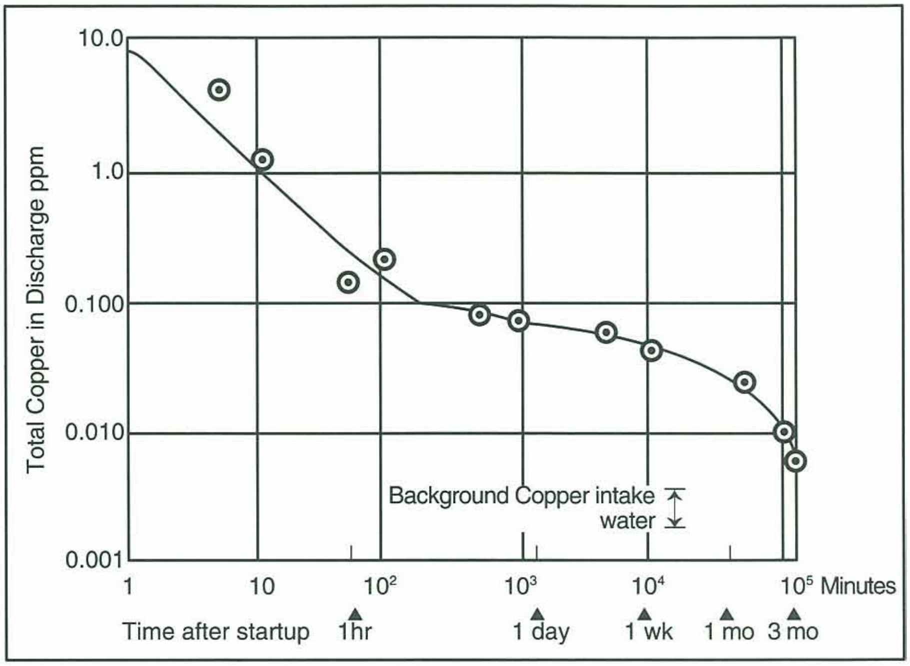


FIGURE II-1.
Formation Rate of Corrosion Film on 90-10 Copper-Nickel in Seawater.

Source: G. Butler and A. D. Mercer, Nature, Vol. 256, No. 5520, pp 179-720. See also: Copper-Nickel Alloy–Resistance to Corrosion and Biofouling in the Application of Copper-Nickel Alloys in Marine Systems, available from Copper Development Association Inc.

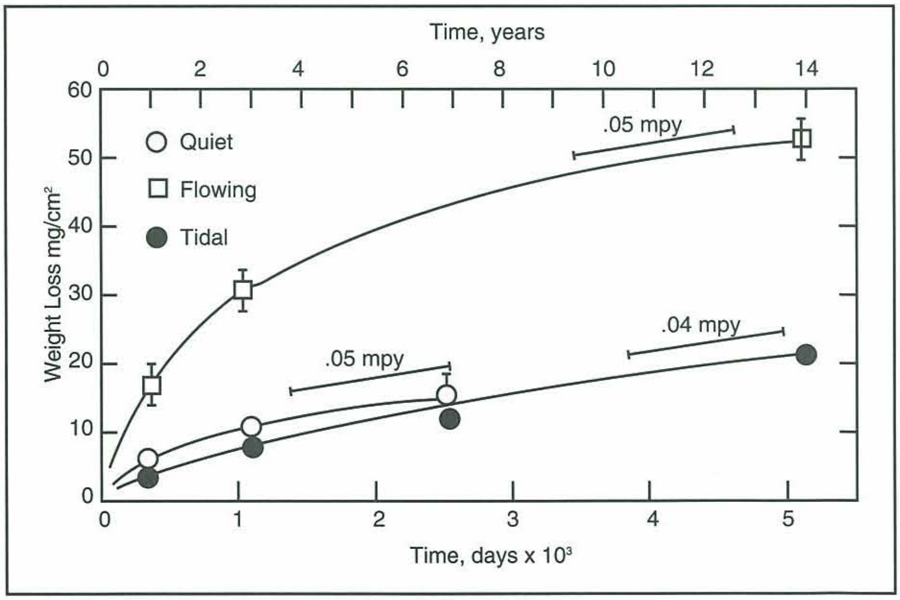
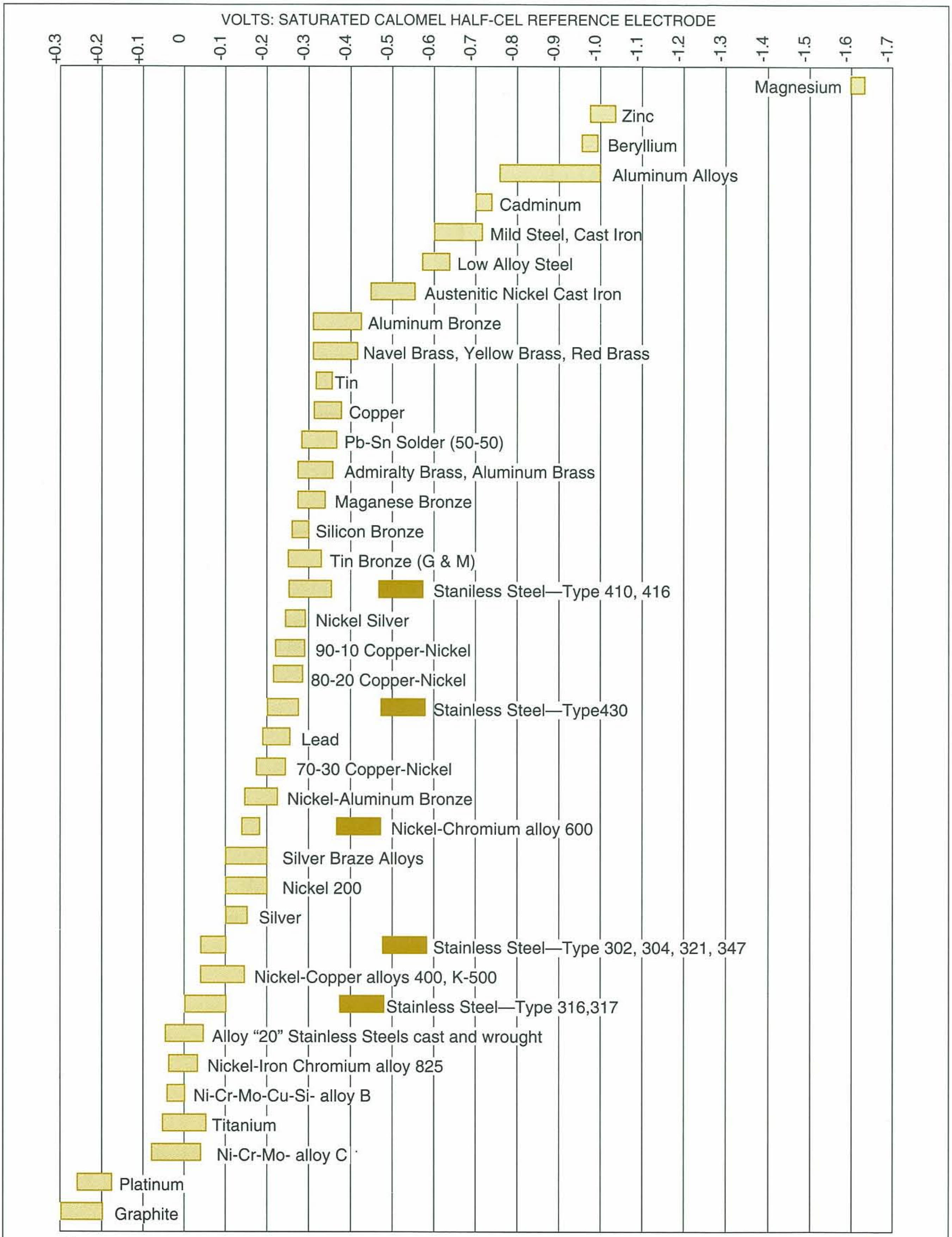


FIGURE II-2.
Weight Loss-Time Curves for 90-10 Copper-Nickel In Seawater.

Source: International Nickel Co., Inc., Marine Corrosion Bulletin MCB-1, 1975.



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol: ▬ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near -0.5 volts.

FIGURE II-3. Galvanic Series

Source: International Nickel Company, Inc.

III. SELECTING COPPER ALLOYS FOR MECHANICAL PROPERTIES

Copper alloys are almost never chosen exclusively for their mechanical properties; however, they are very often selected because they combine favorable mechanical properties with other technical attributes.

Strength

The mechanical properties of cast alloys are derived from, and depend on, a combination of factors. These can be grouped into the composition-related factors that affect the basic strength of the alloy and the structure-related factors that arise when the alloy is cast.

Among the factors affecting the alloys' intrinsic strength are solid solution effects and the presence of hardening phases in the microstructure. Within specific limits depending on the metal, zinc, tin, nickel, aluminum and several other alloying elements form a solid solution with copper that has the same structure as copper itself, but is usually considerably stronger. On the other hand, chromium, zirconium and beryllium exert their greatest strengthening effects when they precipitate as discrete particles.

Microstructural strengthening is actually quite complex. In addition to the effects described above, it can also depend on the formation of additional phases. For example, addition of sufficient zinc to copper-zinc alloys (brasses) produces an incremental jump in strength coinciding with the appearance of the hard beta phase. The formation and/or stability of second phases often also depends on the casting process itself, to the extent that this affects freezing and cooling rates.

Grain size has a strong influence on mechanical properties. Generally speaking, finer structure produce stronger and more ductile castings. The fineness of the cast structure in sand castings depends very significantly on the freezing rate, or more specifically, on the thermal gradient across the solidification region.

This rule does not always apply to other casting processes. For example, continuous and centrifugal castings solidify very rapidly, yet such castings typically exhibit coarse columnar grain structures. The fact that continuous or centrifugal castings can be at least as strong and ductile as sand castings can be explained by their inherently high degree of internal soundness.

Cooling rate can also exert a strong influence on phase transformations. In transformable compositions, the appearance of a particular phase depends on the time the casting spends within a well-defined temperature range. The fineness of the phase's structure, and hence its influence on mechanical properties, depends on how fast the metal cooled while the phase was forming. In some alloy systems, cooling rate remains important down to a few hundred degrees above room temperature.

The key point is that freezing and cooling rates depend largely on section size. Thin sections chill fairly rapidly, whereas large masses or regions near risers remain liquid for a long time and may cool very slowly once solidified. A casting with widely varying section sizes will freeze and cool over a range of rates, producing a variety of metallurgical structures and a corresponding range of mechanical properties. Uniform properties are best assured by reasonably uniform section thicknesses throughout. Here, the advice of experienced foundrymen and metallurgists can be invaluable.

Unless otherwise specified, the mechanical properties given in this guide were taken from standard test bars, and these can be taken as representative of properties that will be developed in sand castings. Other casting methods may produce different mechanical properties in the same alloy. Assuming a given alloy can be cast by several methods, the one with the fastest cooling rate will generally produce the strongest product.

When adherence to minimum mechanical properties is critical to a product's function, it is advisable to specify that test specimens be taken directly from a carefully chosen area of a sample casting. For castings of relatively uniform cross section, coupons taken from extensions provided for the purpose can be used.

Tables 8 through **10**, pages 76-80, rank the cast copper alloys on the basis of their room temperature mechanical properties.

Strength and Temperature

One inherent advantage of single-phase copper alloys with the face-centered cubic (alpha) crystal structure is that their ductility does not deteriorate very much, if at all, down to very low temperatures. Alloys that contain a large volume fraction of beta will suffer some loss of ductility, but even in these alloys, low-temperature embrittlement is not a serious problem.

Table 11, page 81, lists impact properties of a few cast copper alloys at temperatures ranging from 572 F (300 C) to -320 F (-196 C)[8]. **Figures III-1**, **2**, **3** and **4**, page 65, illustrate the effects of temperature on selected mechanical properties of four copper alloys.

As with other engineering alloys, copper alloys are chosen for elevated-temperature service on the basis of their time-dependent deformation behavior. That is:

- The metals slowly deform when held under a constant stress. This process, known as creep, is defined in terms of a given amount of strain (from 0.1% to 1%) for 1,000, 10,000 or 100,000 hours at a given temperature.
- After creep has proceeded to its limit, the metals fail by stress-rupture. The stress-rupture stress is significantly lower than the short-term tensile strength at the same temperature. Behavior is defined in terms of the stress required to cause rupture in a given time (100-100,000 h) over a range of temperatures.
- Applied stresses decrease when metals are held at constant strain, a process known as stress relaxation. Metals are described by the percent stress relaxation with time over the temperature range of interest. Stress relaxation is an important consideration in, for example, high-temperature bolts or spring-loaded electrical contacts.

The copper alloys can be broadly classified into three groups with respect to their elevated-temperature properties:

- High conductivity coppers and leaded alloys, which have only modest high temperature strength and are normally not chosen on this basis.
- Unleaded brasses and bronzes, chromium copper and beryllium coppers, which have intermediate to high strengths and in some cases quite exceptional properties.
- Aluminum bronzes and copper-nickel alloys, which have superior resistance to creep and stress-rupture at elevated temperatures. For example, the 10,000-h stress-rupture strength of cast aluminum bronze is more than three times that of leaded red brass C83600 at 482 F (250 C).

High temperature property data for cast copper alloys is unfortunately not abundant; however, based on data for wrought alloys, 90-10 copper-nickel (comparable with C96200), nickel-aluminum bronze (comparable with C95800) and 70-30 copper-nickel (comparable with C96400) are, in order of increasing 100,000-h stress-rupture strength, the most suitable alloys above 662 F (350 C).[15]

Figures III-5 and **6**, pages 66 and 67, show the effect of temperature on the steady-state creep rate and stress-rupture time, respectively, for alloys C86300, C86500, C92200 and C93700. **Tables 12** and **13**, pages 82 and 83, give creep and stress-rupture data, respectively, for a selection of copper alloys.

Friction and Wear

The unexcelled ability of copper alloys to wear well against steel has led to their widespread use in bearings, wear plates, worm gears and related components. In addition to wear properties, other factors important to the selection of bearing materials include scoring resistance, compressive strength, fatigue resistance, deformability, corrosion resistance, shear strength, structural uniformity, and thermal stability over wide operating ranges, plus cost and availability.[16, 17] These are disussed, along with a complete description of bearing alloys, in the CDA publication, *Cast Bronze Bearings —Alloy Selection and Bearing Design*. The common copper bearing alloys are listed in **Table 14**, page 84.[6]

Fatigue Strength

Gears and other cyclically loaded products are designed in part on the basis of fatigue strength, which describes the change in fracture strength, S, over a large number, N, of stress cycles. S-N curves for alloys C83600, C86500, C87500, C87800, C92200 and C93700 are shown in **Figure III-7**, page 68.

The stress needed to produce failure decreases from the alloy's tensile strength at one stress cycle to less than one-half the tensile strength as N approaches 10^8 cycles. The rate of decrease itself decreases with increasing N, and may eventually become nearly independent of the number of cycles.

For alloys in which the failure stress does in fact become stress-independent, an absolute fatigue strength can be identified. Fatigue behavior can also be described in terms of an endurance ratio, defined as the fatigue strength at a given number of cycles divided by the static tensile strength. **Table 15**, page 85, lists fatigue strengths and endurance ratios for several cast copper alloys.

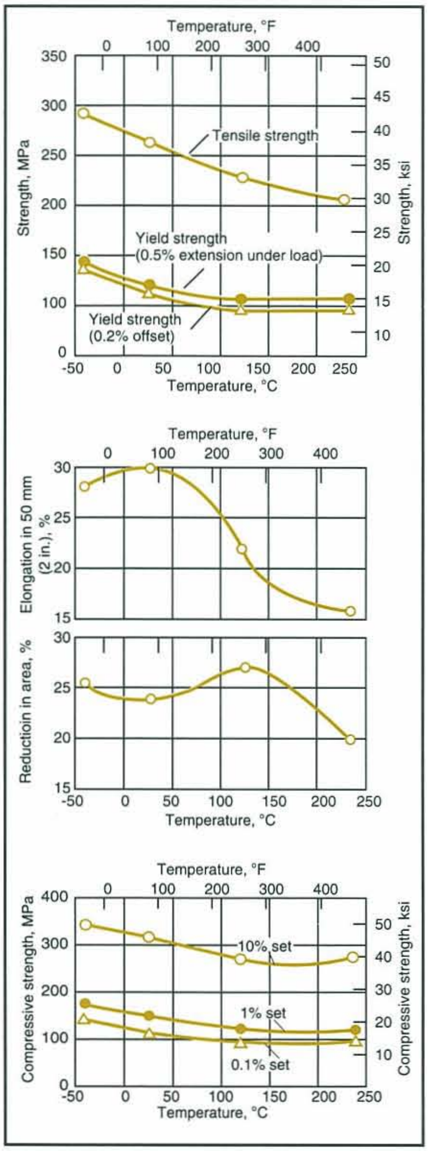


FIGURE III-1.
Effect of Temperature on Mechanical Properties of Alloy C93700.

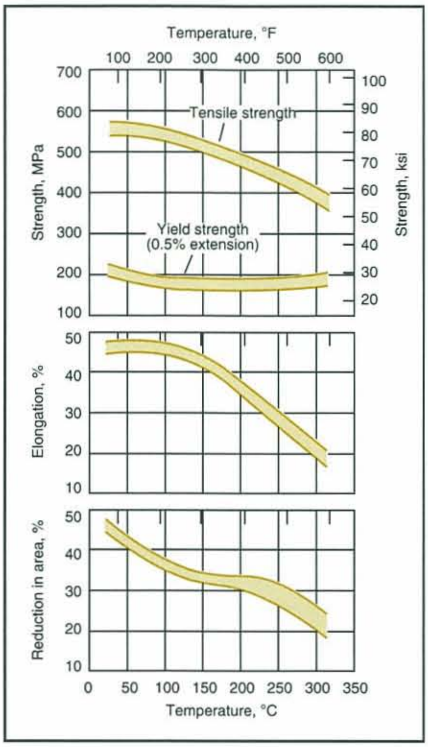


FIGURE III-2.
Effect of Temperature on Tensile Properties of Alloy C95200, As Cast.

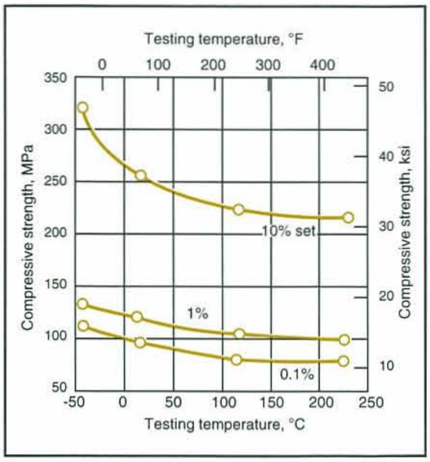


FIGURE III-3.
Effect of Temperature on Compressive Strength of Alloy C83600

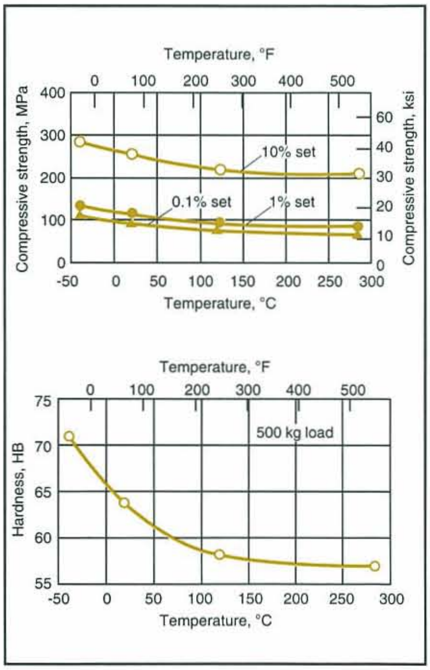
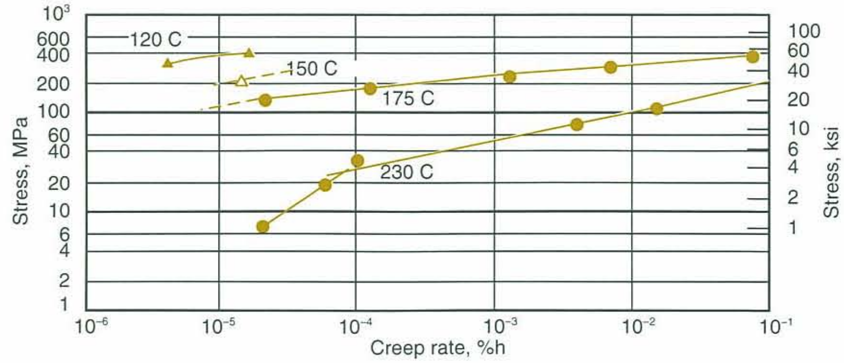
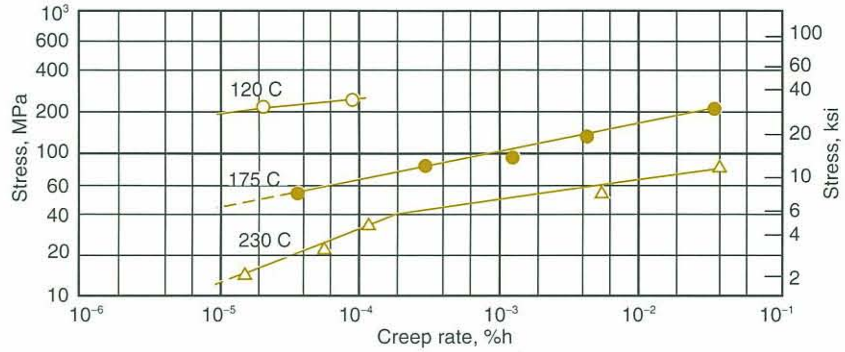


FIGURE III-4.
Effect of Temperature on Compressive Strength and Brinnell Hardness of Alloy C92200.

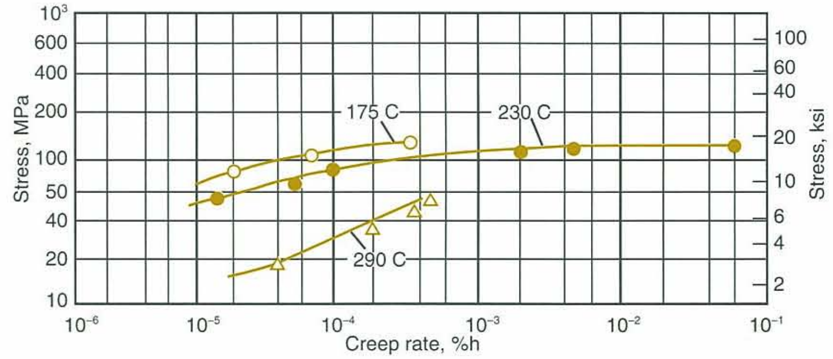


C83600



C86500

C92200



C93700

FIGURE III-5. Typical Stress-Creep Properties of Four Copper Alloys.

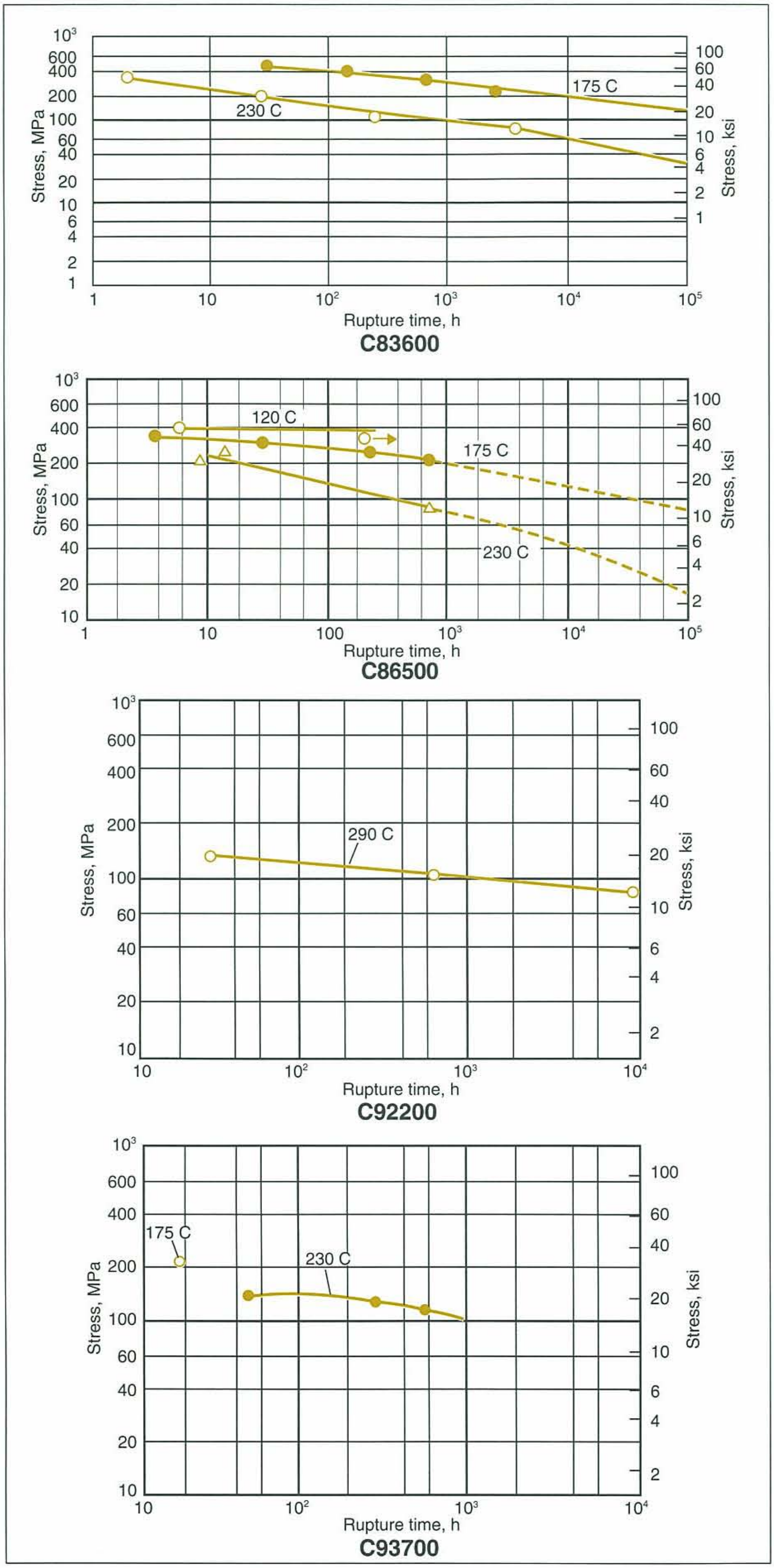
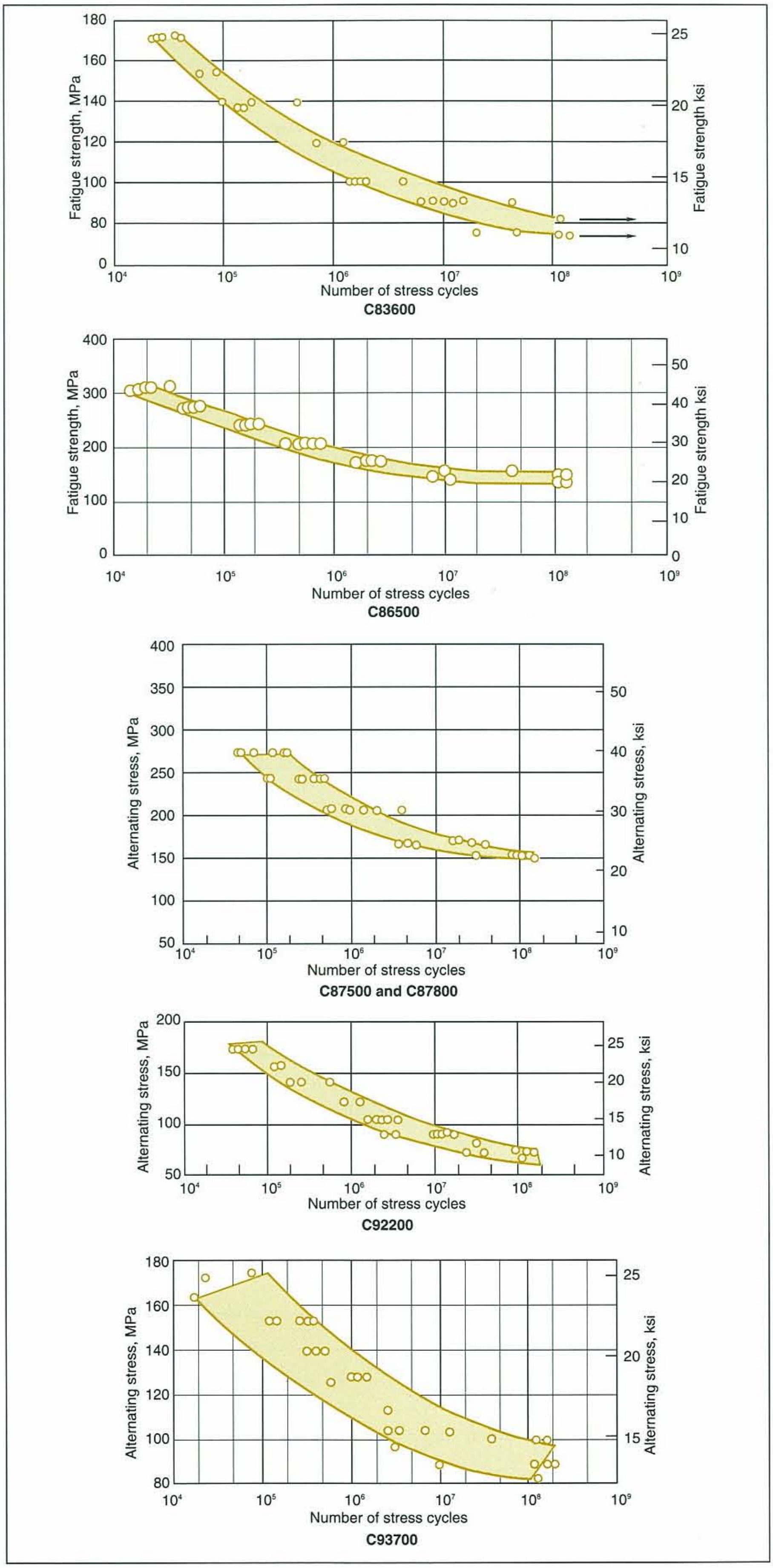


FIGURE III-6. Typical Stress-Rupture Properties of Four Copper Alloys.



C83600

C86500

C87500 and C87800

C92200

C93700

FIGURE III-7. Fatigue Strength of Copper Alloys.

IV. SELECTING COPPER ALLOYS FOR PHYSICAL PROPERTIES

Electrical Conductivity

The International Annealed Copper Standard (IACS) is the recognized standard for metal conductivity. Its value in absolute terms, 0.5800 Megmho/centimeter at 20 C (68 F), corresponds to a resistivity of exactly 17.241 nanohm-meter at that temperature. Highly refined, annealed, wrought coppers have IACS conductivities of 100% or slightly higher at 20 C (68 F), depending on purity. Less-pure coppers and cast copper alloys display conductivities ranging from 95% IACS down to between 5% and 10% IACS. By way of comparison, pure aluminum has a conductivity of about 60% IACS; 5052 aluminum alloy, 35%; carbon steel, 8.5%, and 18-8 stainless steel, about 2.3%.[18]

Electrical conductivity decreases with increasing alloying content, or more precisely, with the amount of alloying element in solid solution. In a precipitation-hardenable alloy, heat treatment changes the amount of alloying element in solid solution, and therefore alters the alloy's conductivity.

For example, the conductivity of chromium copper, C81500 (1% Cr), in the as-cast or solution-annealed state (tensile strength approximately 23-35 ksi, 172-241 MPa) is only 40%-50% IACS; while in the fully hardened condition (tensile strength 51 ksi, 352 MPa) it rises to 80%-90% IACS. The IACS conductivities of some cast copper alloys are listed in **Table 16**, page 86.[19]

Conductivity normally falls with increasing temperature, a factor which must be taken into account in the design of electrical products. This temperature dependence of electrical conductivity for a selection of cast copper alloys is shown in **Figures IV-1**, page 70.[5]

When high strength is not an important design consideration, cast electrical connectors and other current-carrying products can be made from copper C81100. Applications requiring higher strength along with good electrical conductivity can utilize chromium copper, C81500, or one of the cast beryllium coppers, C82000–C82800. Electrical conductivities of the beryllium coppers range between 82% and 18% IACS. Their corresponding tensile strengths range from 45 ksi to 165 ksi (310 MPa to 1,137 MPa) in the heat-treated condition.

Thermal Conductivity

The copper alloys are well known for their very favorable heat transfer properties. **Table 17**, page 87, ranks the copper alloys in order of their thermal conductivities at 20 C (68 F). Notice that unlike most other metals, the copper alloys' thermal conductivities increase with temperature. The phenomenon is illustrated in **Figure IV-2**, page 70. Designers can take advantage of this useful characteristic to improve the efficiency of copper alloy heat exchangers at elevated temperatures.

Magnetic Properties.

Copper is a diamagnetic metal, i.e., it has a negative magnetic susceptibility and is weakly repelled by magnetic fields. This property is shared by many copper alloys. On the other hand, high strength yellow brasses (manganese bronzes), copper-nickel alloys and aluminum bronzes, which contain up to a few percent iron precipitated as islands of an iron-rich phase, can, as a result, be slightly ferromagnetic. Magnetism in these alloys can be reduced several-fold by solution-annealing them at a high temperature, followed by rapid quenching. This retains the iron in solid solution, where it has little magnetic effect.

Although it is not itself ferromagnetic, manganese can also impart ferromagnetic properties to copper alloys, as in the so-called Heusler alloys, which are based on 75% copper, 15% manganese and 10% aluminum. These alloys are ferromagnetic even though they contain none of the naturally ferromagnetic metals: iron, nickel and cobalt.[3]

Thermal Expansion.

The thermal expansion coefficients for copper and single-phase alpha alloys fall in a fairly narrow range between 9.4 - 10.0 x 10^{-6} / °F (16.9 - 18 x 10^{-6} / °C), while those for beta and polyphase alloys (yellow brasses, high strength yellow brasses, silicon brass, etc.) are 10.0 - 12.0 x 10^{-6} / °F (18.0 - 21.6 x 10^{-6} / °C).[3] Thermal expansion coefficients for copper casting alloys are given in **Table 4**, page 42.

Elastic Properties.

Stress-strain curves for copper alloys have the rounded shape that signifies continuous yielding. Since there is no fixed yield point, yield strengths must be defined in terms of a given amount of engineering strain or extension under load. The strain values most often used are 0.2% offset and 0.5%

extension under load; obviously, strength values given for the larger strain will be somewhat higher than those for 0.2% strain. In order to avoid confusion, yield strength and strain should always be cited together.

Cast copper has an elastic modulus of 17,000 ksi (117,000 MPa). Brasses and tin bronzes have somewhat lower moduli while beryllium coppers and some copper-nickel alloys are in general a bit stiffer. Elastic moduli (in tension) for the cast copper alloys are listed in **Table 4**, page 42.

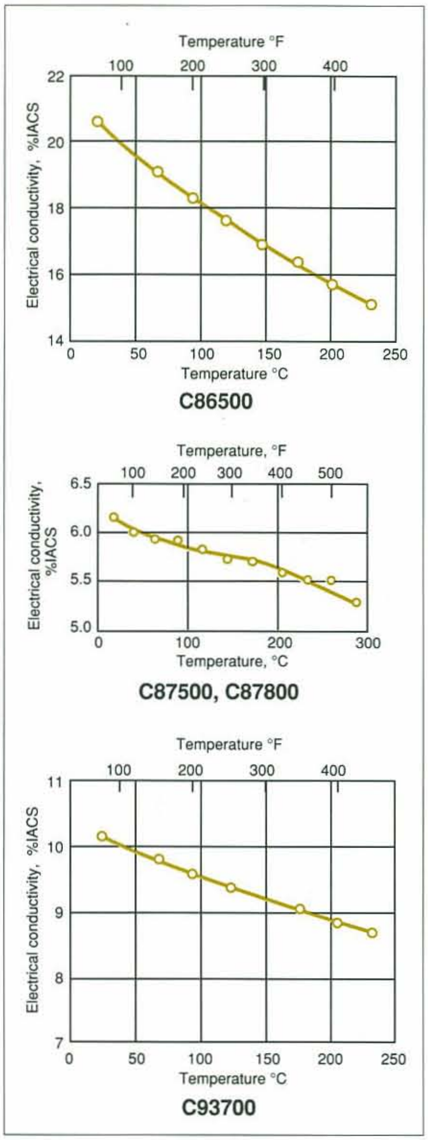


FIGURE IV-1.
Variation of Electrical Conductivity with Temperature for Alloys C86500, C87500, C87800 and C93700.

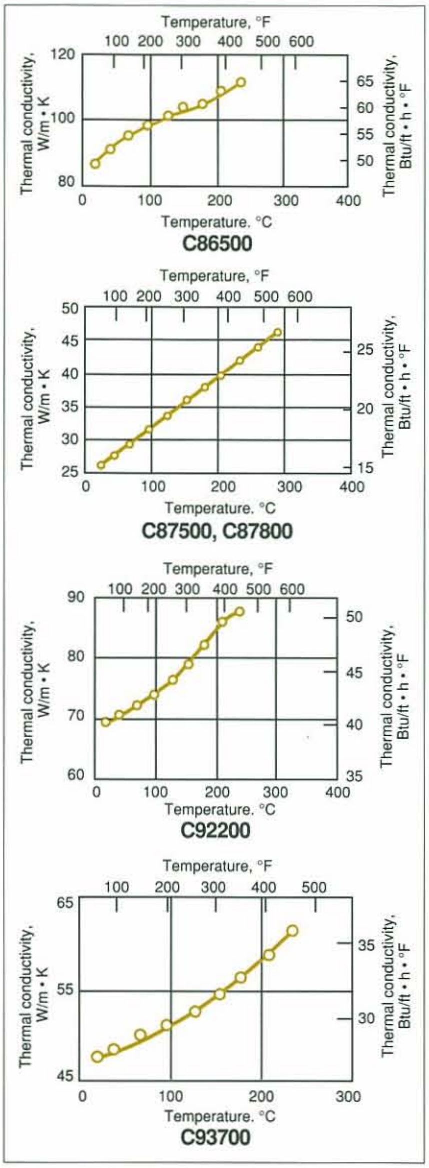


FIGURE IV-2.
Variation of Thermal Conductivity with Temperature for Alloys C86500, C87500, C87800 and C93700.

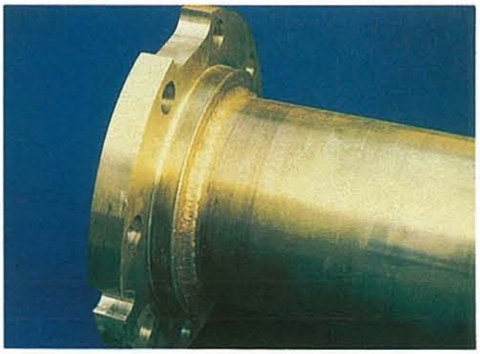


FIGURE V-1
This centrifugally cast flange was welded to the continuously cast aluminum bronze pipe.

FIGURE V-2
Detail of electronic beam (E.B.) welding used to seal prototype spent nuclear fuel container.

V. SELECTING COPPER ALLOYS FOR FABRICABILITY

Castings almost always require further processing after shake-out and cleaning. Machining is the most common secondary operation. Welding is often needed to repair minor defects or to join several castings into a larger assembly. Surface treatments are commonly applied to plaques, statuary and decorative products. All of these processing steps contribute to the cost of the finished item. Therefore, the ease and efficiency with which an alloy can be processed influences its economic viability.

Machinability

As a class, cast copper alloys can be described as being relatively easy to machine, compared with steels, and far easier to machine than stainless steels, nickel-base alloys and titanium, their major competitors for corrosion-resistant products. The copper alloys present a range of machinabilities, and some can be cut considerably faster than others, but none should present extraordinary problems to a skilled machinist.

Easiest to machine are the copper alloys that contain more than about 2% lead. These alloys are free-cutting; that is, they form small, fragmented chips. The chips literally burst away from the cutting tool, generating very little heat and making possible the high machining speeds for which the alloys are known. Tool wear is minimal, and surface finishes are generally excellent.

High speed steel is the accepted tooling material for these alloys, although carbides are commonly used for the stronger leaded compositions. Cutting fluids help reduce the concentration of airborne lead-bearing particulates, but they are not otherwise needed when cutting the highly leaded brasses and bronzes.

The leaded copper casting alloys behave much like wrought free-cutting brass, C36000, which is usually assigned the top "machinability rating" on a scale of 100. Leaded cast copper alloys have ratings greater than about 70; intermediate alloys, between about 30 and 70; while alloys that require special care rank lower, as shown in **Table 18**, page 88. Machinability ratings are based in part on subjective factors and should therefore only be interpreted as qualitative guides. Nevertheless, notice that leaded copper alloys are several times more machinable than carbon steel, including leaded steel, and that about one-half of the cast copper alloys can be machined easier than a common aluminum alloy. Stainless steels and titanium alloys are notoriously difficult to machine. If they had been listed, they would rank at the bottom of the table.

Next in order of machinability are moderate to high strength alloys which contain sufficient alloying elements to form second phases in their microstructures—the so-called duplex or multiphase alloys.

Examples include unleaded yellow brasses, manganese bronzes and silicon brasses and bronzes. These alloys form short, brittle, tightly curled chips that tend to break into manageable segments. Tools ground with chip breakers help promote this process. Surface finishes can be quite good for the duplex alloys; however, cutting speeds will be lower, and tool wear higher, than with the free-cutting grades. Preferred cutting fluids are those that provide a good combination of lubrication and cooling power.

Finally, there are the unleaded single-phase alpha alloys, which include high conductivity coppers, high copper alloys such as chromium copper and the beryllium coppers, tin bronzes, red brasses, aluminum bronzes and copper-nickels. The alloys' properties range from soft and ductile to very strong and tough, which leads to some variation in machinability among members of the group. There is, however, a general tendency for the alloys to form the long, stringy chips that interfere with high speed machining operations.

In addition, pure copper and high-nickel alloys tend to weld to the tool face. This impairs surface finish. Cutting tools used with these alloys should be highly polished and ground with generous rake angles to help ease the flow of chips away from the workpiece. Adequate relief angles will help avoid trapping particles between the tool and workpiece, where they might scratch the freshly machined surface. Cutting fluids should provide good lubrication.

Weldability

Castings are often welded to repair minor defects such as blowholes and small tears. It is also occasionally economical to weld-fabricate several castings (or castings and wrought products) into complex-shaped products that could not easily be produced otherwise. For example, **Figure V-I**, page 70, shows a centrifugally cast flange welded to a continuously cast pipe. Both components are made from nickel-aluminum bronze.

Oxygen-containing copper is difficult to weld because the detrimental oxide structures formed at the high welding temperature severely embrittle the metal. In addition, reducing atmospheres can lead to the formation of internal porosity. For these and other reasons, cast coppers are always deoxidized by the addition of a little phosphorus or boron just before pouring. (Cast oxygen-free coppers do not require deoxidation, but they must be melted and cast under inert atmospheres. Like deoxidized coppers, oxygen-free copper is not subject to weld embrittlement.)

Both gas-tungsten-arc (GTAW or TIG) and gas-metal-arc (GMAW or MIG) can produce X-ray quality welds in copper. Shielded-metal-arc (SMAW or stick) welding can also be used, but is somewhat more difficult to control. Oxyacetylene welding is mainly used to join thin sections. Electron beam (EB) welding produces very precise welds of extremely high quality in both oxygen-free and deoxidized copper. It is used, for example, in the cast-weld fabrication of large electronic devices. EB welding must be performed under vacuum or inert gas, making it considerably more expensive than arc processes. **Figure V-2**, page 70, shows an EB weld used to seal a prototype spent nuclear fuel container.

Electric arc processes are most commonly used to weld the high copper alloys, although oxyacetylene welding is also possible. For age hardenable alloys such as chromium copper or the beryllium coppers, welding should be performed before heat treatment because welding temperatures are high enough to redissolve precipitation hardening elements. This reduces the mechanical properties in and near the weld zone.

The following general comments on the weldability of copper alloy families may be helpful. More detailed information regarding the welding of copper alloys can be found in the AWS/CDA publication, *Copper and Copper Alloys: Welding, Soldering, Brazing, Surfacing*[20], available from CDA.

- Small SMAW weld repairs can be made to red and semi-red brasses, even those containing small amounts of lead, but these alloys are not good candidates for cast-weld fabrication. The yellow brasses, and to some extent, the silicon brasses, present similar difficulties.
- The unleaded manganese bronzes (high strength yellow brasses) can be welded by a variety of techniques, including GTAW and GMAW; however, a post-weld heat treatment should be applied to restore the heat-affected zone to its highest corrosion resistance.
- Unleaded silicon bronzes are the easiest copper alloys to weld, and are used as filler wires for the welding of other copper alloys. GTAW is the preferred process, but GMAW and oxyacetylene are also widely used.
- Manganese bronzes, manganese-aluminum bronzes and nickel-manganese bronzes are routinely welded using electric arc techniques. Stress relief may be required for alloys C86500 and C86800 to minimize susceptibility to stress-corrosion cracking.
- Cast aluminum bronzes, including the manganese-, iron- and nickel-bearing variations, are considered relatively easy to weld; they are not particularly prone to cracking unless their aluminum content is below about 9%.
- Copper-nickels are weldable by both arc and oxyacetlyene techniques. Some softening may occur, but the alloys can be returned to maximum strength by heating and slow-cooling after welding.
- Tin bronzes tend to become hot short and are difficult to weld without cracking. They can, however, be brazed. Nickel-tin bronze, C94700, which can be welded, may require post-weld heat treatment to ensure optimum mechanical properties.

In general, alloys containing appreciable amounts of lead cannot be welded. Lead, being insoluble in the alloys and having a very low melting point, remains liquid long after the weld metal solidifies. The presence of liquid lead promotes the formation of cracks in the high stress fields existing in and near the weld zone. Bismuth behaves in a similar fashion.

A listing of relative weldabilities for some copper alloys is given in **Table 19**, page 89. The ratings are somewhat conservative, and material suppliers should be consulted regarding recommended welding practices for specific alloys.

Brazing, Soldering

All cast copper alloys can be brazed and soldered to themselves as well as to steels, stainless steels and nickel-base alloys. Even leaded copper alloys can usually be brazed, although brazing conditions must be carefully tailored to the alloy in question. Highly leaded alloys, in particular, require special care.

Copper-phosphorus alloys, silver-base brazing alloys (silver solders) and copper-zinc alloys are most often used as filler metals. Gold-base alloys are utilized in electronic applications. Lower strength joints, such as for household plumbing systems, are made with low-melting point tin-base solders.

The heat of brazing may cause some loss of strength in heat treated copper alloys. This can occur during furnace brazing, or for torch brazing, when high melting point filler metals are employed. Special techniques have been developed to avoid or remedy the problem should it arise.

Except in special situations, corrosion performance of the copper alloys themselves is not affected by brazing; however, the corrosion resistance of filler metals may be significantly different from the base metal in certain media, and this should be taken into account.

TABLE 7. Corrosion Resistance Ratings of Copper Casting Alloys in Various Media

Corrosive Medium	Coppers (C80100–C82800)	Tin Bronzes (C90200–C91700)	Leaded Tin Bronzes (C92200–C92900)	High-Leaded Tin Bronzes (C93100–C94500)	Leaded Red Brasses (C83300–C83810)	Leaded Semi-Red Brasses (C84200–C84800)	Leaded Yellow Brasses (85200–C85800)	Leaded High-Strength Yellow Brasses (C86400–C86700)	High-Strength Yellow Brasses (C86100–C86800)	Aluminum Bronzes (C95200–C95900)	Leaded Nickel Brasses (Nickel Silvers) (C97300–C97400)	Leaded Nickel Bronzes (C97600–C97800)	Silicon Bronze (C87300)	Silicon Brasses (C87400–C87800)
Acetate Solvents	B	A	A	A	A	A	B	A	A	A	A	A	A	B
Acetic Acid, 20 %	A	C	B	C	B	C	C	C	C	A	C	A	A	B
Acetic Acid, 50%	A	C	B	C	B	C	C	C	C	A	C	B	A	B
Acetic Acid, Glacial	A	A	A	C	A	C	C	C	C	A	B	B	A	A
Acetone	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Acetylene[*]	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Alcohols[†]	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Aluminum Chloride	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Aluminum Sulfate	B	B	B	B	B	C	C	C	C	A	C	C	A	A
Ammonia, Moist Gas	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ammonia, Moisture-Free	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ammonium Chloride	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ammonium Hydroxide	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ammonium Nitrate	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ammonium Sulfate	B	B	B	B	B	C	C	C	C	A	C	C	A	A
Aniline and Aniline Dyes	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Asphalt	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Barium Chloride	A	A	A	A	A	C	C	C	C	A	A	A	A	C
Barium Sulfide	C	C	C	C	C	C	C	C	B	C	C	C	C	C
Beer[†]	A	A	B	B	B	C	C	C	A	A	C	A	A	B
Beet Sugar Syrup	A	A	B	B	B	A	A	A	B	A	A	A	B	B
Benzine	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Benzol	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Boric Acid	A	A	A	A	A	A	A	B	A	A	A	A	A	A
Butane	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Calcium Bisulfite	A	A	B	B	B	C	C	C	C	A	B	A	A	B
Calcium Chloride (acid)	B	B	B	B	B	B	C	C	C	A	C	C	A	C
Calcium Chloride (alkaline)	C	C	C	C	C	C	C	C	C	A	C	A	C	B
Calcium Hydroxide	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Calcium Hypochlorite	C	C	B	B	B	C	C	C	C	B	C	C	C	C
Cane Sugar Syrups	A	A	B	A	B	A	A	A	A	A	A	A	A	B
Carbonated Beverages	A	C	C	C	C	C	C	C	C	A	C	C	A	C
Carbon Dioxide, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Carbon Dioxide, Moist[†]	B	B	B	C	B	C	C	C	C	A	C	A	A	B
Carbon Tetrachloride, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Carbon Tetrachloride, Moist	B	B	B	B	B	B	B	B	B	B	B	A	A	A
Chlorine, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Chlorine, Moist	C	C	B	B	B	C	C	C	C	C	C	C	C	C
Chromic Acid	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Citric Acid	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Copper Sulfate	B	A	A	A	A	C	C	C	C	B	B	B	A	A
Cottonseed Oil[†]	A	A	A	A	A	A	A	A	A	A	A	A	A	A

A = Recommended B = Acceptable C = Not Recommended

[*] Acetylene forms an explosive compound with copper when moist or when certain impurities are present and the gas is under pressure. Alloys containing less than 65% Cu are satisfactory under this use. When gas is not under pressure other copper alloys are satisfactory.

[†] Copper and copper alloys resist corrosion by most food products. Traces may be dissolved and affect taste or color. In such cases, copper metals are often tin coated.

TABLE 7. Corrosion Resistance Ratings of Copper Casting Alloys in Various Media \continued

Corrosive Medium	Coppers (C80100–C82800)	Tin Bronzes (C90200–C91700)	Leaded Tin Bronzes (C92200–C92900)	High-Leaded Tin Bronzes (C93100–C94500)	Leaded Red Brasses (C83300–C83810)	Leaded Semi-Red Brasses (C84200–C84800)	Leaded Yellow Brasses (85200–C85800)	Leaded High-Strength Yellow Brasses (C86400–C86700)	High-Strength Yellow Brasses (C86100–C86800)	Aluminum Bronzes (C95200–C95900)	Leaded Nickel Brasses (Nickel Silvers) (C97300–C97400)	Leaded Nickel Bronzes (C97600–C97800)	Silicon Bronze (C87300)	Silicon Brasses (C87400–C87800)
Creosote	B	B	B	B	B	C	C	C	C	A	B	B	B	B
Ethers	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ethylene Glycol	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ferric Chloride, Sulfate	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ferrous Chloride, Sulfate	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Formaldehyde	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Formic Acid	A	A	A	A	A	B	B	B	B	A	B	B	B	C
Freon	A	A	A	A	A	A	A	A	A	A	A	A	A	B
Fuel Oil	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Furfural	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Gasoline	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Gelatin†	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Glucose	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Glue	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Glycerine	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrochloric or Muriatic Acid	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Hydrofluoric Acid	B	B	B	B	B	B	B	B	B	A	B	B	B	B
Hydrofluosilicic Acid	B	B	B	B	B	C	C	C	C	B	C	C	B	C
Hydrogen	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrogen Peroxide	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Hydrogen Sulfide, Dry	C	C	C	C	C	C	C	C	C	B	C	C	B	C
Hydrogen Sulfide, Moist	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Lacquers	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lacquer Thinners	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lactic Acid	A	A	A	A	A	C	C	C	C	A	C	C	A	C
Linseed Oil	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Liquor, Black	B	B	B	B	B	C	C	C	C	B	C	C	B	B
Liquor, Green	C	C	C	C	C	C	C	C	C	B	C	C	C	B
Liquor, White	C	C	C	C	C	C	C	C	C	A	C	C	C	B
Magnesium Chloride	A	A	A	A	A	C	C	C	C	A	C	C	A	B
Magnesium Hydroxide	B	B	B	B	B	B	B	B	B	A	B	B	B	B
Magnesium Sulfate	A	A	A	A	B	C	C	C	C	A	C	B	A	B
Mercury, Mercury Salts	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Milk†	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Molasses†	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Natural Gas	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Nickel Chloride	A	A	A	A	A	C	C	C	C	B	C	C	A	C
Nickel Sulfate	A	A	A	A	A	C	C	C	C	A	C	C	A	C
Nitric Acid	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Oleic Acid	A	A	B	B	B	C	C	C	C	A	C	A	A	B
Oxalic Acid	A	A	B	B	B	C	C	C	C	A	C	A	A	B
Phosphoric Acid	A	A	A	A	A	C	C	C	C	A	C	A	A	A
Picric Acid	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Potassium Chloride	A	A	A	A	A	C	C	C	C	A	C	C	A	C
Potassium Cyanide	C	C	C	C	C	C	C	C	C	C	C	C	C	C

A = Recommended B = Acceptable C = Not Recommended

†Copper and copper alloys resist corrosion by most food products. Traces may be dissolved and affect taste or color. In such cases, copper metals are often tin coated.

TABLE 7. Corrosion Resistance Ratings of Copper Casting Alloys in Various Media \continued

Corrosive Medium	Coppers (C80100–C82800)	Tin Bronzes (C90200–C91700)	Leaded Tin Bronzes (C92200–C92900)	High-Leaded Tin Bronzes (C93100–C94500)	Leaded Red Brasses (C83300–C83810)	Leaded Semi-Red Brasses (C84200–C84800)	Leaded Yellow Brasses (85200–C85800)	Leaded High-Strength Yellow Brasses (C86400–C86700)	High-Strength Yellow Brasses (C86100–C86800)	Aluminum Bronzes (C95200–C95900)	Leaded Nickel Brasses (Nickel Silvers) (C97300–C97400)	Leaded Nickel Bronzes (C97600–C97800)	Silicon Bronze (C87300)	Silicon Brasses (C87400–C87800)
Potassium Hydroxide	C	C	C	C	C	C	C	C	C	A	C	C	C	C
Potassium Sulfate	A	A	A	A	A	C	C	C	C	A	C	C	A	C
Propane Gas	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sea Water	A	A	A	A	A	C	C	C	C	A	C	C	B	B
Soap Solutions	A	A	A	A	B	C	C	C	C	A	C	C	A	C
Sodium Bicarbonate	A	A	A	A	A	A	A	A	A	A	A	A	A	B
Sodium Bisulfate	C	C	C	C	C	C	C	C	C	A	C	C	C	C
Sodium Carbonate	C	A	A	A	A	C	C	C	C	A	C	C	C	A
Sodium Chloride	A	A	A	A	A	B	C	C	C	A	C	C	A	C
Sodium Cyanide	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Sodium Hydroxide	C	C	C	C	C	C	C	C	C	A	C	C	C	C
Sodium Hypochlorite	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Sodium Nitrate	B	B	B	B	B	B	B	B	B	A	B	B	A	A
Sodium Peroxide	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Sodium Phosphate	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sodium Sulfate, Silicate	A	A	B	B	B	B	C	C	C	A	C	C	A	B
Sodium Sulfite, Thiosulfate	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Stearic Acid	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sulfur, Solid	C	C	C	C	C	C	C	C	C	A	C	C	C	C
Sulfur Chloride	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Sulfur Dioxide, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sulfur Dioxide, Moist	A	A	A	B	B	C	C	C	C	A	C	C	A	B
Sulfur Trioxide, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sulfuric Acid, 78% or less	B	B	B	B	B	C	C	C	C	A	C	C	B	B
Sulfuric Acid, 78% to 90%	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Sulfuric Acid, 90% to 95%	C	C	C	C	C	C	C	C	C	B	C	C	C	C
Sulfuric Acid, Fuming	C	C	C	C	C	C	C	C	C	A	C	C	C	C
Tannic Acid	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Tartaric Acid	B	A	A	A	A	A	A	A	A	A	A	A	A	A
Toluene	B	B	A	A	A	B	B	B	B	B	B	B	B	A
Trichlorethylene, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Trichlorethylene, Moist	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Turpentine	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Varnish	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Vinegar	A	A	B	B	B	C	C	C	C	B	C	C	A	B
Water, Acid Mine	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Water, Condensate	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Water, Potable	A	A	A	A	A	A	B	B	B	A	A	A	A	A
Whiskey†	A	A	C	C	C	C	C	C	C	A	C	C	A	C
Zinc Chloride	C	C	C	C	C	C	C	C	C	B	C	C	B	C
Zinc Sulfate	A	A	A	A	A	C	C	C	C	B	C	A	A	C

A = Recommended B = Acceptable C = Not Recommended

†Copper and copper alloys resist corrosion by most food products. Traces may be dissolved and affect taste or color. In such cases, copper metals are often tin coated.

TABLE 8. Copper Casting Alloys Ranked by Typical Tensile Strength

UNS Number	Casting Process	Temper, (SAE Suffix)[1]	Tensile Strength	
			ksi	MPa
C82600 C82800	S	TF00	165	1,138
C82500	S	TF00	160	1,103
C82400	S	TF00	155	1,068
C82800	S	011	125	862
C82500 C82600	S	011	120	827
C95500	S, CL	TQ50 (SAE -C)	120	827
C96600	S	TF00	120	827
C86300	S	M01	119	821
C95400	S, CL	TQ50 (SAE -C)	105	724
C95410	S	TQ50	105	724
C82400	S	011	100	690
C95500	S, CL	M01, M02 (SAE -A)	100	690
C82000	S	TF00	96	662
C82200	S	TF00	95	655
C86100	S	M01	95	655
C86200	S, CL, C	M01, M02, M07	95	655
C95700 C99300	S	M01	95	655
C95800	S, CL	M01, M02 (SAE -A)	95	655
C99500	S	TF00	86	593
C86700 C95410	S	M01	85	586
C87800	D	M04	85	586
C94700	S, C	TX00 (SAE -B)	85	586
C95300	S, CL, C	TQ50 (SAE -C)	85	586
C95400	S, CL	M01, M02 (SAE -A)	85	586
C86800	S	M01	82	565
C82600 C82800	S	M01	80	552
C82800	S	TB00	80	552
C95200	S, CL	M01, M02 (SAE -A)	80	552
C99400	S	TF00	79	545
C82500 C95600	S	M01	75	517
C95300	S, CL	M01, M02 (SAE -A)	75	517
C96600	S	TB00	75	517
C99750	S	TQ50	75	517
C86500	S, CL	M01, M02 (SAE -A)	71	490
C82600	S	TB00	70	483
C96400	S	M01	68	469
C87500	S, CL	M01, M02	67	462
C87600 C99400	S	M01	66	455
C82000 C82200	S	011	65	448
C86400 C99750	S	M01	65	448
C99700	D	M04	65	448
C82400 C82500	S	TB00	60	414
C85500	S	M01	60	414
C91600 C91700	CL, PM	M02, M05	60	414
C94800	S	TX00	60	414
C85800	D	M04	55	379
C87300 C87400	S, CL	M01, M02	55	379
C90700	CL, PM	M02, M05	55	379
C97800 C99700	S	M01	55	379
C81400	S	TF00	53	365
C81500	S	TF00	51	352
C82000 C82200	S	M01	50	345
C85700	S, CL	M01, M02	50	345
C94700	S, C	M01, M07 (SAE -A)	50	34
C82000	S	TB00	47	324
C92900	S, PM, C	M01, M05, M07	47	324
C82200	S	TB00	45	310
C90300	S, CL	M01, M02	45	310
C90500	S, CL	M01, M02 (SAE -A)	45	310
C94800	S, C	M01, M07	45	310
C97600	S	M01	45	310
C90700 C92500	S	M01 (SAE -A)	44	303
C91600 C91700 C92600	S	M01	44	303
C92700	S	M01 (SAE -A)	42	290
C90900 C92800	S	M01	40	276
C92200 C92300	S, CL	M01, M02 (SAE -A)	40	276
C85200	S, CL	M01, M02	38	262

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand	C = Continuous	CL = Centrifugal
Die = Die	I = Investment	P = Plaster
	PM = Permanent Mold	

TABLE 8. Copper Casting Alloys Ranked by Typical Tensile Strength \continued

UNS Number	Casting Process	Temper, (SAE Suffix)[1]	Tensile Strength ksi	Tensile Strength MPa
C90200 C97400	S	M01	38	262
C83600	S, CL	M01, M02 (SAE -A)	37	255
C84800	S	M01	37	255
C83400 C84200 C84500 C91100 C91300 C97300	S	M01	35	241
C83800 C93200 C93700	S, CL	M01, M02 (SAE -A)	35	241
C84400	S	M01	34	234
C85400	S, CL	M01, M02	34	234
C93800	CL	M02 (SAE -A)	33	228
C83300 C91000 C93400	S	M01	32	221
C93500	S, CL	M01, M02 (SAE -A)	32	221
C93900	C	M07	32	221
C94400	S	M01	32	221
C81400	S	M01	30	207
C93800	S, CL	M01, M02	30	207
C94300	S	M01	27	186
C80100 C81100 C94500	S	M01	25	172

[1] SAE Suffix

For alloys listed under SAE J462, suffix symbols may be specified to distinguish between two or more sets of mechanical properties, heat treatment, conditions, etc., as applicable.

Most commonly used method of casting is shown for each alloy. However, unless the purchaser specifies the method of casting or the mechanical properties by supplement to the UNS Number, the supplier may use any method which will develop the properties indicated. These suffixes are shown in the shaded areas below the temper designations.

See Society of Automotive Engineers Inc., *SAE Handbook, Vol. 1, Materials,* Warrendale, PA, 1989.

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

Legend: Casting Processes

S = Sand
Die = Die
C = Continuous
I = Investment
CL = Centrifugal
P = Plaster
PM = Permanent Mold

TABLE 9. Copper Casting Alloys Ranked by Typical Yield Strength

Offset Strain as Indicated

UNS Number	Temper	Yield Strength ksi	Yield Strength MPa
0.2% Offset			
C82600 C82800	TF00	155	1,069
C82500	TF00	150	1,034
C82400	TF00	145	1,000
C82800	011	110	758
C82500 C82600	011	105	724
C82400	011	80	551
C82000 C82200	TF00	75	517
C86300	M01	67	462
C82600 C82800 C86100 C87800	M01	50	345
C86200	M01	48	331
C82200	011	40	276
C82500	M01	40	276
C99750	TF00	40	276
C82000	011	37	255
C81400	TF00	36	248
C82800	TB00	35	241
C82600	TB00	30	207
C85800	M04	30	207
C86500	M01	28	193
C82500	TB00	25	172
C82200 C86400	M01	25	172
C82000	M01	20	138
C82400	TB00	20	138
C93700	M01	16	110
C82000	TB00	15	103
C81400	M01	12	83
C82200	TB00	12	83
0.5% Extension			
C96600	TF00	75	517
C95500	TQ50	68	469
C99500	TF00	62	427
C94700	TX00	60	414
C99300	M01	55	379
C95400 C95410	TQ50	54	372
C99400	TF00	54	372
C95700	M01	45	310
C95500	M01	44	303
C86700	M01	42	290
C95300	TQ50	42	290
C81500	TF00	40	276
C99750	TQ50	40	276
C86800 C95800	M01	38	262
C96600	TB00	38	262
C96400	M01	37	255
C95400 C95410	M01	35	241
C95600 C99400	M01	34	234
C87600 C99750	M01	32	221
C91600 C91700	M02, M05	32	221
C95400	M07	32	221
C87500 C91300 C92800 C97800	M01	30	207
C90700	M02, M05	30	207
C94800	TX00	30	207
C86500	M01	29	200
C95200 C95300	M01	27	186
C99700	M04	27	186
C92900	M01	26	179
C87300 C91000 C91100 C99700	M01	25	172
C87400 C97600	M01	24	165
C85500 C94700 C94800	M01	23	159
C90500 C90700 C91600 C91700	M01	22	152
C93900	M07	22	152
C90300 C92700	M01	21	145

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 9. Copper Casting Alloys Ranked by Typical Yield Strength \continued

Offset Strain as Indicated

UNS Number	Temper	Yield Strength ksi	Yield Strength MPa
C90900 C92200 C92300 C92500 C92600	M01	20	138
C93800	M02	20	138
C85700 C93200 C93700	M01	18	124
C83600 C97300 C97400	M01	17	117
C83800 C90200 C93400 C93500 C93800 C94400	M01	16	110
C84400	M01	15	103
C84200 C84500 C84800	M01	14	97
C85200 C94300	M01	13	90
C85400 C94500	M01	12	83
C83300 C83400	M01	10	69
C80100 C81100	M01	9	62

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 10. Copper Casting Alloys Ranked by Compressive Strength*

UNS Number	Temper	Compressive Strength ksi	Compressive Strength MPa
0.1% Set			
C86300	M01	60	414
C86100 C86200	M01	50	345
C95300	TQ50	35	241
C99750	M01	28	193
C87500 C95200	M01	27	186
C86500	M01	24	166
C86400	M01	22	152
C95300	M01	20	138
C93800	M02	19	131
C87300	M01	18	124
C92200	M01	15	103
C83600	M01	14	97
C84500 C90300 C93500 C93700	M01	13	90
C83800 C92600 C93800	M01	12	83
C94300	M01	11	76
C92300	M01	10	69
C85200 C85400	M01	9	62
1% Set			
C90500	M01	40	276
C99750	M01	38	262
C97600	M01	30	207
C86300	M01	30	241
C95300	TQ50	35	241
C92200 C95300	M01	20	138
C84500	M01	16	110
10% Set			
C95500	TQ50	150	1,034
C95700	M01	150	1,034
C95400 C95410	TQ50	120	827
C95500	M01	120	827
C95400 C95410 C95800	M01	100	690
C86300	M01	97	669
C95300	TQ50	90	621
C86400	M01	87	600
C95300	M01	83	572
C86500	M01	79	545
C87500	M01	75	517
C99750	M01	72	496
C95200	M01	70	483
C87300 C87600	M01	60	414
C97600	M01	57	393
C92900	M01	50	345
C93400	M01	48	331
C93700	M01	47	324
C93200	M01	46	317
C94400	M01	44	303
C92600	M01	40	276
C83600 C92200 C93800	M01	38	262
C96200	M01	37	255
C94500	M01	36	248
C92300	M01	35	241
C84500 C84800	M01	34	234
C85200	M01	30	207
C83800	M01	29	200
C85400	M01	28	193
C94300	M01	23	159

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

* **Stress required to produce the indicated percent permanent engineering strain (Set) in a 0.125-in (3.2-mm) thick compression specimen.**

TABLE 11. Impact Properties of Copper Casting Alloys at Various Temperatures*

UNS Number	Temperature	Charpy V-Notch Impact Strength
	° F	ft-lbs
	° C	J
C83600	-305	11
	-188	15
	-100	13
	-74	18
	68	19
	20	26
	392	15
	200	20
	572	13
	300	18
C86500	-305	12
	-188	16
	-100	19
	-74	26
	68	19
	20	26
	212	18
	100	24
C92200	-320	13
	-196	18
	-108	14
	-78	19
	68	19
	20	26
	212	14
	100	19
	392	13
	200	18
	572	12
	300	16
C95200	-320	25
	-188	34
	68	30
	20	41
	212	33
	100	45
C95500	-305	12
	-188	16
	-200	16
	-130	22
	-78	18
	-60	24
	68	18
	20	24
	392	28
	200	38
	572	26
	300	35
C95700	-290	10
	-180	14
	-148	16
	-100	22
	-58	23
	-50	31
	68	32
	20	41

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

* Alloy designations represent UNS compositions closest to British cast alloys listed under BS1400, to which these data apply.

TABLE 12. Creep Strengths of Selected Sand-Cast Copper Alloys*

UNS Number	Test Temperature							
	ksi at 250 F MPa at 121 C	ksi at 350 F MPa at 177 C	ksi at 450 F MPa at 232 C	ksi at 500 F MPa at 260 C	ksi at 550 F MPa at 288 C	ksi at 600 F MPa at 316 C	ksi at 700 F MPa at 371 C	ksi at 800 F MPa at 427 C
C95500	—	—	—	—	—	10.5	5.5	2.4
	—	—	—	—	—	72	38	17
C95400	—	—	—	—	—	7.4	4.4	2.9
	—	—	—	—	—	51	30	20
C95410	—	—	—	—	—	7.4	4.4	2.9
	—	—	—	—	—	51	30	20
C95700	—	—	—	20.4	—	4.2	2.3	—
	—	—	—	141	—	29	16	—
C97600	—	—	32.5	—	22.2	—	—	—
	—	—	224	—	153	—	—	—
C87500	—	28.0	11.0	—	1.4	—	—	—
	—	193	76	—	10	—	—	—
C86300	56.5	19.0	0.5	—	—	—	—	—
	389	131	3.4	—	—	—	—	—
C92200	—	16.0	11.2	—	6.2	—	—	—
	—	110	77	—	4.3	—	—	—
C86500	28.0	6.2	—	1.7	—	—	—	—
	193	43	—	12	—	—	—	—
C83600	—	12.5	11.1	—	7.0	—	—	—
		86	77		48			
C92200	—	16.0	11.2	—	6.2	—	—	—
	—	110	77	—	43	—	—	—
C84800	—	11.9	8.0	—	3.0	—	—	—
	—	82	55	—	21	—	—	—
C93700	—	10.4	7.4	—	1.8	—	—	—
	—	72	51	—	12	—	—	—

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

*** Stress values are based on 0.1% creep in 10,000 hours at the temperatures indicated.**

TABLE 13. Stress-Rupture Properties of Selected Copper Casting Alloys*

UNS Number	Test Temperature ksi at 302 F MPa at 150C	ksi at 392 F MPa at 200 C	ksi at 482 F MPa at 250 C	ksi at 572 F MPa at 300 C	ksi at 662 F MPa at 350 C	ksi at 752 F MPa at 400 C
Cast Bars						
C95800[1]	—	14.8	25.2	16.8	11.2	6.8
	—	288	174	116	77	47
C83600[2]	22	15.9	10.1	—	—	—
	152	110	70	—	—	—
Cast Plate						
C95800[1]	—	—	41.6	24.1	—	—
	—	—		287	166	—
C90500[3]	—	—	9.4	5.7	—	—
	—	—	65	40	—	—
C83600[2]	—	14.2	9.0	—	—	—
	—	98	62	—	—	—

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

* Stress required to produce rupture in 10,000 hours at the temperatures indicated.

[1] Data based on British Standard BS1400, Grade AB2, similar to C95800.

[2] Data based on British Standard BS1400, Grade LG2, similar to C83600.

[3] Data based on British Standard BS1400, Grade G1, similar to C90500.

TABLE 14. Common Bronze Bearing Alloys

UNS Number	SAE No. (Former SAE No.)	Properties, Applications
Copper Tin Alloys (Tin Bronzes)		
C90300	CA903 (620)	Good general purpose bearings with favorable combination of strength, machinability, castability, pressure tightness, corrosion resistance. Tin bronzes operate better with grease lubrication than other bearing bronzes. Widely used in water pump fittings, valve bodies and general plumbing hardware.
C90500	CA905 (62)	
C90700	CA907 (65)	
Copper-Tin-Lead Alloys (Leaded Tin Bronzes)		
C92200	CA922 (622)	Moderate-to-high strength alloys. Lead content provides good machinability but is insufficient to act as "internal lubricant" should normal lubricant be unreliable. Bearings also require good shaft alignment and shaft hardness between 300–400 HB.
C92300	CA923	
C92700	CA927 (63)	
Copper-Tin-Lead Alloys (High-Leaded Tin Bronzes)		
C93200	CA932 (660)	Good bearing properties, excellent casting and machining characteristics. Higher in strength than copper-lead alloys, although they have somewhat lower strength and fatigue resistance than unleaded tin bronzes. C93200 is often considered the "standard" bearing bronze. C93800 is used for general service at moderate loads and high speeds; C94300 is used at lighter loads and high speeds. These alloys conform well to irregularities in the journal. Applications include light duty machinery, home appliances, farm machinery, pumps and thrust washers.
C93400		
C93500	CA935 (66)	
C93600	—	
C93700	CA937 (64)	
C93800	CA938 (67)	
C94100	—	
C94300	CA943	
Manganese Bronze and Leaded Manganese Bronze Alloys (High Strength and Leaded High Strength Yellow Brasses)		
C86300	CA863 (430B)	Alloys exhibit good corrosion resistance; however, they require reliable lubrication and hardened, well-aligned shafts. C83600 is twice as strong as C86400 and is used in applications characterized by high loads and slow speeds. C86400 is better suited to light duty applications.
C86400	—	
Copper-Aluminum Alloys (Aluminum Bronzes)		
C95300	CA953 (68B)	High strength, very corrosion and wear resistant. Widely used in heavy duty applications or where shock loading is a factor. Useful to temperatures higher than 500 F (260 C). Not suitable for high speeds or applications where lubrication is intermittent or unreliable. Alloys C95300, C95400 and C95500 can be heat treated to improve their mechanical properties, as required, for severe applications.
C95400	C954	
C95500	C955	
C95520	—	
C95800	C958	
Copper-Silicon Alloys (Silicon Bronzes and Silicon Brasses)		
C87600	—	Alloys have moderately high strength, good wear resistance and good aqueous corrosion resistance. These alloys are not so widely used for bearings as other bronzes. C87900 can be die cast.
Copper-Beryllium Alloys (Beryllium Copper)		
C82800	—	C82800 is the strongest of all copper casting alloys. It has good corrosion resistance and high thermal conductivity; however, it requires reliable lubrication and hardened, well-aligned shafts. The alloy's use in bearings is limited to those applications where its superior mechanical and thermal properties can justify its relatively high cost.
Copper-Lead Alloys (Leaded Coppers)		
C98200	49	Alloys have fair strength, fair wear resistance and low pounding resistance, but have very favorable antifriction properties and good conformability. They operate well under intermittent, unreliable or dirty lubrication, and can operate under water or with water lubrication. Used at light-to-moderate loads and high speeds, as in rod bushings and main bearings for refrigeration compressors, and as hydraulic pump bushings. Usually require reinforcement.
C98400	—	
C98600	480	
C98800	481	
C98820	484	
C98840	485	

TABLE 15. Fatigue Properties[1] of Selected Copper Casting Alloys

UNS Number	Temper	Fatigue Strength ksi MPa	Endurance Ratio
C80100 **C81100**	M01	9 62	0.360
C81500	TF00	15 103	0.294
C82000	TF00	18[2] 124	0.188[2]
C82400	TF00	23[2] 160	0.148[2]
C82500	TF00	24[2] 165	0.150[2]
C83600	M01	11 76	0.297
C86300	M01	25 172	0.210
C86500	M01	20 138	0.296
C90200	M01	25 172	0.658
C90500	M01	13 90	0.289
C90700	M01	25 172	0.568
C92200	M01	11 76	0.275
C93200	M01	16 110	0.457
C93400	M01	15 103	0.469
C93700	M01	13 90	0.375
C93800	M01	10 69	0.333
C94400	M01	11 76	0.344
C94500	M01	10 69	0.400
C94700	M01	14 97	0.280
C94700	TF00	14 97	0.165
C94800	M01	12 83	0.267
C94800	TX00	12 83	0.200
C95300	M01	22 152	0.293
C95300	TQ50	27 186	0.318
C95400	M01	28 193	0.329
C95500	M01	31 214	0.310
C96200	M01	13 90	0.289
C95200	M01	22 152	0.275
C95400	TQ50	35 241	0.333
C95500	TQ50	38 262	0.317
C95700	M01	33 228	0.347
C95800	M01	31 214	0.326
C96400	M01	18 124	0.265
C97600	M01	16 110	0.356
C99750	M01	19 131	0.292

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

[1] **Measured at 10^8 cycles or as indicated.**

[2] **Measured at 5 x 10^7 cycles**

TABLE 16. Copper Casting Alloys Ranked by Electrical Conductivity

UNS Number	Electrical Conductivity % IACS at 68 F	Megmho per cm at 20 C
C80100	100	0.580
C81100	92	0.534
C81500	82	0.476
C81400	60	0.348
C82200	45	0.261
C82000	45	0.260
C83400	44	0.256
C83300	32	0.186
C85500	26	0.151
C82400	25	0.144
C85700 C86500	22	0.128
C82500 C85800	20	0.116
C82700	20	0.115
C85400	20	0.113
C86400	19	0.111
C82600	19	0.110
C82800 C85200	18	0.104
C86700	17	0.097
C84500	16	0.096
C84200 C84400 C84800	16	0.095
C93500	15	0.088
C83600 C83800	15	0.087
C92200	14	0.083
C90200 C95300 C95400 C95410	13	0.075
C92300 C93200 C93400 C94800 C99400	12	0.070
C90300	12	0.069
C90500 C92700	11	0.064
C93800 C93900	11	0.066
C95200 C96200	11	0.064
C93700	10	0.059
C91600 C91700 C94400 C94500 C99400	10	0.058
C99500	10	0.057
C90700	10	0.056
C91000	9	0.054
C92900 C94300	9	0.053
C86800 C92600 C99300	9	0.052
C91100 C95500 C95600	8	0.049
C86100 C86200	8	0.044
C86300	8	0.046
C95800	7	0.041
C91300	7	0.040
C87400 C87500 C87800	7	0.039
C96300	6	0.036
C87300 C87600	6	0.035
C97300	6	0.033
C97400	6	0.032
C97600	5	0.029
C96400	5	0.028
C97800	4	0.026
C96600	4	0.025
C95700	3	0.018
C99700	3	0.017
C99750	2	0.012

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 17. Copper Casting Alloys Ranked by Thermal Conductivity

UNS Number	Thermal Conductivity Btu/ft²/ft/h/°F at 68 F	W/m • °K at 293 K
C80100	226	391
C81100	200	346
C81500	182	315
C81400 C82000	150	259
C83400	109	188
C82200	106	183
C82400	76.9	133
C82500 C82700	74.9	130
C82600	73.0	126
C82800	70.8	123
C85500	67.0	116
C86400	51.0	88.3
C85400	50.8	87.9
C86500	49.6	85.3
C85200 C85700 C85800	48.5	83.9
C90300 C90500 C92300	43.2	74.8
C83800 C84200 C84400	41.8	72.4
C83600 C84500 C84800	41.6	72.0
C90700 C91600 C91700	40.8	70.6
C93500	40.7	70.4
C92200	40.2	69.6
C95300	36.3	62.8
C94300	36.2	62.7
C90200	36.0	62.3
C95400 C95410	33.9	58.7
C92900 C93200 C93400	33.6	58.2
C94700	31.2	54.0
C93800 C93900 C94400 C94500	30.2	52.3
C95200	29.1	50.4
C92700	27.2	47.0
C93700	27.1	46.9
C96200	26.1	45.2
C99300	25.4	43.9
C95500	24.2	41.9
C94800 C95600	22.3	38.6
C96300	21.3	36.8
C95800	20.8	36.0
C86100 C86200 C86300	20.5	35.5
C96600	17.4	30.1
C97300	16.5	28.6
C96400	16.4	28.5
C87300 C87600	16.4	28.4
C87400 C87500 C87800	16.0	27.7
C97400	15.8	27.3
C97800	14.7	25.4
C97600	13.0	31.4
C95700	7.0	12.1

Unshaded areas = standard U.S. units
Shaded areas = metric units (SI)

TABLE 18. Copper Casting Alloys Ranked by Machinability Rating

UNS Number	Machinability Rating
C36000[1]	100
C83800	90
C84400	
C84500	
C84800	
C83600	84
C84200	80
C85200	
C85400	
C85500	
C85700	
C85800	
C93700	
C93800	
C93900	
C94300	
C94400	
C94500	
C99700	
C99750	
C92800	70
C93200	
C93400	
C93500	
C97300	
C97600	
C86400	65
C83400	60
C95400	
C95410	
C95600	
C97400	
C97800	
C86700	55
C95300	
C87400	50
C87500	
C94800[2]	
C95500	
C95700	
C99400	
C99500	
2011-T3 (Al)[1]	
C92700	45
C92200	42
C92300	
C87300	40
C87600	
C87800	
C92600	
C92900	
C94800[3]	
C83300	35
C81700	30
C82000	
C82200	
C82400	
C82500	
C82600	
C82700	
C82800	
C85300	
C86100	
C86200	
C86800	
C90300	
C90500	
C92500	
C94700[2]	
C86500	26
12L14 (Steel)[1]	21
C81300	20
C81400	
C81500	
C81800	
C90200	
C90700	
C90900	
C91000	
C91600	
C91700	
C94700[3]	
C95200	
C95800	
C96400	
C96600	
C99300	
C96300	15
C80100	10
C81100	
C91100	
C91300	
C96200	
C86800	8
C86300	

[1] Shaded areas identify wrought products included for comparison.
[2] M01 Temper
[3] TF00 Temper

TABLE 19. Joining Characteristics of Selected Copper Casting Alloys

UNS Number	Solder	Braze	OAW	CAW	GMAW	GTAW/ SMAW
C80100	A	A	D	C	C	D
C81100	A	A	D	C	C	D
C81300	A	B	D	C	C	C
C81400	A	B	D	C	C	C
C81500	B	B	D	C	C	D
C82000	B	B	D	C	C	C
C82200	B	B	D	C	C	C
C82400	C	C	D	C	C	C
C82500	C	C	D	C	C	C
C82600	C	C	D	C	C	C
C82700	C	C	D	C	C	C
C82800	C	C	D	C	C	C
C83300	A	B	D	D	C	D
C83400	A	A	C	D	C	D
C83600	A	B	D	D	D	C
C83800	A	B	D	D	D	C
C84200	A	B	D	D	D	C
C84400	A	B	D	D	D	C
C84500	A	B	D	D	D	C
C84800	A	B	D	D	D	C
C85200	A	C	C	D	D	D
C85400	A	A	C	D	D	D
C85500	B	C	D	D	D	D
C85700	B	C	D	D	D	D
C85800	B	B	D	D	D	D
C86100	D	D	B	D	C	B
C86200	D	D	B	D	C	B
C86300	D	D	D	D	D	B
C86400	C	C	D	D	D	D
C86500	C	C	D	D	D	D
C86700	C	C	D	D	D	D
C86800	C	C	D	D	D	D
C87400	D	C	C	D	C	D
C87500	D	C	C	D	C	D
C87600	D	C	B	D	C	C
C87800	D	C	D	D	D	D
C90200	A	B	C	C	C	C
C90300	A	B	C	C	C	C
C90500	A	B	C	C	C	C
C90700	A	B	C	C	C	C
C90900	A	B	C	C	C	C
C91000	A	B	C	C	C	C
C91100	A	B	C	C	C	C
C91300	A	B	C	C	C	C

A = Excellent B = Good C = Fair D = Not Recommended

OAW = Oxyacetylene Welding

CAW = Carbon Arc Welding

GTAW/GMAW = Gas Tungsten Arc/Gas Metal Arc Welding (TIG/MIG)

SMAW = Shielded Metal Arc Welding (Stick)

TABLE 19. Joining Characteristics of Selected Copper Casting Alloys \continued

UNS Number	Solder	Braze	OAW	CAW	GMAW	GTAW/ SMAW
C91600	A	B	C	C	C	C
C91700	A	B	C	C	C	C
C92200	A	A	D	D	D	D
C92300	A	B	D	D	D	D
C92500	A	B	D	D	D	D
C92600	A	B	D	D	D	D
C92700	A	B	D	D	D	D
C92800	A	B	D	D	D	D
C92900	A	B	D	D	D	D
C93200	A	B	D	D	D	D
C93400	B	B	D	D	D	D
C93500	B	B	D	D	D	D
C93700	B	B	D	D	D	D
C93800	B	D	D	D	D	D
C93900	B	D	D	D	D	D
C94300	B	D	D	D	D	D
C94400	B	B	D	D	D	D
C94500	B	D	D	D	D	D
C94700	A	A	C	D	B	B
C94800	A	B	D	D	D	D
C95200	B	B	D	C	A	B
C95300	B	B	D	C	A	B
C95400	B	B	D	C	A	B
C95500	B	C	D	D	B	B
C95600	B	B	D	C	B	C
C95700	B	B	D	B	A	B
C95800	B	C	D	D	B	B
C96200	A	A	D	D	D	C
C96300	A	A	D	D	C	C
C96400	A	A	D	D	B	B
C96600	A	A	B	C	C	C
C97300	A	A	D	D	D	D
C97400	A	A	D	D	D	D
C97600	A	A	D	D	D	D
C97800	A	A	D	D	D	D
C97300	D	B	D	D	B	B
C99700	B	B	B	—	—	—
C99750	B	B	D	D	C	D

A = Excellent B = Good C = Fair D = Not Recommended

OAW = Oxyacetylene Welding

CAW = Carbon Arc Welding

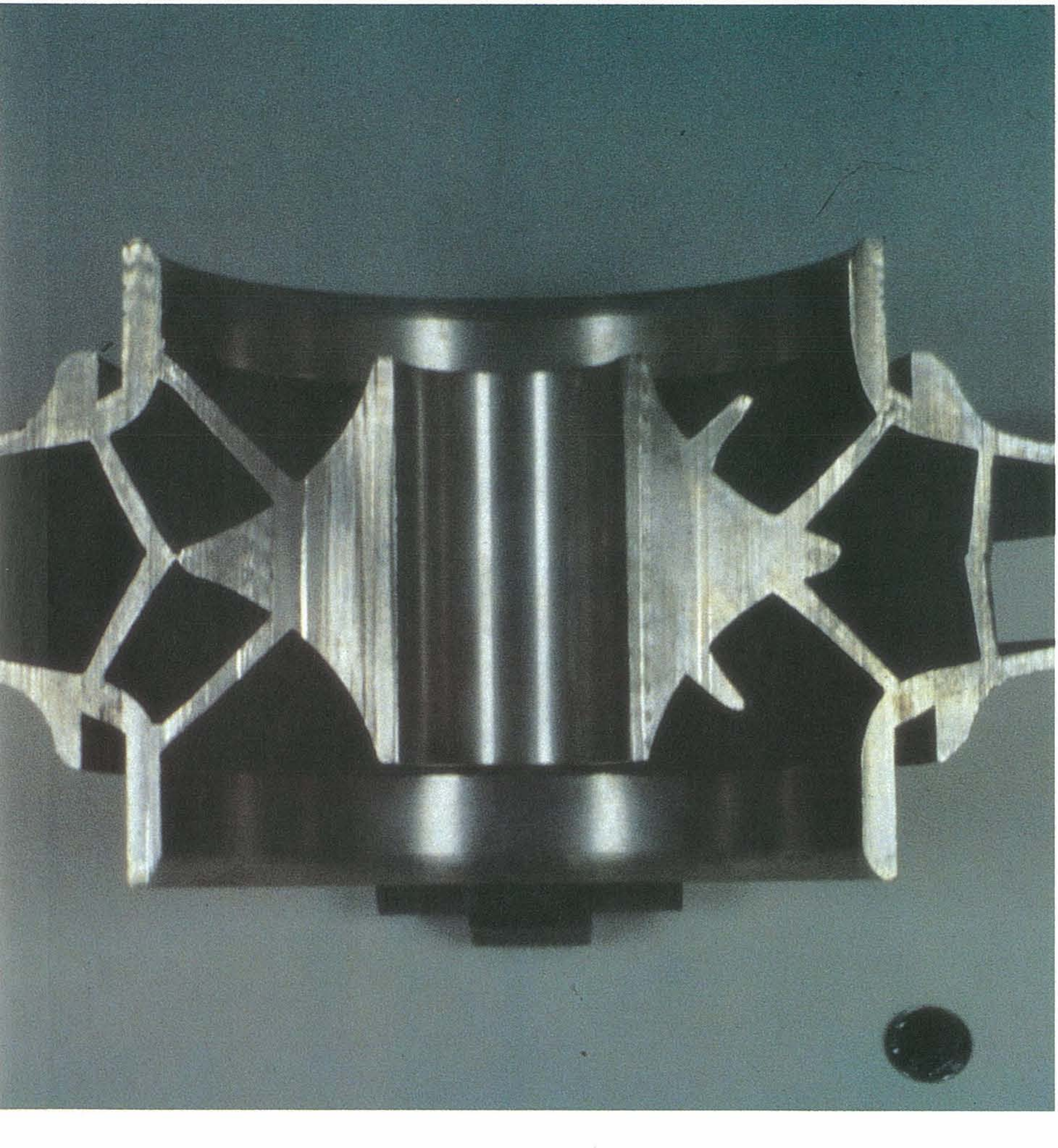
GTAW/GMAW = Gas Tungsten Arc/Gas Metal Arc Welding (TIG/MIG)

SMAW = Shielded Metal Arc Welding (Stick)

TABLE 20. Technical Factors in the Choice of Casting Method for Copper Alloys

Casting Method	Copper Alloys	Size Range	General Tolerances	Surface Finish	Minimum Section Thickness	Ordering Quantities	Relative Cost, (1 Low, 5 High)
Sand	All	All sizes, depends on foundry capability.	±1/32 in up to 3 in; ±3/64 in 3–6 in; add ±0.003 in/in above 6 in; add ±0.020 to ±0.060 in across parting line.	150-500 μin rms	1/8 –1/4 in	All	1–3
No-Bake	All	All sizes, but usually >10 lbs	Same as sand casting	Same as sand casting	Same as sand casting	All	1–3
Shell	All	Typical maximum mold area = 550 in^2 typical maximum thickness = 6 in	±0.005-0.010 in up to 3 in; add ±0.002 in/in above 3 in; add ±0.005 to 0.010 in across parting line.	125–200 μin rms	3/32 in	≥100	2–3
Permanent Mold	Coppers, high copper alloys, yellow brasses, high strength brasses, silicon bronze, high zinc silicon brass, most tin bronzes, aluminum bronzes, some nickel silvers.	Depends on foundry capability; best ≈ 50 lbs Best max. thickness ≈ 2 in	Usually ±0.010 in; optimum ±0.005 in, ±0.002 in part-to-part.	150–200 μin rms, best ≈70 μin rms	1/8 –1/4 in	100–1,000, depending on size.	2–3
Die	Limited to C85800, C86200, C86500, C87800, C87900, C99700, C99750 & some proprietary alloys.	Best for small, thin parts; max. area ≤ 3 ft^2.	±0.002 in/in; not less than 0.002 in on any one dimension; add ±0.010 in on dimensions affected by parting line.	32–90 μin rms	0.05–0.125 in	≥1,000	1
Plaster	Coppers, high copper alloys, silicon bronze, manganese bronze, aluminum bronze, yellow brass.	Up to 800 in^2, but can be larger.	One side of parting line, ±0.015 in up to 3 in; add ±0.002 in/in above 3 in; add 0.010 in across parting line, and allow for parting line shift of 0.015 in.	63–125 μin rms, best ≈ 32 μin rms	0.060 in	All	4
Investment	Almost all	Fraction of an ounce to 150 lbs, up to 48 in.	±0.003 in less than 1/4; ±0.004 in between 1/4 to 1/2 in; ±0.005 in/in between 1/2–3 in; add ±0.003 in/in above 3 in.	63–125 μin rms	0.030 in	>100	5
Centrifugal	Almost all	Ounce to 25,000 lbs. Depends on foundry capacity	Castings are usually rough machined by foundry.	Not applicable	1/4 in	All	1–3

Working with Copper Casting Alloys



VI. CASTING PROCESSES

Selecting the casting process is an important element in the design cycle, even though in some cases, it is a decision that can be left to the foundry. More often than not, the process to be used falls out logically from the product's size, shape and technical requirements. Among the more important factors that influence the choice of casting method are:

- The number of castings to be made;
- The size and/or weight of the casting;
- The shape and intricacy of the product;
- The amount and quality of finish machining needed;
- The required surface finish;
- The prescribed level of internal soundness (pressure tightness) and/or the type and level of inspection to be performed;
- The permissible variation in dimensional accuracy for a single part, and part-to-part consistency through the production run; and,
- The casting characteristics of the copper alloy specified.

Other considerations, such as code requirements, can also play a role in selecting the casting process, but it is primarily the number and size of castings required, along with the alloy chosen, that determine how a casting will be made.

That is not to say that the designer has little choice; in fact, quite the opposite can be true. For example, small parts made in moderate to large quantities frequently lend themselves to several processes, in which case factors such as surface finish, soundness or mechanical properties will bear strongly on the choice of method used. These parameters are set by the designer.

It is convenient to classify the casting processes as being applicable either to general shapes of more or less any form or to specific and usually rather simple shapes. In addition, several new special processes have been commercialized in recent years, one of which is described below.

Processes for General Shapes

Sand Casting. Sand casting currently accounts for about 75% of U.S. copper alloy foundry production. The process is relatively inexpensive, acceptably precise and above all, highly versatile. It can be utilized for castings ranging in size from a few ounces to many tons. Further, it can be applied to simple shapes as well as castings of considerable complexity, and it can be used with all of the copper casting alloys.

Sand casting imposes few restrictions on product shape. The only significant exceptions are the draft angles that are always needed on flat surfaces oriented perpendicular to the parting line. Dimensional control and consistency in sand castings ranges from about ± 0.030 to ± 0.125 in (± 0.8 to 3.2 mm). Within this range, the more generous tolerances apply across the parting line. Surface finish ranges between approximately 300 and 500 µin (7.7 - 12.9 µm) rms. With proper choice of molding sands and careful foundry practice, surprisingly intricate details can be reproduced. There are a number of variations on the sand casting process.

In *green sand casting*—still the most widely used process—molds are formed in unbaked (green) sand, which is most often silica, SiO_2, bonded with water and a small amount of a clay to develop the required strength. The clay minerals (montmorillonite, kaolinite) absorb water and form a natural bonding system that holds the sand particles together. Various sands and clays may be blended to suit particular casting situations.

The mold is made by ramming prepared sand around a *pattern*, held in a *flask*. The patterns are withdrawn, leaving the *mold cavity* into which metal will be poured. Molds are made in two halves, an upper portion, the *cope*, and a lower portion, the *drag*. The boundary between cope and drag is known as the *parting line*.

Cores, made from sand bonded with resins and baked to give sufficient strength, may be supported within the mold cavity to form the internal structure of hollow castings. *Chills* of various designs may be embedded in the mold cavity wall to control the solidification process.

Risers are reservoirs of molten metal used to ensure that all regions of the casting are adequately fed until solidification is complete. Risers also act as heat sources and thereby help promote directional solidification. Molten metal is introduced into the mold cavity through a *sprue* and distributed through a system of *gates* and *runners*. **Figure VI-1a**, page 98, shows the sequence of steps used to make a typical sand casting. Note how the gates, runners and risers are situated to ensure complete and even filling of the mold. A series of sand cast valves are illustrated in **Figure VI-1b**.

Bench molding operations are performed by hand. Quality and part-to-part consistency depend largely on the skill of the operator. The labor-intensive nature of bench molding usually restricts it to prototypes or short production runs. Patterns are another significant cost factor, especially if their cost cannot be amortized over a large number of castings. Still, bench molding remains the most economical method when only a few castings must be produced.

The *machine molding* method is automated and therefore faster than bench molding, but the casting process is essentially similar. Molding machines sling, ram, jolt or squeeze sand onto patterns, which in this case may consist of several parts arranged on a mold board. Dimensional control, surface finish and product consistency are better than those achievable with bench molding. Favorable costs can be realized from as few as several dozen castings. Machine-molded sand casting is therefore the most versatile process in terms of production volume.

Waterless molding aims to eliminate the sometimes detrimental effects of moisture in the molding sand. Clays are treated to react with oils rather than water to make them bond to the sand particles. The hot strength of the waterless-bonded sand is somewhat lower than that of conventional green sands. This reduces the force needed to displace the sand as the casting shrinks during solidification, which in turn reduces the potential for hot tearing. On the other hand, sands with low hot strength have a greater tendency to be damaged by hot metal flowing into the mold.[1]

For large castings, molds may be baked or partially dried to increase their strength. The surfaces of skin-dried molds are treated with organic binders, then dried by means of torches or heaters. To make dry sand molds, simple organic bonding agents such as molasses are dissolved in the bonding water when making up the green sand mixture. The entire mold is then baked to develop the desired hot strength. Besides hardening the mold, removing water also reduces the chance for blowholes and other moisture-related casting defects. Baking and skin drying are expensive operations and the dry sand methods are rapidly being replaced by a variety of *no-bake processes*, described below.

There are three general types of low-temperature-curing, chemical binders: *Cement* has traditionally been used as a bonding agent in the extremely large molds used to cast marine propellers and similar products. Cement - bonded molds are extremely strong and durable, but they must be designed carefully since their inability to yield under solidification shrinkage stresses may cause hot tearing in the casting.

Organic binders utilize resins that cure by reaction with acidic catalysts. Furan-, phenolic-, and urethane-base systems are the most popular of the large variety of currently available bonding agents. Of the *inorganic binders,* the well-known liquid sodium silicate-CO_2 process is most widely used for copper alloy castings.

No Bake (Air Set). In this process, silica sand is mixed with a resin that hardens when exposed to the atmosphere. The process requires no water. It can be used for molds as well as cores. It is applicable to products as small as 20 lb (9 kg), although it is mainly used for large castings weighing up to 20,000 lb (9,100 kg). The no-bake process has become very popular in the past 10 years.

Shell Molding. Resin-bonded sand systems are also used in the shell molding process, in which prepared sand is contacted with a heated metal pattern to form a thin, rigid shell, **Figure VI-2a**, page 99. As in sand casting, two mating halves of the mold are made to form the mold cavity. Common shell-molding binders include phenol-formaldehyde resins, furan or phenolic resins and baking oils similar to those used in cores. Non-baking resins (furans, phenolics, urethanes) are also available; these can claim lower energy costs because they do not require heated patterns.

The shell molding process is capable of producing quite precise castings and nearly rivals metal-mold and investment casting in its ability to reproduce fine details and maintain dimensional consistency, **Figure VI-2b.** Surface finish, at about 125 µin (3.2 µm) rms, is considerably better than that from green sand casting.

Shell molding is best suited to small-to-intermediate size castings. Relatively high pattern costs (pattern halves must be made from metal) favor long production runs. On the other hand, the fine surface finishes and good dimensional reproduceability can, in many instances, reduce the need for costly machining. While still practiced extensively, shell molding has declined somewhat in popularity, mostly because of its high energy costs compared with no-bake sand methods; however, shell-molded cores are still very widely used.

Plaster Molding. Copper alloys can also be cast in plaster molds to produce precision products of near-net shape. Plaster-molded castings are characterized by surface finishes as smooth as 32 µin rms and dimensional tolerances as close as ± 0.005 in (± 0.13 mm), and typically require only minimal finish machining. In some cases, rubber patterns can be used. These have the advantage of permitting re-entrant angles and zero-draft faces in the casting's design.

Gypsum plaster ($CaSO_4$) is normally mixed with refractory or fibrous compounds for strength and specific mechanical properties. The plaster must be made slightly porous to allow the escape of gases as the castings solidify. This can be achieved by *autoclaving* the plaster molds in steam, a technique known as the Antioch process. This produces very fine cast surfaces suitable for such precision products as tire molds, pump impellers, plaques and artwork. It is relatively costly.

Foaming agents produce similar effects at somewhat lower costs. Labor cost remains relatively high, however. Foamed plaster molds produce very fine surface finishes with good dimensional accuracy, but they are better suited to simple shapes.

Most plaster mold castings are now made using the Copaco process, which utilizes conventional wood or metal patterns and gypsum-fibrous mineral molding compounds. The process is readily adapted to automation; with low unit costs, it is the preferred plaster-mold method for long production runs. On the whole, however, plaster molding accounts for a very small fraction of the castings market.

Refractory Molds. Of the several refractory-mold-based methods, the Shaw process is probably the best known. Here, the wood or metal pattern halves are dipped into an aggregate slurry containing a methyl silicate binder, forming a shell. After stripping the pattern, the shell is fired at a high temperature to produce a strong refractory mold. Metal is introduced into the mold while it is still hot. This aids feeding but it also produces the relatively slow cooling rates and coarse-grained structures that are typical of the process.

Dimensional accuracy as good as ± 0.003 in (± 0.08 mm) is attainable in castings smaller than about one inch (25 mm), while tolerances as close as ± 0.045 in (±1.1 mm) are claimed in castings larger than 15 in (630 mm) in cross section. Additional allowances of about 0.010-0.020 in (0.25-0.5 mm) must be included across the parting line. Surface finishes are typically better than 80 µin (2 µm) rms in nonferrous castings.

Very fine surface finishes and excellent reproduction of detail are characteristic of the *investment* casting, or lost wax process. The process was practiced by several ancient cultures and has survived virtually without modification for the production of artwork, statuary and fine jewelry. Today, the process's most important commercial application is in the casting of complex, net shape precision industrial products such as impellers and gas turbine blades.

The process first requires the manufacture of an intricate metal die with a cavity in the shape of the finished product (or parts of it, if the product is to be assembled from several castings). Special wax, plastic or a low-melting alloy is cast into the die, then removed and carefully finished using heated tools. Clusters of wax patterns are dipped into a refractory/plaster slurry, which is allowed to harden as a shell or as a monolithic mold.

The mold is first heated to melt the wax (or volatilize the plastic), then fired at a high temperature to vitrify the refractory. Metal is introduced into the mold cavity and allowed to cool at a controlled rate. The sequence of steps involved in the investment method are illustrated in **Figure VI-3a**, page 100.

Investment casting is capable of maintaining very high dimensional accuracy in small castings, although tolerances increase somewhat with casting size. Dimensional consistency ranks about average among the casting methods; however, surface finishes can be as fine as 60 µin (1.5 µm) rms, and the process is unsurpassed in its ability to reproduce intricate detail.

Investment casting is better suited to castings under 100 lbs (45 kg) in weight. Because of its relatively high tooling costs and higher than average total costs, the process is normally reserved for relatively large production runs of precision products, and is not often applied to copper alloys.

Metal-Mold Processes. Reusable or metal-mold processes are used more extensively for copper alloys in Europe and England than in North America; however, they are gaining recognition here as equipment and technology become increasingly available. Permanent mold casting in North America is identified as gravity die casting or simply die casting in Europe and the U.K. The process called die casting in North America is known as pressure die casting abroad.

Permanent mold casting utilizes a metallic mold. The mold is constructed such that it can be opened along a conveniently located parting line. Hot metal is poured through a sprue to a system of gates arranged so as to provide even, low-turbulence flow to all parts of the cavity. Baked sand cores can be provided just as they would be with conventional sand castings. Chills are unnecessary since the metal mold provides very good heat transfer. The nature of the process necessitates adequate draft angles along planar surfaces oriented perpendicular to the parting line. Traces of the parting line may be visible in the finished casting and there may be some adherent flashing, but both are easily removed during finishing.

Permanent mold castings are characterized by good part-to-part dimensional consistency and very good surface finishes (about 70 µin, 1.8 µm). Any traces of metal flow lines on the casting surface are cosmetic rather than functional defects. Permanent mold castings exhibit good soundness. There may be some microshrinkage, but mechanical properties are favorably influenced by the castings' characteristically fine grain size. The ability to reproduce intricate detail is only moderate, however, and for products in which very high dimensional accuracy is required, plaster mold or investment processes should be considered instead.

Permanent mold casting is more suitable for simple shapes in mid-size castings than it is for very small or very large products. Die costs are relatively high, but the absence of molding costs makes the overall cost of the process quite favorable for medium to large production volumes. **Figures VI-4b** and **VI-4c**, page 101,shows typical permanent-mold castings.

Die casting involves the injection of liquid metal into a multipart die under high pressure. Pneumatically actuated dies make the process almost completely automated. Die casting is best known for its ability to produce high quality products at very low unit costs. Very high production rates offset the cost of the complex heat-resisting tooling required; and with low labor costs, overall casting costs are quite attractive.

The process can be used with several copper alloys, including yellow brass, C85800, manganese bronzes, C86200 and C86500, silicon brass, C87800, the special die casting alloys C99700 and C99750, plus a few proprietary compositions. These alloys can be die cast because they exhibit narrow freezing ranges and high beta phase contents. Rapid freezing is needed to complement the process's fast cycle times. Rapid freezing also avoids the hot shortness associated with prolonged mushy solidification. Beta phase contributes the hot ductility needed to avoid hot cracking as the casting shrinks in the unyielding metal mold.

Highly intricate copper alloy products can be made by die casting (investment casting is even better in this regard). Dimensional accuracy and part-to-part consistency are unsurpassed in both small (<1 in, 25 mm) and large castings. The attainable surface finish, often as good as 30 µin (0.76 µm) rms, is better than with any other casting process. Die casting is ideally suited to the mass production of small parts. The process is illustrated in **Figure VI-5a**, page 102.

Extremely rapid cooling rates (dies are normally water cooled) results in very fine grain sizes and good mechanical properties. Leaded alloys C85800 and C99750 can yield castings that are pressure tight, although lead is incorporated in these alloys more for its favorable effect on machinability than for its ability to seal porosity. **Figure VI-5b** shows a selection of die cast products.

Processes for Specific Shapes

Continuous Casting. Picture a mold cavity whose graphite or water-cooled metal side walls are fixed, while the bottom wall, also cooled, is free to move in the axial direction as molten metal is poured in from the top, **Figure VI-6a**, page 103. This is the continuous casting process. It is used to produce bearing blanks and other long castings with uniform cross sections. Continuous casting is the principal method used for the large-tonnage production of semi-finished products such as cast rods, tube rounds, gear and bearing blanks, slabs and custom shapes.

The extremely high cooling and solidification rates attending continuous casting can, depending on the alloy, produce columnar grains. The continuous supply of molten metal at the solidification interface effectively eliminates microshrinkage and produces high quality, sound products with very good mechanical properties. With its simple die construction, relatively low equipment cost, high production rate and low labor requirements, continuous casting is a very economical production method.

Centrifugal Casting. This casting process has been known for several hundred years, but its evolution into a sophisticated production method for other than simple shapes has taken place only in this century. Today, very high quality castings of considerable complexity are produced using this technique.

To make a centrifugal casting, molten metal is poured into a spinning mold. The mold may be oriented horizontally or vertically, depending on the casting's aspect ratio. Short, squat products are cast vertically while long tubular shapes are cast horizontally. In either case, centrifugal force holds the molten metal against the mold wall until it solidifies. Carefully weighed charges insure that just enough metal freezes in the mold to yield the desired wall thickness, **Figure VI-7a**, page 103. In some cases, dissimilar alloys can be cast sequentially to produce a composite structure. **Figure VI-7b** shows a section of a four-inch (100-mm) thick vessel shell consisting of a pure copper outer ring surrounding a nickel-aluminum bronze liner.

Molds for copper alloy castings are usually made from carbon steel coated with a suitable refractory mold wash. Molds can be costly if ordered to custom dimensions, but the larger centrifugal foundries maintain sizeable stocks of molds in diameters ranging from a few inches to several feet.

The inherent quality of centrifugal castings is based on the fact that most nonmetallic impurities in castings are less dense than the metal itself. Centrifugal force causes impurities (dross, oxides) to concentrate at the casting's inner surface. This is usually machined away, leaving only clean metal in the finished product. Because freezing is rapid and completely directional, centrifugal castings are inherently sound and pressure tight. Mechanical properties can be somewhat higher than those of statically cast products.

Centrifugal castings are made in sizes ranging from approximately 2 in to 12 ft (50 mm to 3.7 m) in diameter and from a few inches to many yards in length. Size limitations, if any, are likely as not based on the foundry's melt shop capacity. Simple-shaped centrifugal castings are used for items such as pipe flanges and valve components, while complex shapes can be cast by using cores and shaped molds, **Figure VI-7c**. Pressure-retaining centrifugal castings have been found to be mechanically equivalent to more costly forgings and extrusions.

In a related process called centrifuging, numerous small molds are arranged radially on a casting machine with their feed sprues oriented toward the machine's axis. Molten metal is fed to the spinning mold, filling the individual cavities. The process is used for small castings such as jewelry and dental bridgework, and is economically viable for both small and large production quantities. Several molding methods can be adapted to the process, and the unit costs of centrifuged castings will depend largely on the type of mold used.

Special Casting Processes

Recent years have seen the introduction of a number of new casting processes, often aimed at specific applications. While these techniques are still to some extent under development and while they are certainly not available at all job shop foundries, their inherent advantages make them valuable additions to the designer's list of options.

Squeeze Casting. This interesting process aims to improve product quality by solidifying the casting under a metallostatic pressure head sufficient to (a) prevent the formation of shrinkage defects and (b) retain dissolved gases in solution until freezing is complete. This method was originally developed in Russia and has undergone considerable improvement in the U.S. It is carried out in metal molds resembling the punch and die sets used in sheet-metal forming.

After introducing a carefully metered charge of molten metal, the upper die assembly is lowered into place, forming a tight seal. The "punch" portion of the upper die is then forced into the cavity, displacing the molten metal under pressure until it fills the annular space between the die halves.

Proponents of squeeze casting claim that it produces very low gas entrapment and that castings exhibit shrinkage volumes approximately one-half those seen in sand castings. Very high production rates, comparable to die casting but with considerably lower die costs, are also claimed.

The process produces the high quality surfaces typical of metal mold casting, with good reproduction of detail. Rapid solidification results in a fine grain size, which in turn improves mechanical properties. It is claimed that squeeze casting can be applied to many of the copper alloys, although die and permanent mold casting alloys should be favored.

Selecting a Casting Process

A product's shape, size and physical characteristics often limit the choice of casting method to a single casting process, in which case the task simply becomes one of selecting a reliable foundry offering a fair price. If there is a choice of casting methods, it may be worthwhile to consult a trusted foundry, since the foundryman's experience can be a source of cost-saving ideas. In any event, it is advantageous to limit selection of the casting method to a few choices early in the design process so that the design and the casting method meet each other's requirements.

Making the selection is not inherently difficult, although it should be emphasized that the help of a skilled foundryman can be invaluable at this point. The factors listed at the beginning of this chapter determine the best suited and most economical process. **Table 20**, page 91, adapted from several sources,[3, 21] defines the broad limits on process-selection parameters.

FIGURE VI-1b Sand casting lends itself to a large range of product sizes. It is the most versatile casting process.

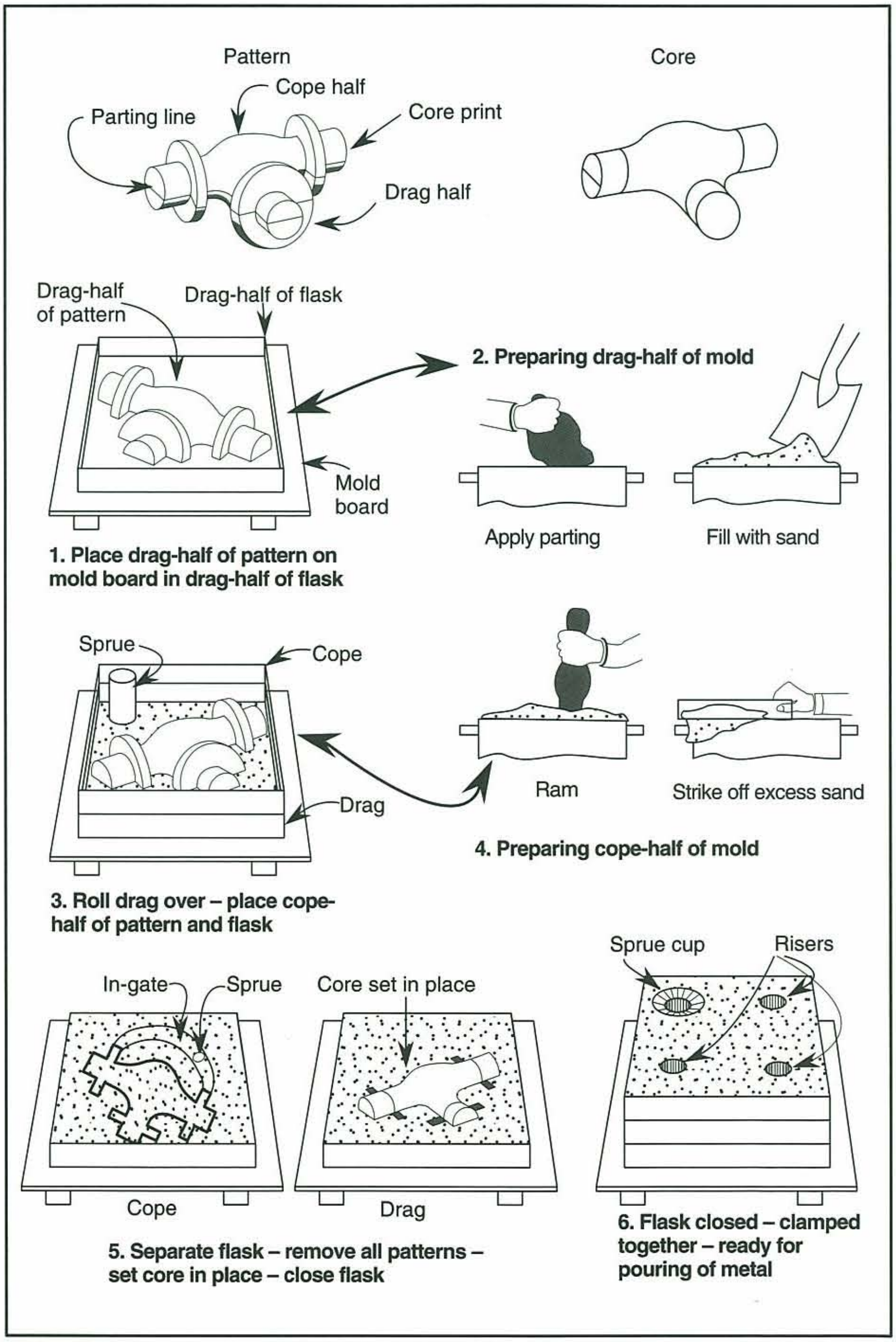
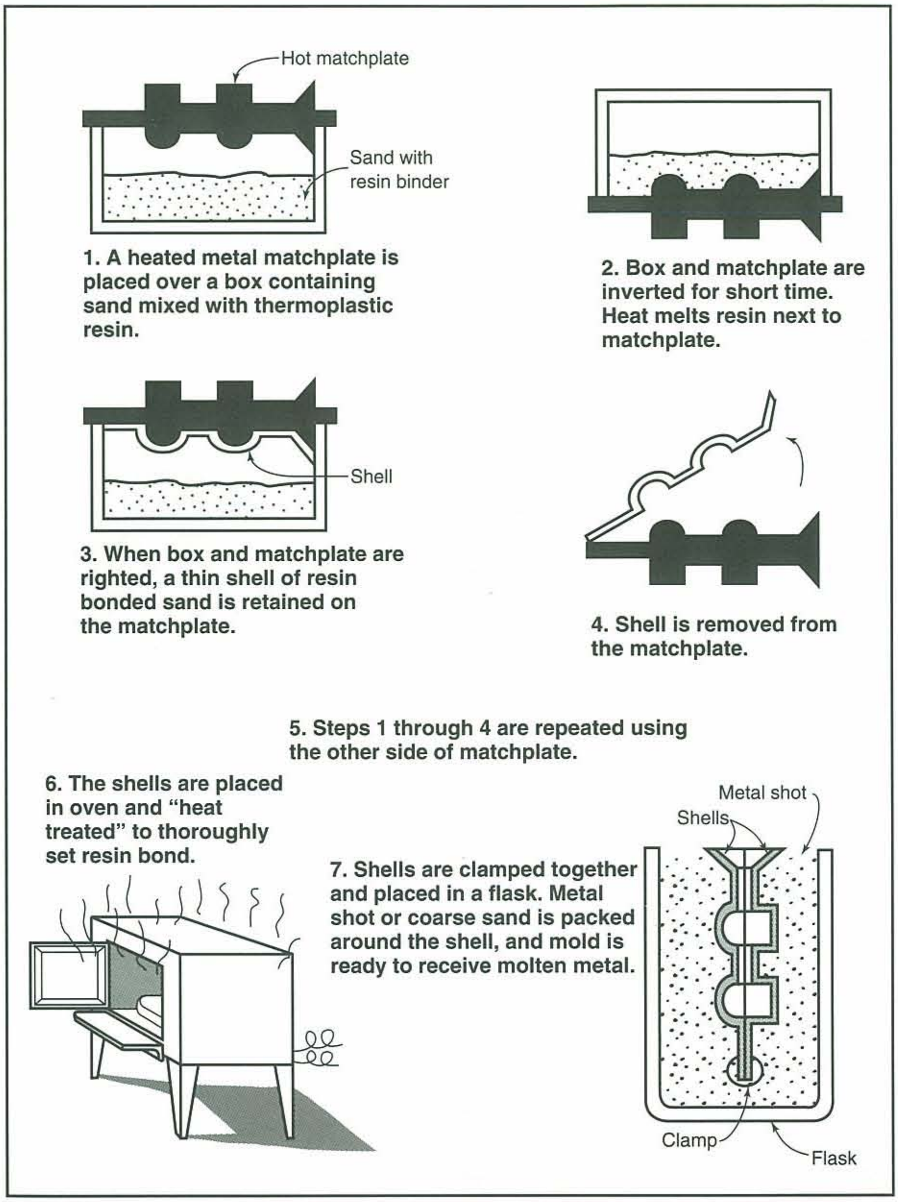


FIGURE VI-1a Making a mold for sand casting.



1. A heated metal matchplate is placed over a box containing sand mixed with thermoplastic resin.

2. Box and matchplate are inverted for short time. Heat melts resin next to matchplate.

3. When box and matchplate are righted, a thin shell of resin bonded sand is retained on the matchplate.

4. Shell is removed from the matchplate.

5. Steps 1 through 4 are repeated using the other side of matchplate.

6. The shells are placed in oven and "heat treated" to thoroughly set resin bond.

7. Shells are clamped together and placed in a flask. Metal shot or coarse sand is packed around the shell, and mold is ready to receive molten metal.

FIGURE VI-2a Shell molding process

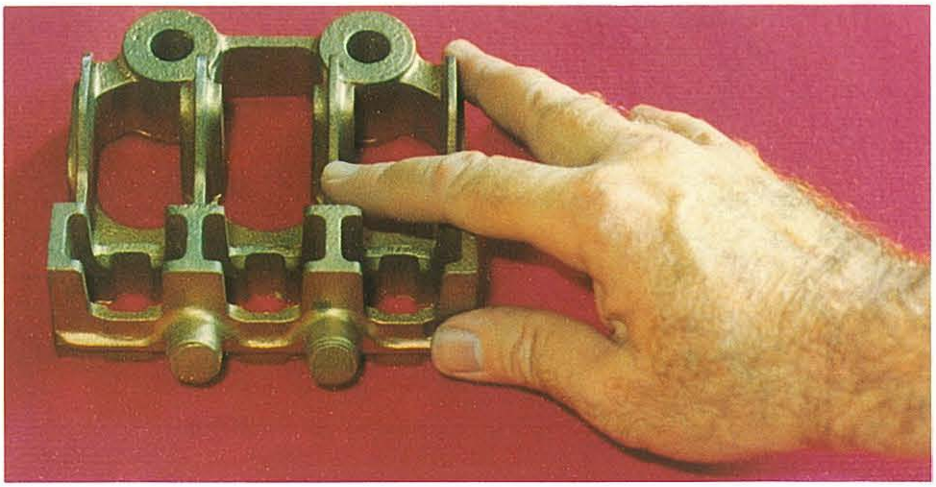
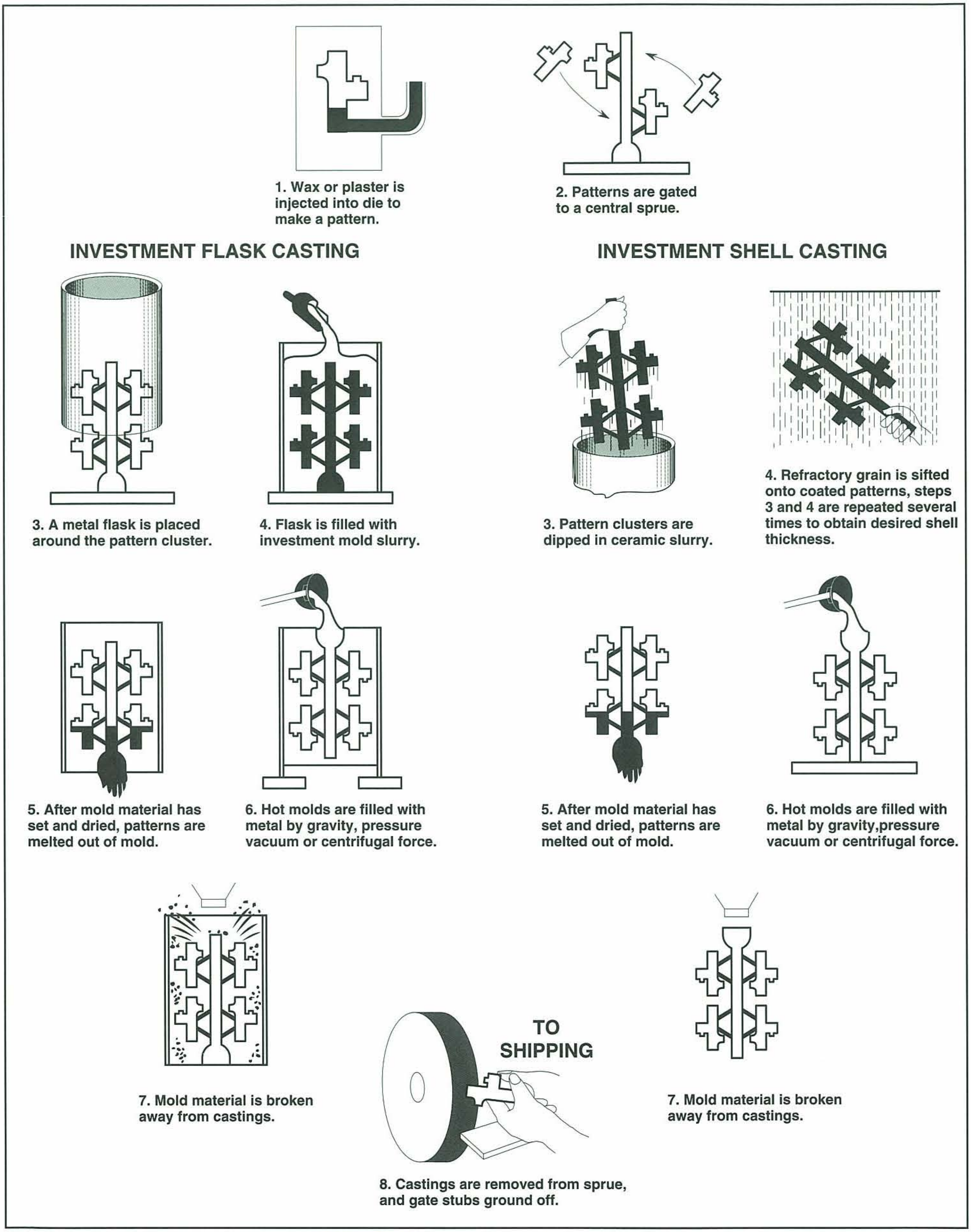


FIGURE VI-2b
Shell molding is capable of producing precise castings. Surface finishes exceed those of sand castings.



1. Wax or plaster is injected into die to make a pattern.

2. Patterns are gated to a central sprue.

INVESTMENT FLASK CASTING

3. A metal flask is placed around the pattern cluster.

4. Flask is filled with investment mold slurry.

5. After mold material has set and dried, patterns are melted out of mold.

6. Hot molds are filled with metal by gravity, pressure vacuum or centrifugal force.

7. Mold material is broken away from castings.

INVESTMENT SHELL CASTING

3. Pattern clusters are dipped in ceramic slurry.

4. Refractory grain is sifted onto coated patterns, steps 3 and 4 are repeated several times to obtain desired shell thickness.

5. After mold material has set and dried, patterns are melted out of mold.

6. Hot molds are filled with metal by gravity,pressure vacuum or centrifugal force.

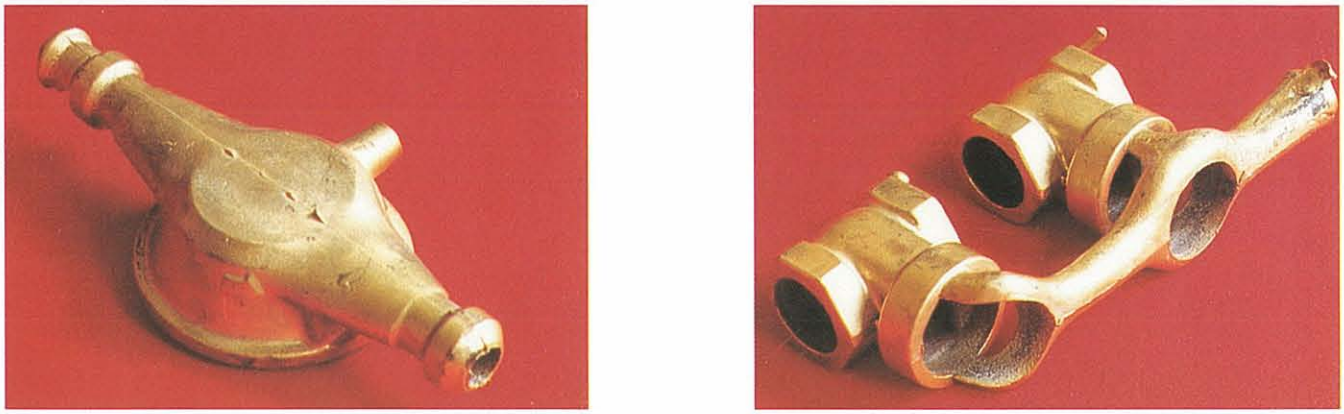
7. Mold material is broken away from castings.

8. Castings are removed from sprue, and gate stubs ground off.

FIGURE VI-3a Investment casting processes

FIGURES VI-3b
A selection of investment castings. Note the exceptional surface finish and fine detail.

FIGURES VI-4b,c
Typical permanent mold castings. The process is also called gravity die casting.



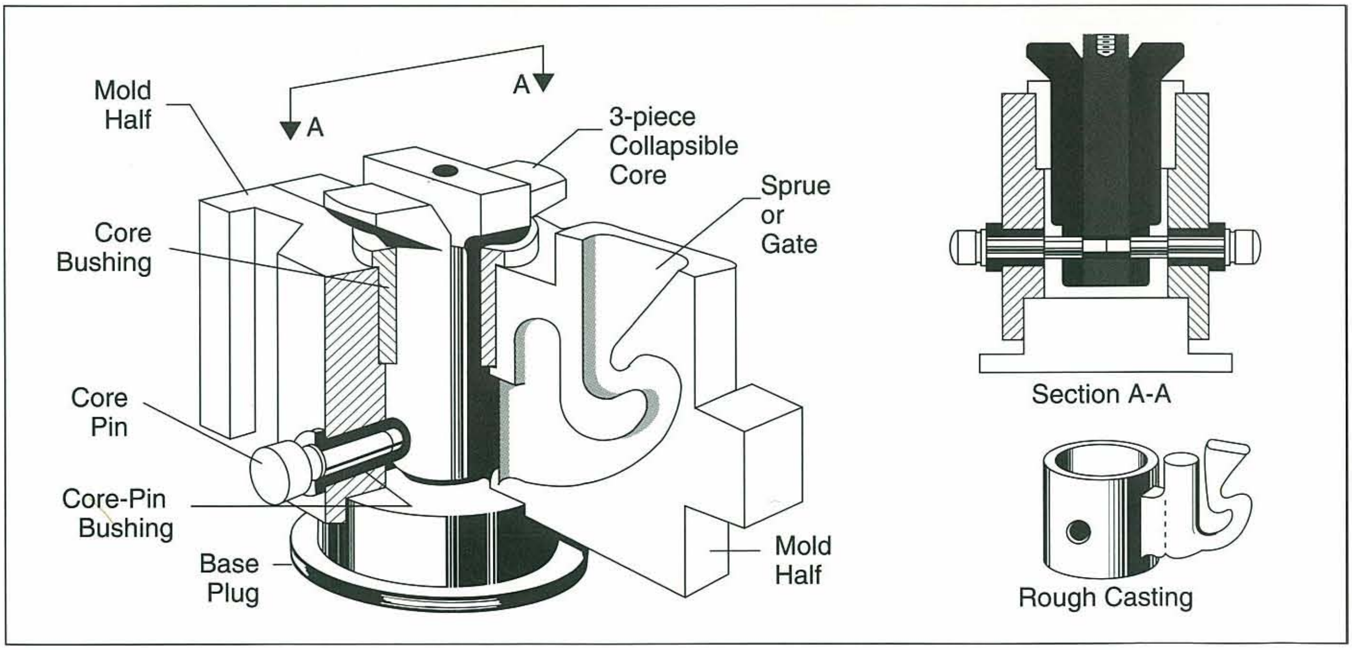


FIGURE VI-4a Permanent mold casting process

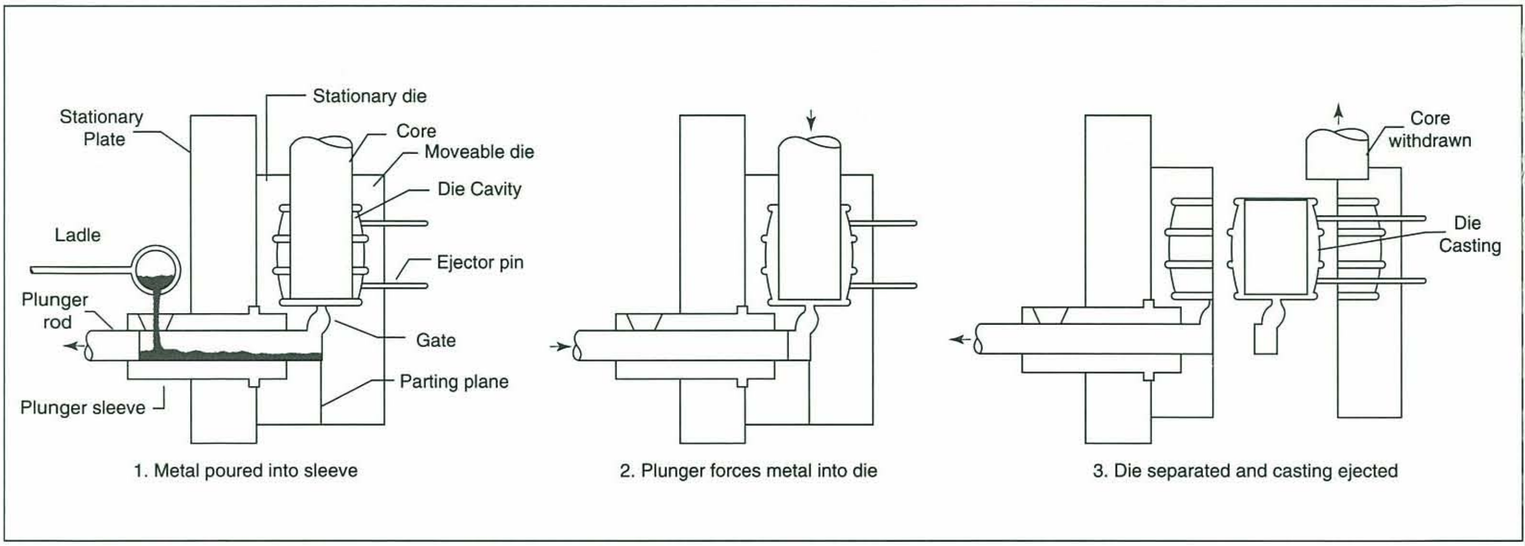


FIGURE VI-5a Die casting process

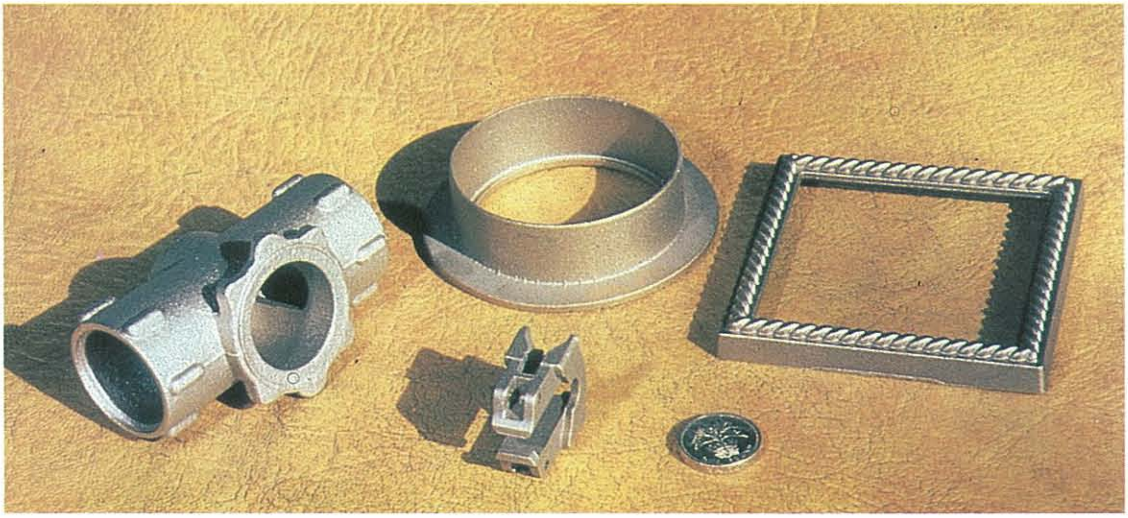


FIGURE VI-5b
Die cast brass products. Note the fine surface finish and good reproduction of detail.

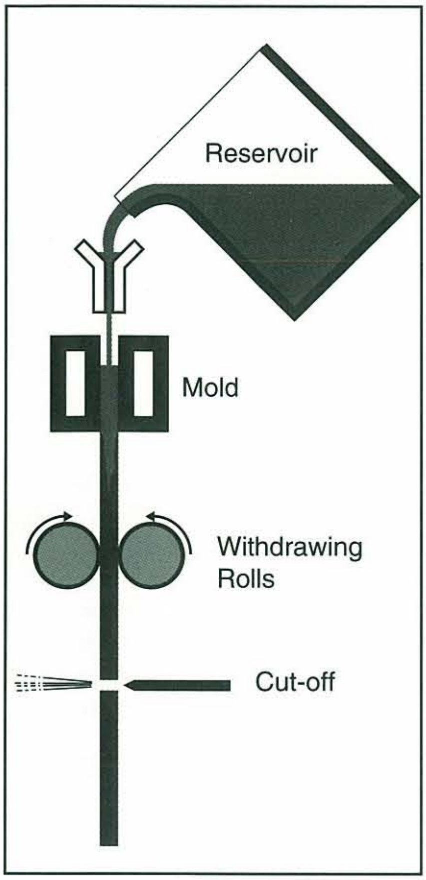


FIGURE VI-6a
Continuous casting process

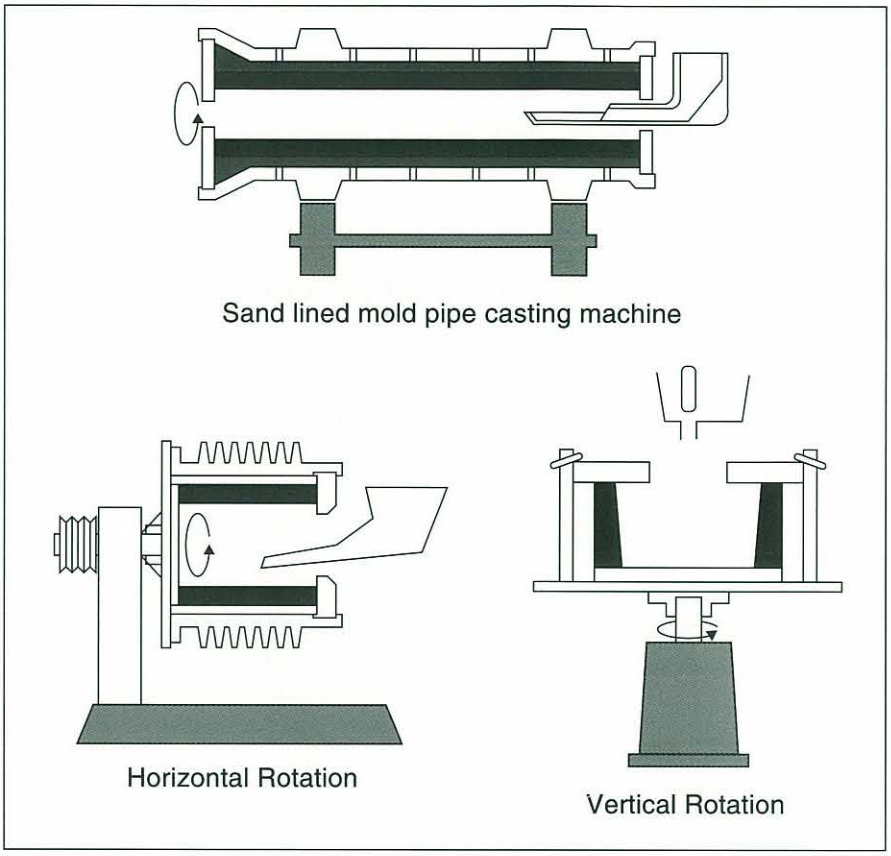


FIGURE VI-7a Centrifugal casting processes

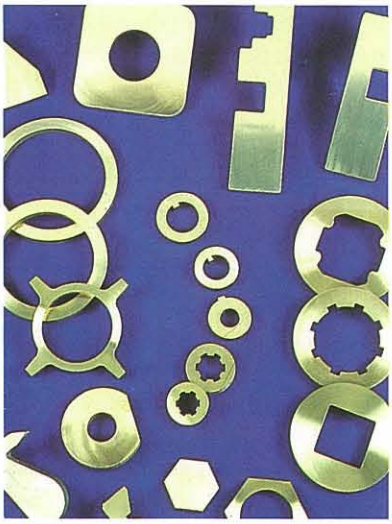


FIGURE VI-6b
A selection of continuous cast products in cross section. This process is commonly used to produce such products as gear blanks and sleeve bearing pre-forms.

FIGURE VI-7b
A composite centrifugal casting; the outer shell is pure copper while the inner liner is nickel-aluminum bronze.

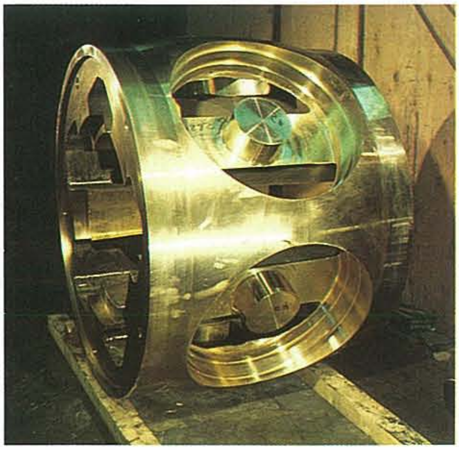


FIGURE VI-7c
Centrifugally cast hub for a variable pitch naval propeller. Note the extensive use of cores to form the complex shape.

VII. CASTING DESIGN PRINCIPLES

The many factors involved in proper casting design are discussed in a number of excellent texts, including those published by the Non-Ferrous Founders' Society and the American Foundrymen's Association.[1-3] This guide cannot deal with casting design in the degree of detail to which those publications are devoted, but it may be helpful to point out a few of the general principles that govern the manufacture of quality castings. It must be emphasized that successful casting design is a cooperative process involving all the parties involved. The advice of a skilled foundryman and patternmaker is invaluable, and the earlier in the design process such consultation is sought, the better.

The most important point to bear in mind when designing a casting is that the design doesn't simply set the shape of the product, it also determines the way that the casting will solidify—to the extent this is independent of foundry practice. It may be helpful to review the material presented earlier on the freezing behavior of the various copper alloys.

Short-freezing alloys, such as pure copper, high copper alloys and yellow brasses, aluminum bronzes and copper-nickels solidify from the mold walls inward and tend to form shrinkage cavities in regions where the last remaining liquid metal solidifies, **Figure VII-1**, page 106.

Long-freezing alloys, such as tin bronzes, leaded alloys and the red and semi-red brasses solidify by going through a mushy stage more or less uniformly throughout the casting's volume. They tend to form internal porosity, as shown in **Figure VII-2**, page 106; this cannot always be avoided, but it can often be tolerated.

There is a spectrum of freezing behaviors between the short- and long-freezing alloys. Exactly how a casting solidifies depends on alloy composition, casting shape, pouring temperature and the rate of heat extraction. For both short- and long-freezing alloys, however, it is important to ensure that the metal freezes in a directional manner such that the last metal to solidify within the mold cavity (not including the metal left in risers) is adequately fed by liquid metal until solidification is complete. No partially liquid region of the casting should be shut off from a supply of molten metal. Hot spots should be avoided since these tend to remain liquid longest.

The simplest way to ensure proper solidification is by the placement of risers. These reservoirs of liquid metal are placed either where they can feed relatively thin sections that might otherwise freeze off and isolate adjacent regions of the casting or where they can, with their high sensible heat, help bring about directional solidification.

Risers must be large enough to remain liquid well after the casting has solidified. Risers are more important in the casting of short-freezing alloys, where feeding takes place over considerable distances. In long-freezing alloys, risers are less helpful in promoting directional solidification and are used instead to ensure uniform solidification rates.

The design and placement of risers is beyond the scope of this alloy selection guide, but the designer should recognize their importance. Since the need for risers may affect the shape or layout of a casting, it is best to consult with the foundryman about riser placement before committing to a final configuration.

It is also important to take into consideration the shrinkage stresses a casting may be subjected to as it solidifies. The ability of a casting to resist such stresses without cracking depends on the alloy's structure, solidification behavior and elevated-temperature properties. The presence of a second phase, particularly beta, tends to improve strength and ductility at high temperatures, and this reduces the tendency for restrained sections to tear as the metal solidifies and shrinks. The type of molding material is also important. Properly made sand molds can accommodate shrinkage, while permanent or plaster molds cannot.

As an example of the interplay between metal and molding material in the choice of a casting process, consider the alpha-beta structure of yellow brasses. The alloys' good high temperature ductility, along with their relatively short freezing range, suit them to the permanent mold and die casting processes.

Design Fundamentals

Observing a few simple rules will go a long way toward avoiding the most prevalent design-based casting defects. It should become apparent that these rules are based on the solidification behaviors described above.[1, 22]

- Avoid abrupt changes in section thickness. Taper the larger section such that it blends into the thinner section, **Figure VII-3**, page 107.
- Always avoid sharp internal corners. Use generous fillets and rounded corners wherever possible to avoid the formation of hot spots.
- Minimize the use of L intersections, avoid X intersections, and take care in designing T intersections. Use rounded corners insofar as possible, and substitute two Ts for each X intersection wherever possible, **Figure VII-4**, page 107.
- Visualize how the metal will solidify, and design the casting to take this into account. Consider the type of freezing the candidate alloy will undergo and use this understanding to avoid shrinkage cavities or porosity.
- Identify the constraints the solidifying and cooling casting will undergo, and formulate the design accordingly to avoid hot tearing.
- Do not hesitate to add metal (padding) to facilitate the feeding of thin sections and remove metal where it creates an abrupt change in section size. Removing metal may, in fact, strengthen the casting.
- If there is a possibility that shrinkage stresses will demand some degree of flexibility during solidification, use curved members in place of straight sections whenever possible.

Following these guidelines will help ensure that the casting design process will begin correctly, and that the need for changes later on—when they may be more expensive—will be minimized.

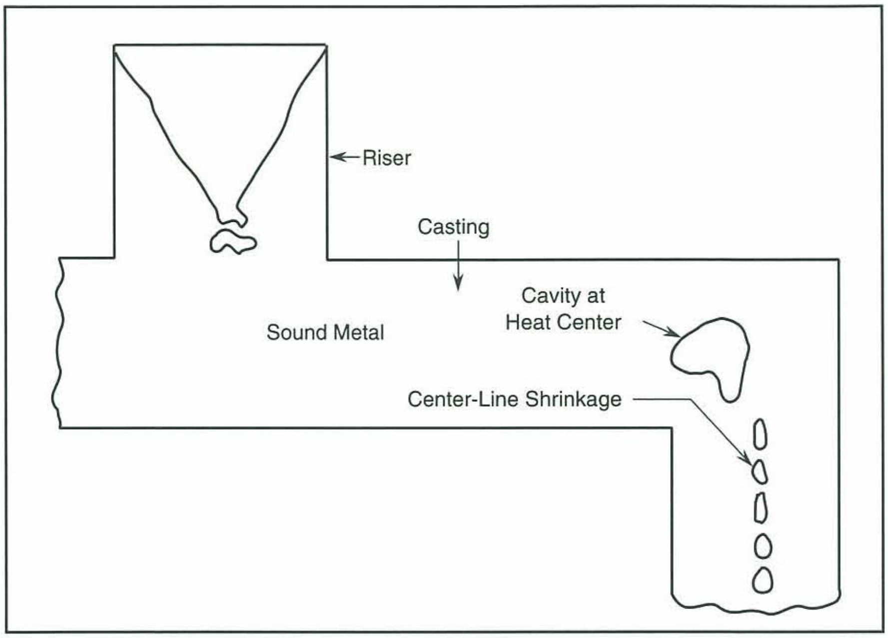


FIGURE VII-1.
Formation of shrinkage cavities for alloys that solidify by skin formation.

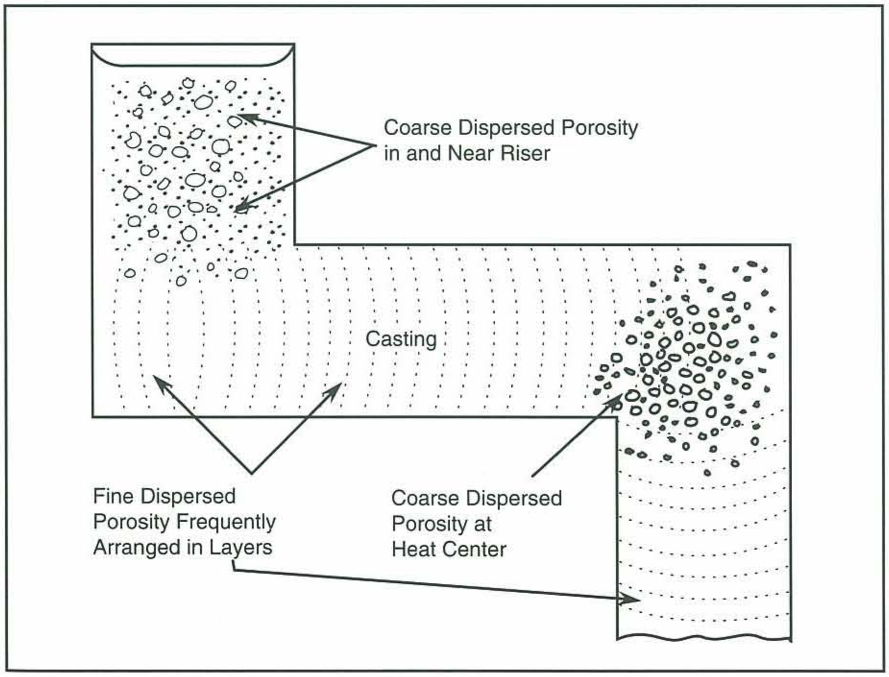


FIGURE VII-2.
Formation of internal porosity for alloys that solidify over long freezing ranges.

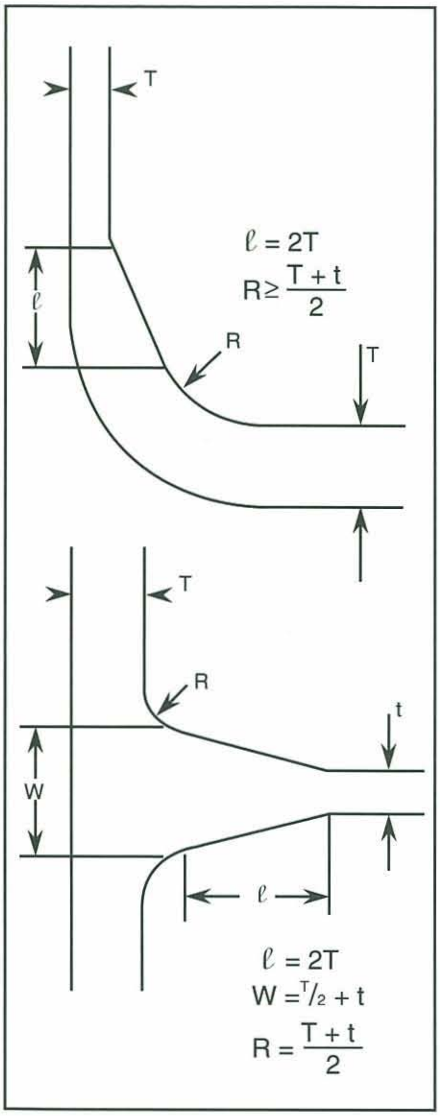


FIGURE VII-3. Recommendations for the design of junctions involving different wall thicknesses.

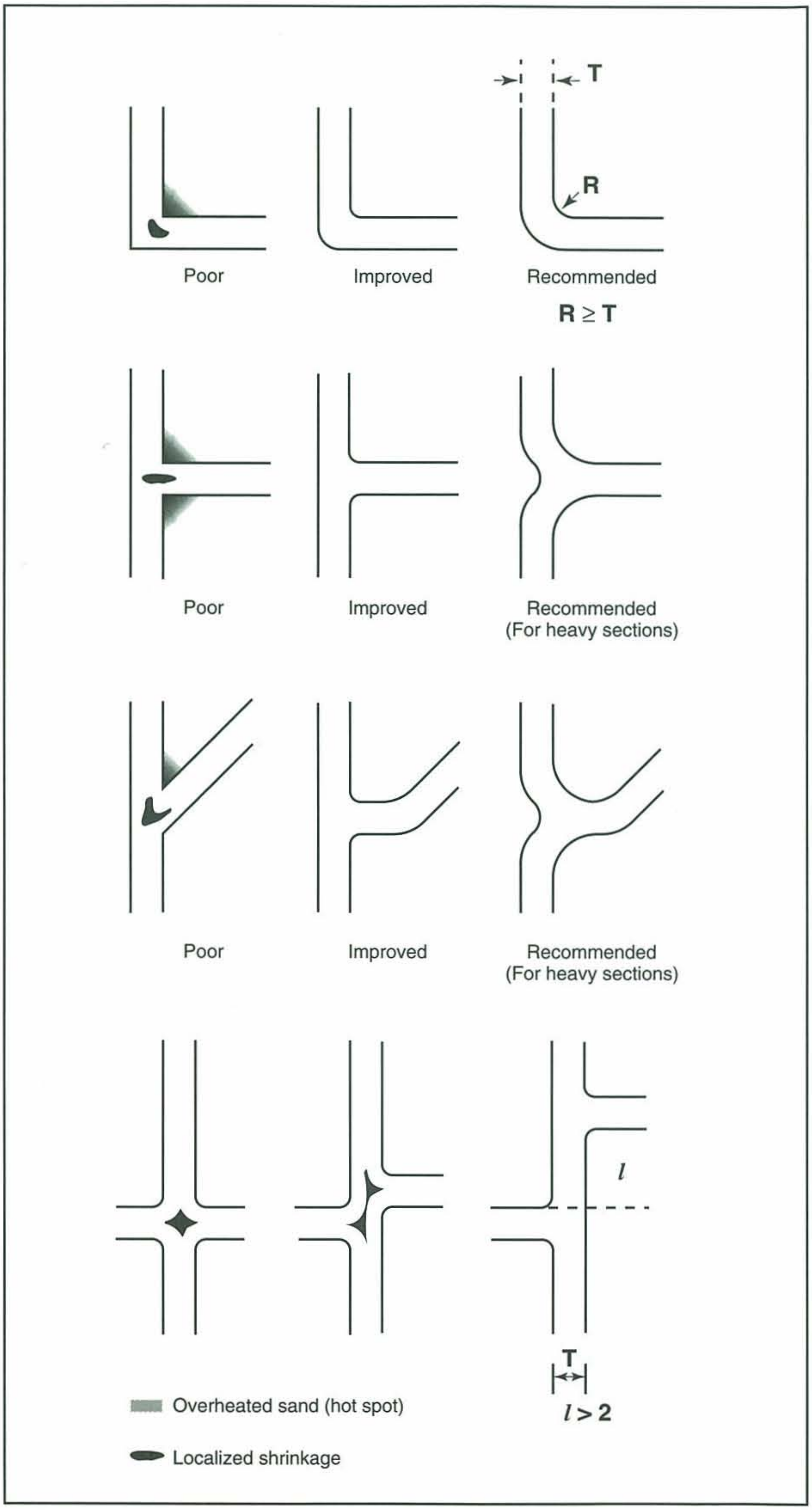


FIGURE VII-4. Examples of redesign to prevent the formation of hot spots.

Specifying and Buying Copper Casting Alloys

VIII. ORDERING A COPPER ALLOY CASTING

In order to increase the likelihood that a successful casting will result, the buyer must give proper attention to design principles, alloy selection and/or specification, the choice of casting method and the type and rigor of inspection procedures. This is especially true when the foundry is an independent job shop, where communication among designer, metallurgist and foundryman may not be so close as it might be in an in-house or captive operation.

The following ordering guidelines are based on practices recommended by the Non-Ferrous Founders' Society. Some may seem like minor, unimportant points; these are exactly the kind that have a way of becoming very significant when ignored:[3]

- **Alloy Selection**. Identify the alloy unambiguously. This normally involves nothing more than specifying the appropriate UNS designation. Conforming specifications should be cited, where applicable, and special compositional requirements may be added, if needed. Heat treatment and/or annealing conditions should be spelled out. Avoid ordering alloys by common names, as these can be inexact, and that can lead to disagreement. Also, common or descriptive names usually don't satisfy quality assurance requirements.
- **Casting Design.** Describe the casting's design using appropriate drawings for the product, pattern and mold layout. Ideally, drawings will represent a consensus arrived at among the designer, metallurgist, patternmaker and foundryman. All parties involved should accept the design package before production begins.
- **Patterns.** Patterns may be supplied by either the customer or the foundry. Whatever the arrangement, the foundry should be consulted regarding the type, material, layout and coring requirements for the patterns involved.
- **Molding Method.** The molding method used will generally be based on either the product's quality requirements, the type of alloy and/or the number of castings to be produced. Any special requirements or limitations of the casting method should be carefully addressed by the designer—and understood by both designer and foundryman—before committing the job to production.
- **Inspection Requirements.** Quality control requirements are usually spelled out or given as options in conforming specifications, and the designer/customer need only refer to these documents to determine what may be reasonably expected of the foundry. Where conforming specifications are not called out, it becomes very important that all quality requirements are thoroughly agreed upon before any metal is poured.

  Typical requirements include chemical composition, mechanical properties tests on concurrently cast test bars, radiography and/or other non-destructive examination. Performance qualifications such as pressure tests can also be called for in the case of large production runs or new designs involving safety-related products.
- **Prototype Production.** Unfortunately, many casting mistakes do not become evident until the product has been cast, cleaned, machined and inspected, i.e., until all of the value has been added. It is therefore common practice to make a few trial runs, particularly for complex castings with extensive coring. Costs are involved, but they can be offset in part by reclaiming the metal.

  Assuming the metal composition is correct, failed prototype castings make ideal corrosion test specimens. It is far less costly to modify the design, change the foundry practice or tweak the alloy composition than it is to repair or reject an entire production lot of faulty products.

Page 110 contains a sample request for quotation for a typical copper alloy sand casting. The sample product described illustrates many of the fundamental requirements of a well-written RFQ.

If proper consideration is given to the quotation request, in most instances the actual purchase order will mirror the RFQ and may in fact be drawn directly from the quotation request form. However, should any changes be made between the RFQ and the actual purchase order, these should be specifically called to the foundry's attention, as it is possible that they may affect the price quoted.

Customers can obtain useful information on specific foundry capabilities from a number of reliable sources. This publication, along with

CDA's Copper Select software can provide information on which copper alloys may be best for various customer applications. Foundry associations such as the Non-Ferrous Founders' Society (NFFS) routinely publish membership directories or buyers' guides.

A computer disk directory is available from NFFS to help casting buyers select the correct foundry to fill their casting needs. This program contains basic information on foundries, such as their phone and fax numbers, key personnel, distinctive alloys, production capacities and number of employees. It also indexes foundries geographically, by industries served. More specifically, the system allows the user to combine several of these parameters into a single search to locate those foundries that are ideally suited to supply their casting needs and to automatically generate quotation requests for the foundries selected.

Additional information on the Copper Select program is available from CDA at 800-CDA-DATA. Both the traditional printed version and the computer version of the North American Directory of Non-Ferrous Foundries can be ordered from NFFS by calling 708-299-0950.

REQUEST FOR QUOTATION

Today's Date	Quote Not Later Than	Expected Decision Date
October 8, 1994	11/30/1994	12/01/1994

FROM: James Pfister

JAMIESON MANUFACTURING INC.
120 Roosevelt Street
Ridge Park, IL 60640
Phone: 708/555/0515 – FAX 708/555-0512

Please quote your best price for the articles described herein.
Please base your quote on the terms and conditions specified.

Drawing or Part Number: S330-8406
Specification: MIL-B-24480
Material/Commercial Designation: UNS C95800

THIS IS NOT AN ORDER

Pattern Description:
1 split pattern mounted on 36×50 boards; 5 wood coreboxes.
Surface Finish:
500 µin rms
Non-Destructive Test Requirements:
to MIL-STD 278E, Cat. 2–Sub. Cat. J
Documentation (Reports) Required:
Yes
Other Requirements:
Pressure test to 125 psi under water.
Actual ☐ or Estimated ☒ Casting Weight: 125 lb/56.7 kg

Quote Required Tooling: ☒ Separately ☐ Included
Quote Quantities: 5, 10, 50
Anticipated Annual Use: 100 pieces
Anticipated Pattern Life: 10 years
Expected Order Quantity/Frequency: 10/month
Required Turn-Around: 4-6 weeks after pattern is sampled & approved

Additional information that may be required to prepare your quote will be provided as needed. Contact the requesting agent noted below.

Signed:________________________________

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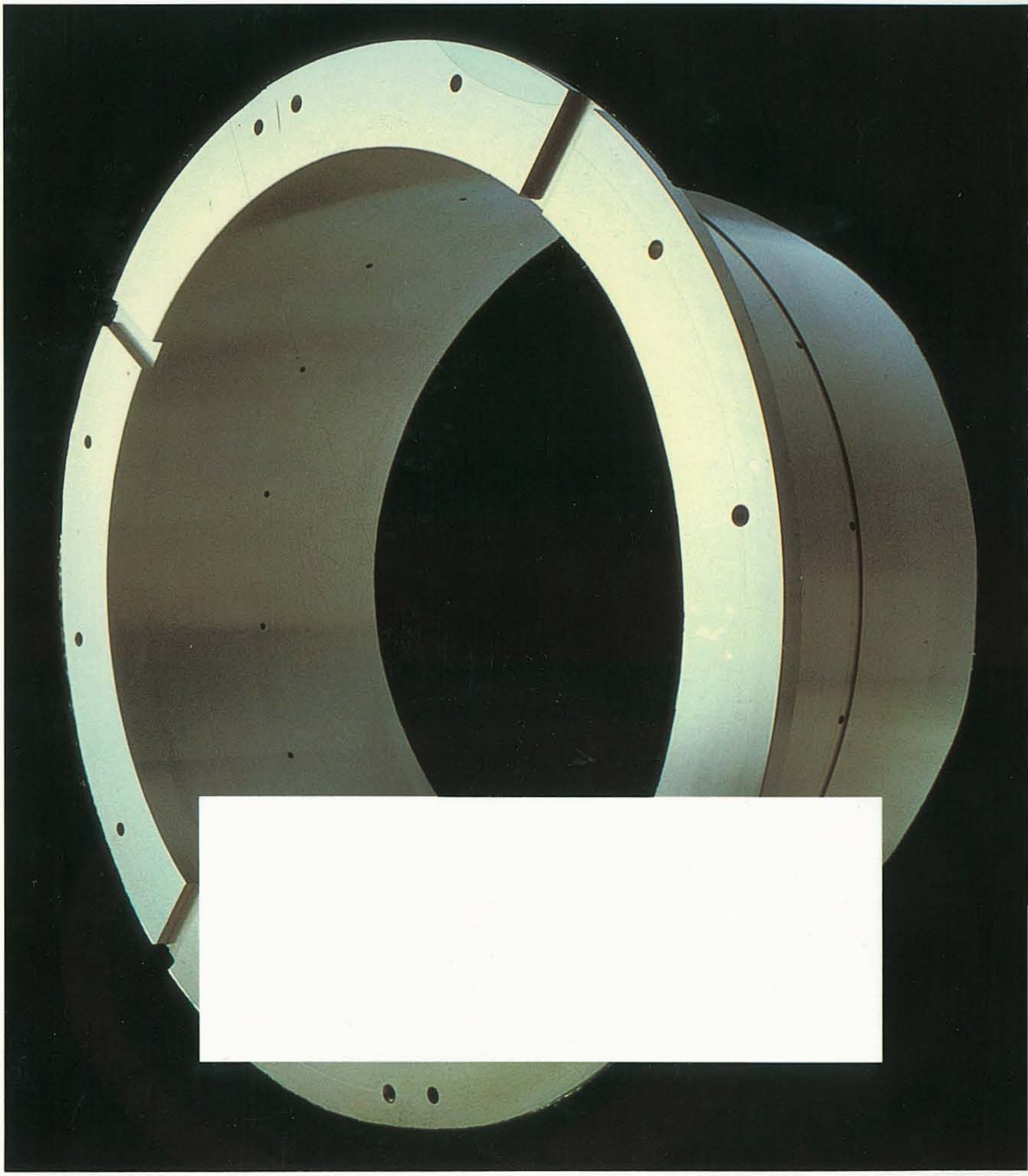

NFFS

Non-Ferrous Founders' Society

CDA

Copper Development Association

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