

## **COPPER ALLOYS, CAST COPPER ALLOYS**

Copper [7740-50-3](qv) alloy castings are used for their generally superior corrosion resistance (see Corrosion and corrosion control), high electrical and thermal conductivities, and good bearing and wear qualities. Some of the alloys are heat-treatable and couple high strength with good electrical and thermal conductivity. Irregular and complex external and internal shapes can be produced by various casting methods. The production of the same configurations by other methods may be mechanically impractical or too costly.

The cold- and hot-working properties of castings are not important because castings are usually not subject to mechanical forming operations; thus the chemical compositions of casting alloys have greater latitudes than those of comparable wrought alloys. However, the chemistry of the heat-treatable alloys must be carefully controlled to attain the proper hardening effects. Furthermore, compositions that do not lend themselves to forming operations are available in cast form for specific applications, such as in the bearing field for alloys containing up to 40% lead (see Bearing materials). Wrought methods for making the same product are unsatisfactory because the intermediate annealing of the alloy causes the lead to separate from the matrix and then from the material itself. The tolerance for impurities is normally greater in castings than in wrought alloys because the former are not mechanically formed.

However, in those cast alloys likely to be repaired or joined by welding (qv) some impurities can be very detrimental. On the basis of consumption, red brass alloys, Unified Numbering System (UNS) C 83600 (85%Cu, 5%Sn, 5%Pb, 5%Zn), UNS C 84400 (81%Cu, 3%Sn, 7%Pb, 9%Zn), and UNS C93200 (83%Cu, 7%Sn, 7%Pb, 3%Zn), are the most important of the cast copper alloys.

### **1. Properties and Characteristics**

Cast copper alloys can be classified into two main groups: single-phase alloys, characterized by moderate strength, high ductility (except for leaded varieties), moderate hardness, and good impact strength; and polyphase alloys, having high strength, moderate ductility, and moderate impact strength.

#### **1.1. Single-Phase Alloys**

Copper–tin–zinc–lead alloys, tin bronzes, and the leaded tin bronzes have a narrow range of properties, namely, 234–303 MPa (34,000–44,000 psi) tensile strength, 103–152 MPa (15,000–22,000 psi) yield strength, and more than 20% elongation and reduction in area. Leaded alloys are lower in all the properties cited above. The fatigue strength of these alloys is, in general, in proportion to the tensile strength. Most of the alloys have a fatigue strength of about one-third times the tensile strength at 100 million cycles.

Alloys containing nickel and/or aluminum have high strength and the impact data may exhibit scatter if the cooling rate or composition has not been closely controlled.

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**Table 1. Boundary Shift for Manganese–Bronze Alloys**

Alloy composition <sup>a</sup> , wt %						Shift	New boundary, % Zn
Cu	Sn	Pb <sup>b</sup>	Fe	Al	Mn		
58–63	0.5–1.5	0.8–1.5	0.5 <sup>c</sup>	0.5		0	38
58–62	0.5–1.5	0.5–1.3	0.8–1.5	0.25–1.0	0.1–0.5	–1.98	36
55–60	1.0 <sup>c</sup>	0.3	0.4–2.0	0.5–1.5	1.5 <sup>c</sup>	–2.80	35
60–68	0.1 <sup>c</sup>	0.1 <sup>c</sup>	2.0–0.4	3.0–7.5	2.5–5.0	–22.32	16

<sup>a</sup> Remainder is zinc in all cases.

<sup>b</sup> Lead is insoluble and therefore does not enter into the calculation.

<sup>c</sup> Maximum value.

### 1.2. Polyphase Alloys

The two-phase alloys have a rather wide range of properties resulting from variations within the structure. If the second phase is distributed in critical depression, the hardness and strength are at a maximum and the ductility is at a moderate level. Tensile strength may be 415–825 MPa (60,000–120,000 psi); yield strength, 170–585 MPa (25,000–85,000 psi); and elongation, 10–40%.

The effect of a second phase is demonstrated in the copper–aluminum system, where increasing aluminum concentration causes the alloy system to change to a polyphase alloy. By obtaining a fine dispersion of the  $\gamma_2$  phase, the yield strength is increased from 225 to 480 MPa (33,000–70,000 psi). Alpha–beta aluminum alloys respond to heat treatment with a general improvement of mechanical properties. Heat treatment is accomplished by heating to 815–870°C, quenching in water, and reannealing at 370–535°C, depending on the size and section of the casting. Different combinations of strength, hardness, and ductility can be obtained. Some nickel in aluminum bronze is in solid solution with the matrix and helps refine the  $\gamma_2$  precipitate, and a smaller amount is in the  $\kappa$ -intermetallic compound.

The desired balance of ductility and strength can be obtained in age-hardenable alloys, such as beryllium copper, by controlling the amount of precipitate. For higher strength, aging is conducted to provide a critical size dispersion. Greater amounts of precipitate are obtained by increasing the beryllium content of the alloy.

Copper–chromium and copper–nickel–silicon–chromium alloys are also precipitation hardenable. The precipitates are nickel silicides, chromium silicides, and elemental chromium. If conductivity is critical, the chromium–silicon ratio should be held at 10:1 so that appreciable amounts of either element are not left in solid solution in the copper after aging. Lithium can be used as a deoxidizer in copper alloys when conductivity is important. For a discussion of the principle of age- or precipitation-hardening copper alloys, see Copper alloys, wrought copper and wrought copper alloys.

Manganese bronzes form an interesting series in the alpha–beta area of the copper–zinc system. The mechanical properties are dependent on the relative amounts of the two phases and their distribution. Because the copper contents of the manganese–bronze alloys are relatively close together, they do not by themselves account for the presence of varying quantities of beta phase. The differences in beta content are accounted for by the effect of other elements on the location of the phase boundary between the alpha phase and the alpha–beta phase in the copper–zinc system. Aluminum, iron, and manganese all tend to shift the phase boundary from the value of 38% zinc. The shift of the phase boundary is given as  $-0.87 \times \% \text{ Mn}$ ,  $+1.0 \times \% \text{ Fe}$ , and  $-4 \times \% \text{ Al}$ . The boundary shift for the manganese–bronze alloys may be computed and is shown in Table 1.

This computation is also referred to as calculating the zinc equivalent of the alloy. The increase in strength in this alloy series is caused by increased amounts of beta phase in the structure. The silicon bronzes show similar hardening effects accompanying a second phase. Typical mechanical properties and electrical conductivity for various cast alloys are shown in Table 2.

Table 2. Properties of Cast Copper Alloys<sup>a</sup>

Common name	UNS designation	0.5% Yield strength, MPa <sup>b</sup>	Compressive yield strength, MPa <sup>b</sup>	Tensile strength, MPa <sup>b</sup>	Elongation in 5 cm, %	Brinell hardness, 500-kg load	Electrical conductivity, % IACS	Thermal conductivity at 20°C, W/(m·K) <sup>c</sup>
copper	C80100	62		172	40	44	100	391
chromium–copper								
cast	C 81500	83		214	35	63	45	
precipitation-hardened		296		379	18	110	82	315
beryllium–copper	C 81700	469	551 <sup>d</sup>	620	8	217 <sup>e</sup>	48	188
ASTM B22								
high strength yellow brass	C 86300	124	413 <sup>f</sup>	820	83	225	8.0	35.4
gun metal	C 90500	138–158	276 <sup>g</sup>	310	25	75	11.0	74
tin–bronze 84:16	C 91100	172		214	2	135 <sup>e</sup>	8.5	
tin–bronze 81:19	C 91300	207		214		170 <sup>e</sup>	7.0	
high leaded tin–bronze	C 93700	124	90 <sup>f</sup>	214	20	60	10.0	47
ASTM B61								
steam–bronze	C 92200	137	262 <sup>d</sup>	2276	20	65	14	69
ASTM B62								
leaded red brass	C 83600	103	96 <sup>f</sup>	241	32	62	15	73
ASTM B66								
phosphor–bronze	C 94400	110	303 <sup>d</sup>	221	18	55	10	52
high leaded tin–bronze	C 93800	110	83 <sup>f</sup>	208	16	55	11.5	52
medium bronze	C 94500	83	248 <sup>d</sup>	172	12	50	10	52
high leaded tin–bronze	C 94300	90	76 <sup>f</sup>	186	10	48	9	62
ASTM B148								
aluminum–bronze 9A	C 95200	172–208	186–214 <sup>f</sup>	482–600	22–38	110–140	11	50
aluminum–bronze 9B								
cast	C 95300	208–241	110–138 <sup>f</sup>	482–586	20–35	110–160	13	62
heat-treated	C 95300	276–379	241–310 <sup>f</sup>	551–655	12–16	160–225 <sup>e</sup>		
aluminum–bronze 9D								
cast	C 95500	276–345	827 <sup>d</sup>	620–724	7–20	175–210 <sup>e</sup>	8.5	41
heat-treated	C 95500	413–551	1034 <sup>d</sup>	758–855	5–12	215–260 <sup>e</sup>		
aluminum–silicon–bronze	C 95600	234		517	18	140 <sup>e</sup>	8.5	38
manganese–aluminum–bronze	C 95700	310	1034 <sup>d</sup>	655	26	180 <sup>e</sup>	3.0	12
nickel–aluminum–bronze	C 95800	262	689 <sup>d</sup>	655	25	159 <sup>e</sup>	7.0	35
ASTM B176								
die-casting yellow brass	C 85800	207 <sup>h</sup>		379	15		20	
die-cast silicon–brass	C 87800	345 <sup>h</sup>		586	25		6.7	28
silicon–yellow brass	C 87900	241 <sup>h</sup>		482	25		15.0	
ASTM B584								
leaded red brass	C 83600	103	96	255	32	60	15.0	71.9
	C 83800	83–117	76–83	207–262	15–27	50–60	15.0	73
leaded semired brass	C 84400	90–117		200–269	18–30	50–60	18.0	73
	C 84800	103	90	234	30	55–59	16.4	73
leaded yellow brass	C 85200	83–96	55–96 <sup>f</sup>	241–276	25–40	40–50	15–22	83.9
commercial no. 1								
yellow brass	C 85400	76–103	62 <sup>f</sup>	208–262	20–35	40–60	18–25	88
yellow brass	C 85700	96–138		276–310	15–40	50–75	20–26	83.9
high strength yellow brass	C 86200	331	345 <sup>f</sup>	655	20	180 <sup>e</sup>	7.5	35.4
	C 86300	672 <sup>h</sup>	413 <sup>f</sup>	820	18	225 <sup>e</sup>	8.0	35.4

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Table 2. *Continued*

Common name	UNS designation	0.5% Yield strength, MPa <sup>b</sup>	Compressive yield strength, MPa <sup>b</sup>	Tensile strength, MPa <sup>b</sup>	Elongation in 5 cm, %	Brinell hardness, 500-kg load	Electrical conductivity, % IACS	Thermal conductivity at 20°C, W/(m·K) <sup>c</sup>
lead high strength yellow brass	C 86400	172 <sup>h</sup>	158 <sup>f</sup>	448	20	105 <sup>e</sup>	19.0	88
high strength yellow brass	C 86500	193 <sup>h</sup>	165 <sup>f</sup>	489	30	130 <sup>e</sup>	22	86
lead high strength yellow brass	C 86700	289		586	20	155 <sup>f</sup>	16.7	
silicon-bronze	C 87200	172	124 <sup>f</sup>	379	30	85	6.0	28.4
silicon-brass	C 87400	165		379	30	70	6.7	27.7
silicon-brass	C 87500	207	183 <sup>f</sup>	462	21	115	6.7	27.7
tin-bronze	C 90300	145	90 <sup>f</sup>	310	30	70	12	74.7
gun metal	C 90500	152	276 <sup>g</sup>	310	25	75	11	74.7
lead tin-bronze	C 92300	138	241 <sup>d</sup>	276	25	70	12	74.7
high lead tin bronze								
83:7-7-3	C 93200	117–148	317 <sup>d</sup>	207–262	12–20	67	12	58.1
85:5:9:1	C 93500	83–103	90 <sup>f</sup>	193–241	20–35	55–65	15	71
80:10:10	C 93700	124	122 <sup>f</sup>	241	20	60	10	46.9
78:7:15	C 93800	96–138	90–100 <sup>f</sup>	172–227	10–18	50–60	11.5	52
70:5:25	C 94300	76–103	83–96 <sup>f</sup>	158–207	7–16	72–55	9	62.6
nickel-tin bronze								
cast	C 94700	138–158		310–345	25–35	85	12	53.9
heat-treated	C 94700	345–413		517–551	5–10	180 <sup>e</sup>		
lead nickel-tin bronze								
cast	C 94800	138–158		310–345	20–35	80	12	38.6
heat-treated		207		413	8	120 <sup>e</sup>		
	C 94900	103		262	15			
copper-nickel 90:10	C 96200	172		310	20		11	45
copper-nickel 70:30	C 96400	221		413	20	140 <sup>e</sup>	5	29
12% nickel-silver	C 97300	117		241	20	55	5.7	28.5
15% nickel-silver	C 97400	117		262	20	70	5.5	27.3
20% nickel-silver	C 97600	117		262	20	70	5	22
25% nickel-silver	C 97800	165		276	20	80	4.5	25.4

<sup>a</sup> Mechanical property data were developed from separately cast test bars; values shown are based on technical literature.

<sup>b</sup> To convert MPa to psi, multiply by 145.

<sup>c</sup> To convert W/(m·K) to Btu–ft<sup>2</sup>/(ft·h·°F), multiply by 0.578.

<sup>d</sup> 0.1 cm set/cm.

<sup>e</sup> 3000 kg load.

<sup>f</sup> 0.001 cm set/cm.

<sup>g</sup> 0.01 cm set/cm.

<sup>h</sup> Offset of 0.2%.

### 1.3. Stresses and Stress Relieving

Nonuniform cooling leads to unbalanced residual stress patterns in the casting. Exposure of stressed castings to environments containing ammonia, ammoniacal compounds, or mercury can cause cracking of the alloys. Castings stressed to a level of ca 80 MPa (12,000 psi) and greater may crack in mercury environments, and stress levels of only a few MPa may produce cracks when exposed to ammonia. The coppers and copper-nickel-iron alloys usually have very high resistance to stress-corrosion cracking and do not require stress relieving.

Stress relieving to safe stress levels can be accomplished by a thermal treatment, sometimes called stress-relief annealing even though annealing may not be involved. The following alloys are all effectively stress relieved by heating at 260°C for 24 min/cm of section: high copper alloys, red brass, semired brass, yellow brass, manganese-bronze, silicon-bronze, tin-bronze, and nickel-bronze. Aluminum-bronze alloys are treated at 316°C for 24 min/cm of section.

If the casting is loaded or stressed externally in service, prior thermal stress treatment is of little value. Stress-corrosion cracking does not distinguish between residual or applied stresses.

#### 1.4. Machinability.

The cast copper alloys can be placed in three groups relative to machinability and are rated in the same general manner as wrought copper alloys. Group one contains the leaded alloys and is considered to be free-machining. Lead causes chip breakage during machining operations, permitting higher cutting speeds, decreased tool wear, and improved surface finish.

Alloys in the second group are polyphase alloys having a second phase generally harder than the matrix, which can cause brittleness and some chip breakage. This group comprises leaded tin bronze, silicon bronze, high tin bronze, aluminum bronze, and manganese bronze. Group three, the most difficult to machine, consists of high strength manganese and aluminum-bronze high in iron or nickel content. Machinability ratings are listed by alloy in Table 3.

#### 1.5. Electrical and Thermal Conductivities

Electrical conductivity is customarily expressed as a percentage of The International Annealed Copper Standards (IACS) adopted in 1913 to represent the average electrical conductivity of high grade copper. Elements in solid solution with copper often have a marked effect on both the electrical and the thermal conductivity of the alloy. Alloying elements present in significant concentrations as well as low concentrations of deoxidized elements decrease both properties. Wrought alloys have higher conductivities than the comparable casting alloys; wrought alloys usually have lower concentrations and fewer alloying elements. Sound copper castings requiring at least an 85% electrical conductivity IACS require care in the preparation of their melts. Impurities such as iron, silicon, tin, zinc, aluminum, or a phosphorus deoxidizer cannot be used because small residual concentrations markedly lower conductivity. Calcium boride or lithium helps to produce sound castings having better conductivities.

The thermal conductivity of copper having an electrical conductivity of 100% IACS is 391 W/(m·K) at 20°C. The Wiedemann-Franz ratio of thermal conductivity and the product of electrical conductivity times absolute temperature are approximately constant. Many copper alloys have increasing thermal conductivity with increase in temperature, whereas electrical conductivity decreases.

Electrical conductivity is comparatively easy to measure, whereas thermal conductivity is not. Electrical conductivity values for the important cast alloys are listed in Table 2. Figure 1 schematically shows the electrical conductivity of cast copper-base alloys compared with various other cast metals and alloys. The equation  $Y = 4.184 + 3.93x$  gives an approximation of thermal conductivity in relation to electrical conductivity, where  $Y$  is in W/(m·K) at 20°C and  $x$  is the % IACS at 20°C.

#### 1.6. Bearing and Wear Properties

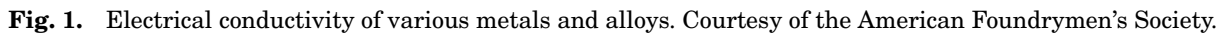
Copper alloys have been used as bearing materials (qv) because of the combination of moderate to high strength, very good corrosion resistance (Table 4), wear resistance, and self-lubricating characteristics. Bearing alloys containing copper can be placed into three groups: phosphor-bronze alloys; copper-tin-lead alloys; and aluminum-bronze and silicon-bronze alloys.

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**Table 3. Machinability Ratings for Cast Copper Alloys<sup>a</sup>**

Common name	UNS designation	Machinability rating, %
<i>Free-cutting alloys</i>		
leaded red brass	C 83600	90
	C 83800	90
leaded semired brass	C 84400	90
	C 84800	90
leaded yellow brass	C 85200	80
commercial no. 1 yellow brass	C 85400	80
yellow brass	C 85700	80
die-casting yellow brass	C 85800	80
high leaded tin-bronze	C 93200	70
	C 93500	80
bushing-bronze	C 93700	80
high leaded tin-bronze	C 93800	80
	C 94300	80
phosphor-bronze	C 94400	80
medium bronze	C 94500	80
12% nickel-silver	C 97300	70
<i>Moderately machinable alloys</i>		
leaded high strength yellow brass	C 86400	65
	C 86700	55
silicon-bronze	C 87200	40
silicon-brass	C 87400	50
silicon-brass	C 87500	50
die-cast silicon-brass	C 87800	40
stream-bronze	C 92200	40
leaded tin-bronze	C 92300	40
leaded nickel-tin-bronze		
cast	C 94800	50
heat-treated	C 94800	40
aluminum-bronze 9A	C 95200	50
aluminum-bronze 9B	C 95300	55
aluminum-bronze 9C	C 95400	60
aluminum-bronze 9D	C 95500	50
aluminum-silicon-bronze	C 95600	60
manganese-aluminum-bronze	C 95700	50
nickel-aluminum-bronze	C 95800	50
15% nickel-silver	C 97400	60
20% nickel-silver	C 97600	65
25% nickel-silver	C 97800	60
<i>Difficult-to-machine alloys</i>		
copper	C 80100	10
chrome-copper	C 81500	20
beryllium-copper	C 81700	30
high strength yellow brass	C 86200	30
	C 86300	8
	C 86500	25
tin bronze	C 90300	30
gun metal	C 90500	30
tin bronze 84:16	C 91100	10
tin bronze 81:19	C 91300	10
nickel-tin bronze		
cast	C 94700	30
heat-treated	C 94700	20
copper nickel 90:10	C 96200	10
copper nickel 70:30	C 96400	20

<sup>a</sup> Ratings are compared with free-cutting brass—60% Cu, 3% Pb, 37% Zn—which has a rating of 100%.

[illegible]





	High													
	Leaded										Leaded strength			
	Tin	High		Leaded		Leaded		yelow		Aluminum	Leaded	Leaded	Silicon	Silicon
		tin	tin	red	semired	low	high	low						
Copper	bronze	bronze	bronze	brass	brass	brass	brass	brass	brass	bronze	brass	bronze	bronze	brass
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
glycerin	A	A	A	A	A	A	A	A	A	A	A	A	A	A
hydrochloric (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
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
liquors														
black	B	B	B	B	B	C	C	C	C	B	C	C	B	B
green	C	C	C	C	C	C	C	C	C	B	C	C	C	B
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 <sup>c</sup>	A	A	A	A	A	A	A	A	A	A	A	A	A	A
molasses <sup>c</sup>	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
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
seawater	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

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Table 4. *Continued*

		High												
		High			Leaded						High			
		Leaded	leaded	Leaded	Leaded	yel-	high	yel-		Leaded	Leaded	Silicon	Silicon	
	Tin	tin	tin	red	semired	low	strength	low	Aluminum	nickel	nickel	Silicon	Silicon	
	Copper	bronze	bronze	brass	brass	brass	brass	brass	bronze	brass	bronze	brass	brass	
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 hypochloride	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 sulfide, 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
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
78 to 90%	C	C	C	C	C	C	C	C	C	B	C	C	C	C
90 to 95%	C	C	C	C	C	C	C	C	C	B	C	C	C	C
fuming	C	C	C	C	C	C	C	C	C	A	C	C	C	C
tanic 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
trichlorethylened														
dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
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
condensate	A	A	A	A	A	A	A	A	A	A	A	A	A	A
potable	A	A	A	A	A	A	B	B	B	A	A	A	A	A
whiskey <sup>c</sup>	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

<sup>a</sup> A is recommended; B, acceptable; C, not recommended (1).

<sup>b</sup> Acetylene under pressure forms an explosive compound with copper when moist or when certain impurities are present. Alloys containing less than 65% Cu are satisfactory under this use. When gas is not under pressure other copper alloys are satisfactory.

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

Phosphor-bronze alloys contain Cu, Sn or Cu, Sn, Pb, and have a residual phosphorus concentration of a few hundredths to 1%. Nickel can be added to refine the grain structure and is claimed to disperse the lead phase. Copper-tin bearings have high water resistance, high hardness, and moderately high strength.

An alloy containing 11% Sn, formerly referred to as gear bronze, is used, as its name implies, for making gears. Bronze alloys containing 18–20% Sn are successfully used for high loads and slow movement. A maximum load of 17 MPa (2500 psi) is permissible for the 17% Sn alloy. These alloys contain high amounts of phosphorus to improve hardness. Zinc in these alloys leads to seizing and galling and therefore is limited to a maximum of 0.25%.

Copper–tin–lead alloys are softer and are used as bearing material for lighter loads, below 5.5 MPa (800 psi), moving at moderate speeds. These materials include alloys UNS C 93700 (80% Cu, 10% Sn, 10% Pb), UNS C 93200 (83% Cu, 7% Sn, 7% Pb), and UNS C 93500 (85% Cu, 5% Sn, 9% Pb). Alloy C 93700 is an excellent general bearing material widely used in machine tools and in electrical and railroad equipment. Alloys C 93500 and C 93700 cost slightly less and are used in maintenance service. Alloys UNS C 93800 (78% Cu, 7% Sn, 15% Pb) and UNS C 94300 (70% Cu, 5.0% Sn, 25.0% Pb), containing higher quantities of lead, are used where high loads are encountered under poor operating conditions, that is, with poor or no lubrication, in a corrosive environment, or in dirty applications.

Aluminum bronze alloys containing 8–9% Al are widely used for bushings and bearings in light or high speed applications. Alloys containing 11% Al, both cast and heat-treated, are well suited for heavy service, such as in valve guides, rolling mill bearings, screw-down nuts, cams, and wear plates. As the aluminum content increases above 11%, the material becomes harder and stronger but ductility decreases. Alloys containing more than 13% Al have a Brinell hardness of 300 or greater, and the material is brittle. High (>13%) aluminum content alloys are often used as forming dies, particularly for forming stainless steel.

Manganese and silicon are frequently added to increase strength and hardness of aluminum bronze alloys. These elements form hard, intermetallic compounds that are imbedded in the softer matrix, producing a condition that enhances bearing and wear-resistance qualities. Aluminum bronzes generally have excellent bearing properties when used against steel. They operate efficiently with a minimum of lubrication and resist galling and scoring of the mating surface.

### 1.7. Joining Characteristics

Cast copper alloys may be joined by welding (qv), brazing, and soldering techniques with varying degrees of ease and success (see also Soldiers and brazing alloys). Table 5 lists a number of copper-base casting alloys and indicates the ease with which they can be joined by various methods.

### 1.8. Mechanical Properties

Most alloys containing tin, lead, or zinc have moderate tensile and yield strengths and high elongation. Higher tensile or yield strengths are available through the use of aluminum and manganese bronzes, silicon bronzes and bronzes, and some nickel alloys. Some of these alloys, such as beryllium–copper, chromium–copper, and some aluminum–bronze, are heat-treatable to attain maximum tensile strengths. Mechanical and physical properties for copper-base casting alloys are summarized in Table 2.

The entire group of leaded alloys are the easiest to cut and machine. Most cast alloys can be joined by welding, brazing, and soldering (Table 5).

Copper–tin bearings have high resistance to wear, high hardness, and moderately high strength. Copper–tin–lead alloys are used when a softer material is needed and moving parts are at moderate speeds and loads are light. High strength manganese–bronze alloys have high tensile strength, hardness, and resistance to shock. General uses are for slow-motion and relatively high compression applications.

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**Table 5. Joining Characteristics of Cast Copper Alloys<sup>a</sup>**

Common name	UNS designation	Weldability			Braz- ability	Solder- ability
		Oxyacet- ylene	Carbon arc	Metal arc		
copper	C 80100	NR	F	NR	E	E
chromium–copper	C 81500	NR	F	NR	G	G
beryllium–copper	C 81700	NR	NR	NR	G	G
leaded red brass	C 83600	NF	NR	F	G <sup>b</sup>	E
leaded semired brass	C 84800	NR	NR	F	G <sup>b</sup>	E
steam bronze	C 92200	NR	NR	NR	E <sup>b</sup>	E
tin bronze						
leaded	C 92300	NR	NR	NR	G <sup>b</sup>	E
high leaded	C 93200, C 93500, C 93700 C 93800, C 94300, C 94500	NR NR	NR NR	NR NR	G <sup>b</sup> P <sup>b</sup>	G G
phosphor bronze	C 94400	NR	NR	NR	G <sup>b</sup>	G
high strength yellow brass	C 86200	G	NR	G	P	P
	C 86300	P	P	G	P	P
	C 86500	P	P	P	F	F
leaded	C 86400	P	P	P	F	F
aluminum bronze						
9B <sup>c</sup>	C 95300	NR	F	G	G	G
9C <sup>c</sup>	C 95400	NR	G	E	E	G
9D <sup>c</sup>	C 95500	NR	P	G	F	G
silicon bronze	C 87200	G	P	F	F	NR
silicon brass	C 87500	F	NR	NR	F	NR
	C 97300, C 97400, C 97600,					
nickel silver	C 97800	NR	NR	NR	E	E

<sup>a</sup> E, excellent; G, good; F, fair; P, poor; NR, not recommended.

<sup>b</sup> Strain must be avoided during brazing and cooling to control cracking.

<sup>c</sup> Aluminum bronzes must use special flux for brazing and soldering.

## 2. Production Methods

### 2.1. Precautions

Care should be taken not to impair the quality of the metal as a result of the melting operation. The best practice is to select scrap of known good quality. The use of miscellaneous scrap may not be economical, despite the lower cost of such material; however, it is not common practice to make much use of virgin metals.

Ingots produced by secondary smelters and refiners and made to specifications are a good source of melting stock. Scrap, such as sprues and gates, and turnings from the foundry's own castings are very acceptable melting materials.

The melt may be exposed to gaseous and solid impurities unless suitable precautions are taken. The most deleterious of these contaminants are hydrogen or water vapor, which may produce a porous structure in the cast alloy and ruin its quality. Oily scrap may also cause gaseous contamination of the melt. If an open flame can come in contact with the melt, care should be taken to ensure a slightly oxidizing flame, preferably containing 0.1–0.2% excess oxygen.

Electric furnaces do not utilize gas as fuel, and it is possible to operate with a near-neutral atmosphere. Care must be taken not to introduce water with the charge. Damp fluxes, charcoal, and other melt additives are sources of water contamination; patched and newly lined furnaces or ladles must be thoroughly dried before use. Some foundries use electrical strip heaters to slowly remove most of the moisture and use torch flames to complete drying and fusing the surface of the refractory. Rapid drying may lead to cracked refractory. Most

molding methods can be used for the production of copper alloys. The choice of molding methods is based on cost, surface finish requirements, and tolerances.

## 2.2. Sand Casting

Sand casting is the most popular method of molding for cast copper alloys. It is the least expensive near net shape process, and pattern costs are low. Dimensional tolerance capabilities vary widely and are the least accurate when compared with other methods of casting.

Sand (usually silica), clay (bentonite), and water are the basic mixture of ingredients for green sand casting. The clay coats the sand and bonds the mixture. Water is used to help coat the clay and activate its binding capabilities. Binders for the sand are generally two-part resin–catalyst systems. The catalysts can be in liquid or gaseous form.

The dimensional capabilities and tolerances of chemically bound systems are better than those of green sand. The cost for producing components with these methods is 1.5 to 2 times higher than the cost of producing green sand.

## 2.3. Permanent-Mold Castings

The permanent mold is a reusable die usually made of cast iron, high alloy steel, or beryllium–copper. The process utilizes both gravity and low pressure pouring techniques and can be semiautomated. Sand cores can be used for internal coring. The molds are expensive to produce; therefore, the process is used when large quantities of castings are required. Some of the advantages over sand casting are tighter dimensional tolerances, excellent cast surface finish, higher mechanical properties, better internal soundness, reduced machining costs, and higher yields. Permanent molding is usually limited to short freezing range alloys such as aluminum, silicon, and manganese bronzes. Yellow brasses are also commonly used. Generally, tolerance control is within 0.010 cm/cm, although closer control is possible.

## 2.4. Die Casting

Die casting is a process by which molten metal is injected into a metal die under pressure. Automatic or semiautomatic cyclic operations are normally employed. The die assembly consists of two halves with metal cores. The die-casting machine consists of a press, a special melting furnace, an injection mechanism, and necessary controls. The die halves are fixed to the opposing platens of the press so that they match when the press is closed. The other moving parts, including the injection mechanism designed to introduce molten metal at high velocity and under pressure into the die cavity, are integrated with the press so as to operate automatically in proper sequence as the press opens and closes.

The proper coordination and regulation of such factors as speed and pressure of the injection plunger, temperatures of both the dies and the metal, and gating and venting influence the quality of die castings, especially with regard to soundness of structure and surface finish.

Die casting is a special form of permanent-mold casting. Cost is an important factor in selecting this process. Yellow brass (UNS C 85700) is the largest volume alloy to be die cast, although other permanent-mold alloys may be used. The method is used when a difficult cored section or relatively large surface area to volume components are required. Cast sections having tolerances of 0.070 cm/cm of thickness are not difficult to obtain. Die casting is best suited for large numbers of small, intricate pieces.

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### **2.5. Plaster-Mold Casting**

Plaster-mold casting is similar to sand casting but uses gypsum plaster as the molding medium. It uses a match plate or cope and drag patterns, cope and drag mold assemblies, cores, and gravity pouring. The tooling is relatively low in cost. The plaster process provides casting of superior surface finish, accurate reproduction, high dimensional accuracy, and reduced machining costs. High volume production is limited to small-parts applications that can be automated. The process is used extensively for prototyping in advance of die and permanent-mold casting designs. Nonleaded copper alloys, such as aluminum bronze, yellow brass, manganese bronze, silicon bronze, and low nickel bronze, are best suited for plaster-mold casting. Lead in the alloy must be kept to a minimum because the lead reacts with the plaster thereby causing defects. Tolerances of within 0.005 cm/cm can be achieved. Parting line tolerances are within 0.10 cm/cm.

### **2.6. Centrifugal Casting**

Centrifugal casting consists of pouring the melt into a rotating mold, which may be in either a horizontal or vertical position. Most alloys can be cast by this method. Size of castings is not a constraint. Castings from a hundred grams to several metric tons may be produced. Clean castings can be produced because dross and nonmetallics, which are lighter than the base metal, are thrown toward the surface, where they can be removed by subsequent machining. However, machining and scrap cost must be considered. Soundness is enhanced by high pressures and consequent effective feeding during the solidification process.

Mechanical properties of centrifugally cast copper alloys vary with the alloy and mold material. Centrifugal castings made in sand molds, where relatively slow cooling prevails, have poorer mechanical properties than castings made in metal or graphite molds. However, even centrifuged castings made in sand molds have higher tensile strength than the same alloy and configuration cast statically in conventional sand molds. The combination of handling molten metal and rotating equipment emphasizes the need for exercising safe operating practice and caution in the casting process.

### **2.7. Investment Casting**

Investment casting, also known as the lost-wax process, is a method for making intricate or complex castings to close dimensional tolerances. The process consists of making a pattern from materials such as plastic or wax. The patterns are assembled onto a cluster, dipped in a ceramic slurry, stuccoed with aggregate, then allowed to dry. Slurry dip and stucco steps are repeated until a 0.64–0.96 cm shell has been built. The wax is removed by flash firing or autoclaving. The shell is then fired in an oven to develop strength. Metal is melted and poured into a hot shell.

The investment-casting process offers extreme precision, excellent surface finishes, and part-to-part consistency. This method is the most costly method of producing cast components to near net shape. Its value is realized through the high production of complex castings.

### **2.8. Continuous Casting**

Continuous-casting methods are being applied to the production of copper-base alloys. The molten metal is continuously poured into the top of the water-cooled, lubricated mold, and the solid cast shape is continuously withdrawn mechanically from the bottom of the mold. The process is continuous as long as molten metal is available and the mold does not wear out. It may be made semicontinuous by casting a few meters in length, then stopping the process and removing the casting from the system; after suitable mold preparation, the process can be restarted.

**Table 6. Comparison of Casting Methods<sup>a</sup>**

Factor	Casting method						
	Sand	Die	Invest-ment	Perma-nent mold	Plaster	Centri-fugal	Contin-uous
tolerance	C	A	A	B	A	D	C
surface finish	D	B	A	C	A	D	C
thickness of section	C	D	D	C	D	A	A
pattern cost	A	E	B	C	B	A	A
ease of getting into production	A	D	B	C	B	C	C
production rate	B	A	C	C	D	B	C
cost per piece	B	A	C	C	D	A	C
flexibility as to alloy	A	D	A	D	C	A	A
limitation of size	A	D	C	B	D	A	A

<sup>a</sup> Comparisons are all relative based on letters A through E; A is most advantageous.

Where more than one strand of casting is required, a multihole, water-cooled die can be fixed to the bottom of a holding furnace and the metal withdrawn as a solid strand from the bottom of the furnace, either in a horizontal or vertical plane.

The process requires considerable equipment, and skills in casting must be acquired. Continuous casting is useful where soundness and high volume of parts are needed. The process is also used to produce shapes, such as billets, bars, and cakes, as starting materials for the wrought-product industry.

## 2.9. Comparison of Casting Methods

Table 6 compares several factors of various casting procedures. The factors are rated A through E; letter A is the most advantageous.

**Table 7. Nominal Composition of Some Casting Alloys**

Common name	UNS designation	Nominal composition, wt %						
		Cu	Sn	Pb	Zn	Fe	Al	Others
copper	C 80100	99.95						0.05 <sup>a</sup>
chrome-copper	C 81500 <sup>b</sup>	98.0 <sup>c</sup>						1.0 Cr
beryllium-copper	C 81700 <sup>b</sup>	94.25 <sup>c</sup>						1.0 Ag 0.4 Be 0.9 Co 0.9 Ni
ASTM B22								
high strength yellow brass	C 86300	63.0			25.0	3.0	6.0	3.0 Mn
gun metal	C 90500	88.0	10.0		2.0			
tin bronze 84:16	C 91100	84.0	16.0					
tin bronze 81:19	C 91300	81.0	19.0					
high leaded tin bronze	C 93700	80.0	10.0	10.0				
ASTM B61								
steam bronze	C 92200	88.0	6.0	1.5	4.5			
ASTM B62								
leaded red brass	C 83600	85.0	5.0	5.0	5.0			
ASTM B66								
phosphorus bronze	C 94400	81.0	8.0	11.0				0.35 P
high leaded tin bronze	C 93800	78.0	7.0	15.0				
medium bronze	C 94500	73.0	7.0	20.0				

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**Table 7. Continued**

Common name	UNS designation	Nominal composition, wt %						
		Cu	Sn	Pb	Zn	Fe	Al	Others
high leaded tin bronze	C 94300	70.0	5.0	25.0				
ASTM B67								
journal bronze	C 94100	70.0	5.5	18.0	3.0 <sup>a</sup>			
ASTM B148								
aluminum bronze 9A	C 95200	88.0				3.0		9.0
aluminum bronze 9B	C 95300	89.0				1.0		10.0
aluminum bronze 9C	C 95400	85.0				4.0		11.0
aluminum bronze 9D	C 95500	81.0				4.0	11.0	4.0 Ni
aluminum–silicon bronze	C 95600	91.0					7.0	2.0 Si
manganese–aluminum bronze	C 95700	75.0				3.0	8.0	12.0 Mn, 2.0 Ni
nickel–aluminum bronze	C 95800	81.0				4.0	9.0	1.0 Mn, 5.0 Ni
ASTM B176								
die-casting yellow brass	C 85800	58.0	1.0	1.0	40.0			
die-cast silicone brass	C 87800	82.0			14.0			4.0 Si
silicon–yellow brass	C 87900	65.0			34.0			1.0 Si
ASTM B584								
leaded red brass	C 83800	83.0	4.0	6.0	7.0			
leaded semired brass	C 84400	81.0	3.0	7.0	9.0			
	C 84800	76.0	3.0	6.0	15.0			
leaded yellow brass	C 85200	72.0	1.0	3.0	24.0			
commercial no. 1 yellow brass	C 85400	67.0	1.0	3.0	29.0			
yellow brass	C 85700	63.0	1.0	1.0	34.7		0.3	
high strength yellow brass	C 86200 <sup>d</sup>	64.0			26.0	3.0	4.0	3.0 Mn
leaded high strength yellow brass	C 86400	59.0		1.0	40.0	2.0 <sup>a</sup>	1.5 <sup>a</sup>	1.5 <sup>a</sup> Mn
high strength yellow brass	C 86500	58.0	0.5		39.5	1.0	1.0	1.5 <sup>a</sup> Mn
leaded high strength yellow brass	C 86700	58.0		1.0	41.0	3.0 <sup>a</sup>	3.0 <sup>a</sup>	3.5 <sup>a</sup> Mn
silicon bronze	C 87200	89.0 <sup>c</sup>	1.0 <sup>a</sup>	0.5 <sup>a</sup>	5.0 <sup>a</sup>	2.5 <sup>a</sup>	1.5 <sup>a</sup>	1.5 <sup>a</sup> Mn, 4.0 Si
silicon brass	C 87400	83.0			14.0			3.0 Si
silicon brass	C 87500	82.0			14.0			4.0 Si
tin bronze	C 90300	88.0	8.0		4.0			
leaded tin bronze	C 92300	87.0	8.0	1.0 <sup>a</sup>	4.0			
high leaded tin bronze	C 93200	83.0	7.0	7.0	3.0			
	C 93500	85.0	5.0	9.0	1.0			
nickel–tin bronze	C 94700	88.0	5.0		2.0			5.0 Ni
leaded nickel–tin bronze	C 94800	87.0	5.0	1.0 <sup>a</sup>	2.5 <sup>a</sup>			5.0 Ni
	C 94900	80.0	5.0	5.0	5.0			5.0 Ni
12% nickel–silver	C 97300	56.0	2.0	10.0	20.0			12.0 Ni
15% nickel–silver	C 97400	59.0	3.0	5.0	16.0			17.0 Ni
20% nickel–silver	C 97600	64.0	4.0	4.0	8.0			20.0 Ni
25% nickel–silver	C 97800	66.0	5.0	2.0	2.0			25.0 Ni
copper–nickel 90:10	C 96200	87.5				1.5		10.0 Ni, 0.9 Mn
copper–nickel 70:30	C 96400	68.0				0.7		30.0 Ni, 0.8 Mn

<sup>a</sup> Maximum value.

<sup>b</sup> Responds to heat treatment.

<sup>c</sup> Minimum value.

<sup>d</sup> Several compositions are available that meet mechanical property specifications.



### 3. Alloy Identification and Chemistry

The nominal chemical composition and identification of the most important copper casting alloys are listed in Table 7. These alloys are identified by name and by the Unified Numbering System. The use of names is not recommended.

#### 3.1. Effect of Various Alloying Elements

The mechanical properties of cast copper alloys are a function of alloying elements and their concentrations. The specific effects of a number of these alloying elements are given in the following sections.

##### 3.1.1. Zinc

Zinc [7740-66-6] is added to copper as a predominating alloying element in concentrations of 5–40%, forming the alloy series known as the brasses. Zinc increases the tensile strength at a significant rate up to a concentration of ca 20%, whereas the tensile strength increases only slightly more for additions of zinc of 20–40%. The Rockwell F scale hardness is substantially an increasing straight-line function with zinc additions of 5–35%. The higher zinc concentrations in high strength yellow brass alloys form a duplex alpha–beta structure.

Zinc up to 5% is added to tin bronze alloys to tighten the structure and to act as a deoxidizer, thereby aiding in producing sound castings for pressure applications. In yellow brasses zinc can impart a freedom from gas porosity because, as the melt is heated until the zinc boils, the zinc vapor sweeps the melt free of gas.

Zinc is not considered a very harmful impurity to most alloys. Cast copper–zinc alloys are described as red brasses and leaded red brasses, semired, silicon, yellow, and high strength yellow brasses. Red brasses contain zinc as the principal alloying element along with some tin and lead. Semired brasses contain less copper than do red brasses. Yellow brasses contain zinc as the principal alloying element accompanied by small amounts of tin and lead or other designated elements. High strength yellow brasses are alloys that contain zinc with smaller amounts of iron, aluminum, nickel, and lead.

##### 3.1.2. Tin

Tin [2440-31-5] added to copper in concentrations of 5–20% forms the tin–bronze alloy series. Leaded tin bronze is also produced. Typically a deoxidizer is added to the melt to produce a clean structure. Phosphorus is the usual element employed as a deoxidizer. Zinc may also be used, but it is not effective as a deoxidizer until it is present in concentrations of ca 2%. Delta tin eutectoid develops in some castings containing as little as 6–8% tin because of nonequilibrium freezing conditions. The copper–tin constitution diagram under equilibrium condition indicates delta tin should not form until the tin concentration exceeds 16% at 520°C. Tin imparts strength and hardness to copper-base alloys, making them tough and wear resistant. Worm gears are often made from tin–bronze containing 8% or more tin. Tin also enhances the corrosion resistance of copper-base alloys in nonoxidizing media.

Small amounts of tin (3–5%) are added to leaded red brass and semired brasses to increase the strength and hardness of alloys. For example, alloy UNS C 94700 (88% Cu, 5% Sn, 5% Ni, and 2% Zn) deoxidized with phosphorus, is heat-treatable to provide high strength.

Tin is usually not regarded as an impurity except in high tensile strength manganese–bronze where it is limited to 0.2% maximum. Tin lowers both the tensile strength and the ductility of the alloy.

##### 3.1.3. Lead

Lead [7439-92-1] is added to copper in amounts up to 40%. Lead is insoluble in copper-base alloys, and because of its low melting point it is found distributed in the grain boundaries of the casting. Because it imparts a certain degree of brittleness to the structure, it enhances machining operations by causing the alloy to break into chips as cutting tools are thrust into the matrix. Nonleaded alloys usually machine with the formation

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of long curls rather than chips, and the surface is not as smooth. Additions of lead up to 1.5% significantly improve machinability without a serious decrease in tensile strength. Lead concentrations of 5–25% greatly increase machinability. Alloys with lead concentrations equal to or greater than the tin content are used for bearing applications requiring resistance to both wear and friction. Lead added to copper in amounts of about 35–40% forms a useful bearing alloy.

Lead is considered undesirable in high strength manganese bronze, silicon bronze, and silicon brass. It affects the surface of silicon bronze and silicon brass, causing noticeable darkening and pockmarking.

### 3.1.4. Silicon

Silicon [7740-21-3] added to copper forms alloys of high strength and toughness along with improved corrosion resistance, particularly in acidic media. Silicon in small amounts can improve fluidity. Silicon is a very harmful impurity in leaded tin bronze alloys, however, because it contributes to lead sweat and unsoundness.

### 3.1.5. Aluminum

Aluminum [7429-90-5] added as the predominating alloying element to copper forms a series of high strength alloys called aluminum bronzes. Aluminum forms solid solutions with copper up to about 9.5%. High strength yellow brasses contain aluminum in varying amounts. Some of the aluminum-bearing alloys form a second phase (beta) and are heat-treatable. With still larger ( $>12\%$ ) amounts of aluminum, another extremely hard phase, gamma-2, forms.

Aluminum present in leaded tin bronze alloys promotes unsoundness.

### 3.1.6. Iron

Iron [7439-89-6] added to copper alloys adds strength to the silicon, aluminum, and manganese bronzes. It combines with aluminum or manganese to form hard, intermetallic compounds. The hard compounds embedded in the matrix, which have high melting points and act as a grain refiner, increase the alloy's wear-resistance qualities. Undissolved iron in the alloy leads to nonuniform hardness and interferes with machining.

### 3.1.7. Phosphorus

Phosphorus [7723-14-0] is used principally as a deoxidizer in copper and high copper alloys. The alloy should contain a minimum residual of 0.02% phosphorus to ensure complete deoxidization. Lesser amounts of residual phosphorus can form an equilibrium system with copper and oxygen. Such castings are subject to damage (embrittlement) when heated in a hydrogen atmosphere, depending on temperature and hydrogen concentration of the environment.

### 3.1.8. Boron

Boron [7440-42-8] is a commercial deoxidizer.

### 3.1.9. Manganese

Manganese [7439-96-5] is added as an alloying element in high strength brasses, where it forms compounds with other elements such as iron and aluminum. Manganese may also be used as a deoxidizer, although that is not a common usage.

### 3.1.10. Nickel

Nickel [7740-02-0] added to copper markedly whitens the resulting alloy. The element added to copper at the rate of 10–30% produces the so-called cupronickel alloys, which have very high corrosion resistance. Iron, up to a nominal 1.4%, added along with nickel significantly enhances the resistance toward cavitation or impingement corrosion. Added to bronzes, nickel refines the cast grain structure and adds toughness. Nickel

improves strength and corrosion resistance. An alloy series containing 10–25% nickel along with tin, lead, and zinc as principal alloy elements is known as the nickel–silvers. Nickel, also added to some of the high tin–gear bronze alloys to enhance wear properties, does not have deleterious effects as an impurity, and many specifications allow about 1%.

#### **3.1.11. Beryllium**

Beryllium [7440-41-7] added to copper forms a series of age- or precipitation-hardenable alloys. These heat-treatable alloys are the strongest of all known copper-base alloys (see Copper alloys, wrought copper and wrought copper alloys).

#### **3.1.12. Chromium**

Chromium [7440-47-3] also forms heat-treatable copper alloys. These alloys, in the heat-treated condition, have a Brinell hardness of about 120 and an electrical conductivity of about 80% IACS.

#### **3.1.13. Arsenic, Antimony, and Phosphorus**

Arsenic [7440-38-2], antimony [7440-36-0], and phosphorus can be added in small quantities (0.05%) to the all alpha-phase brass alloys containing less than 80% copper to inhibit the dezincification type of corrosion in yellow brass alloys.

## **4. Economic Aspects**

Casting is used for irregular external and internal shapes that are impractical, impossible, or too costly to produce using other methods. The choice of an alloy for any casting usually depends on four factors: metal cost, castability, properties, and final cost. A cost analysis determines the most economical method of producing a casting, although frequently the choice can be based on experience.

Metal cost, a minor consideration if only a few castings are made, becomes of prime importance when large amounts of metal are required, the casting is needed in large quantities or is a competitive item, or when metal cost is a significant factor in the final cost. Final cost must be considered, because the initial advantage of a lower metal cost may be eliminated by an increasing cost resulting from an inherent property of the alloy. One such property is castability.

Castability is not to be confused with fluidity, which is the ability of a molten alloy to fill a mold cavity in every detail. Castability is the ease with which an alloy responds to ordinary foundry practice without undue attention to gating, risering, melting, sand conditions, and any other factors involved in producing sound castings.

## **5. Health and Safety Factors**

During melting and pouring, certain metals, such as zinc, volatilize, enter the atmosphere, and immediately oxidize to solid particulates, forming a smoke. Some of these fumes or smokes can be hazardous to health, depending on the chemical composition of the particulate, its concentration in the off-gas, and the duration of exposure. More and more melt and casting shops are significantly controlling the atmospheric conditions in working areas by the use of adequate ventilating hoods, ducts, and exhaust fans in strategic locations. Rather than being exhausted into the atmosphere outside the operating plant, the particulates can be captured in bag-filtering and automatic collection systems (see Air pollution control methods). Care must be exercised in the design and operation of such devices to prevent hot gases or sparks from igniting the bag-filter material.

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Fires in the collecting system can be very costly. Gas temperatures are controlled by the length of the ducts between the heat source and the filter and also by the volume of gas being moved through the system. Often a cyclone duct collector is placed in the system just before the baghouse for the purpose of collecting sparks from smoldering or burning carbonaceous material to prevent them from contacting the filters in the baghouse. Workers may also wear masks.

Local and national agencies have set limits on the quantities of particulates permissible in casting-shop atmospheres and in the exhaust from collection systems. Agencies in the United States are the EPA, NIOSH, and OSHA.

Particulates collected in foundry atmospheres have been found to contain compounds of zinc, copper, lead, iron, aluminum, magnesium, and silicon as well as carbon and oily material. The specific composition and concentration of any smoke depends on the composition of the material being melted and on the melting and pouring practice.

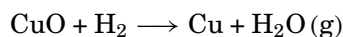
## 6. Foundry Practice

### 6.1. Copper and High Copper Alloys

Copper castings contain a minimum of 99.7% copper. High copper alloys contain more than 94% copper. The coppers are generally specified to have high electrical conductivity and therefore must be of high purity. It is usually necessary to start with ingots of fire-refined or electrolytic-grade copper, although high grade or number one copper scrap of known chemistry may also be used (see Recycling, nonferrous metals.)

Copper is susceptible to gassing and must therefore be protected from direct flame contact during melting. Copper melts can be contaminated with either hydrogen or oxygen. Hydrogen is soluble in the melt and oxygen forms copper oxide (see Copper compounds). Melts should be protected from air by the use of a melt cover such as dry charcoal or carbon pieces. A cover decreases the area of the melt exposed to air and also reduces the amount of fuming.

Copper(II) oxide [1317-38-0] can also cause porosity in the finished casting by combining with hydrogen formed by the dissociation of water in the mold material to form steam within the melt, thus causing holes during solidification.



If no cover is used, copper should be melted under a slightly oxidizing atmosphere to reduce possible hydrogen solution. The oxides floating on the melt then tend to become the cover.

Copper melt heated to a temperature 30–55°C above its melting point should be deoxidized using calcium boride [1200-99-7],  $\text{CaB}_6$ , lithium [7439-93-2], or copper–phosphorus 15% alloy. The deoxidizer is plunged beneath the melt surface. A shrink test may be made by pouring a test piece ca 4 cm in diameter by 10–13 cm in length into a mold of the same type to be used for the cast pieces. If the test piece shrinks, the melt is considered ready to pour. Experience is generally a good guide.

If the test piece contains many holes, gas is indicated and the melt may be flushed with nitrogen to control this situation. Small amounts of deoxidizer should be added to the gas-free melt until shrinking of the test piece occurs.

Cores should be made with a minimum amount of binder or volatile compounds and should also be readily collapsible because copper is susceptible to hot tearing.

Deoxidized copper is a high shrinkage material, and castings must be suitably risered to provide proper feeding. Exothermic compounds, such as iron oxide and magnesium, may be added to the top of the riser to keep the copper hot and molten to aid in feeding. Insulation and exothermic riser sleeves may also be used.

**Table 8. Properties of Copper and High Copper Alloys**

Property	Copper C 80100	Chromium–copper C 81500	Beryllium–copper C 81700
melting point, °C	1064–1083	105–1085	1029–1068
pouring temperature, °C			
light castings	1149–1204	1149–1204	1132–1188
heavy castings	1110–1166	1110–1165	1093–1149
specific gravity	8.94	8.82	8.75
dross generation	very low	high	low
gassing	high	moderate	moderate
cast yield	low	low	moderate
pattern maker's shrinkage, cm/m	1.56	2.08	1.56

Contamination of the melt with elements that remain in solid solution must be avoided, and excess deoxidizer must be controlled to obtain castings of high electrical conductivity. Properties are shown in Table 8.

Coppers and high copper alloys can be successfully cast using the centrifugal, continuous, investment, permanent, plaster, and sand molding methods.

#### 6.1.1. Uses

Copper and high copper alloys are typically used as electrical and thermal conductors. UNS C 80100 is corrosion and oxidation resistant; UNS C 81500 (chromium–copper alloy) is used structurally where strength and hardness are required; and UNS C 81700 (beryllium–copper alloy) is used structurally where high strength and hardness are required.

### 6.2. Red Brass Alloys

In forming red brass alloys, which include leaded red and leaded semired brasses, caution should be exercised to prevent gas absorption by flame impingement or the melting of oily scrap, or metal loss through excessive oxidation of the melt surface. To prevent excessive zinc volatilization, the melt must be poured as soon as it reaches the proper temperature. The melt should be finally deoxidized and cast at ca 1065–1230°C as measured with a pyrometer. Fluxing is usually not needed if clean material has been melted.

The deoxidizer (copper–phosphorus 15% alloy) is added just before pouring in a quantity calculated to result in less than 0.01% residual phosphorus. The suggested addition is ca 1 g/kg of melt. Zinc-containing scrap should be melted first, and then any ingot copper along with zinc necessary to replace any burned out during melting. The amount of make-up zinc to be added varies with practice and is judged by experience. Care should be taken not to heat the melt more than 83°C above the pouring temperature. Proper gating and risering is very important to compensate for the alloy shrinkage that occurs. Directional solidification techniques must be employed to assure the integrity of the casting. Chills are often utilized in the mold to assist the solidification direction.

Properties of red brass alloys are given in Table 9. The members of this group are cast using the centrifugal, continuous, investment, and sand molding methods. General tensile strengths vary from 170 to 210 MPa (25,000–30,000 psi) minimum as cast in sand molds.

#### 6.2.1. Uses

Leaded red brass alloys are used in plumbing goods, in fittings and small gears (UNS C 83600), and in low pressure valves and fittings and general hardware (UNS C 83800). Leaded semired brasses are used in general

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**Table 9. Properties of Red Brass Alloys**

Property	Leaded red brass		Leaded semired brass	
	C 83600	C 83800	C 84400	C 84800
melting point, °C	854–1010	843–1004	843–1060	832–954
pouring temperature, °C				
light castings	1149–1288	1149–1266	1149–1260	1149–1260
heavy castings	1066–1177	1066–1177	1066–1177	1066–1177
specific gravity	8.7–8.88	8.6–8.7	8.6–8.8	8.55–8.70
dross generation	low	low	moderate	moderate
gassing	moderate	moderate	moderate	moderate
cast yield	high	high	high	high
pattern maker's shrinkage, cm/m	1.56	1.56	1.56	1.56

hardware, low pressure valves, and fittings; ornamental casting and plumbing goods (UNS C 84400); and in cocks and faucets (UNS C 84800).

### 6.3. Tin Bronze Alloys

Tin bronze alloys are successfully melted in any type of foundry furnace. Best results are obtained by protecting the melt from either direct flame contact or excessive oxidation. Melting should be carried out in a slightly oxidizing atmosphere. Rapid melting is desired to reduce the opportunity of gas absorption in the melt. Fracture tests exhibit an open grain and discoloration when the melt has been exposed to reducing conditions, contaminants such as Al and Si, or excessive superheating. Oily scrap should be avoided. Pouring temperatures range from 1010 to 1260°C and should be measured with a pyrometer. Pouring should take place at a temperature that gives the best results for a particular gating or risering system. The temperature should be high enough to avoid internal shrinkage that can lead to voids, because gating and risering may not always completely eliminate such internal unsoundness. Directional solidification needs to be planned as part of the gating system.

Alloy scrap should be melted first and then have any copper added to the melt. It is general practice to deoxidize the melt before pouring. The alloys may be degassed by superheating ca 40°C to boil the zinc and allowing it to quietly air cool before pouring. Zinc must be added to replace the amount boiled off. Flushing the melt with dry nitrogen also degasses the melt. Lost zinc must be replaced. Gating and risering of castings of alloys is very important, and careful consideration should be exercised for each configuration. Sound castings are made by following fundamental foundry techniques.

Properties of copper–tin–lead alloys are listed in Table 10. The members of the tin bronze alloy group are cast using the centrifugal, continuous, permanent, plaster, and sand molding methods. Leaded tin–bronze alloys have minimum tensile strengths of 234–248 MPa (34,000–36,000 psi) as cast in sand molds, whereas the minimum tensile strengths for high leaded tin–bronze alloys are 138–207 MPa (20,000–30,000). The values are based on measurement of test bars cast in sand molds.

#### 6.3.1. Uses

Leaded tin bronzes are used as valves and as fittings for pressure parts (UNS C 92200) and for high pressure steam (UNS C 92300). The high leaded tin bronze alloys are used as bearings and bushings (UNS C 93200); as small bearings, bushings, and backing for babbitt-lined bearings (UNS C 93500); as high speed and high pressure bearings (UNS C 93700); as general service, moderate pressure, acid mine water exposure bearings (UNS C 93800); and as high speed and light load bearings (UNS C 94300).

**Table 10. Properties of Tin-Bronze Alloys**

Property	Gun metal C 90500	Tin bronze 84:16 C 91100	Tin bronze 81:19 C 91300	Steam bronze C 92200	Leaded tin bronze C 92300	High leaded tin bronze				
						C 93200	C 93500	C 93700	C 93800	C 94300
melting point, °C	854–999	818–960	818–889	826–988	854–999	954–982	854–999	762–929	854–954	899–927
pour <i>t</i> , °C										
light castings	1093– 1260	1093– 1232	1093– 1204	1093– 1260	1149– 1260	1093– 1232	1038– 1204	1093– 1232	1093– 1232	1093– 1204
heavy castings	1038– 1149	1038– 1121	1038– 1093	1038– 1149	1049– 1149	1038– 1121	1038– 1204	1010– 1149	1038– 1149	1010– 1093
specific gravity	8.7			8.6–8.8	8.7–8.87	8.85–8.9	8.87	8.9–9.1	9.1–9.4	9.2–9.5
dross	low	low	low	low	low	low	low	low	low	low
generation gassing	moderate	moderate to high	moderate to high	moderate	moderate	moderate	moderate	moderate	moderate	moderate to high
cast yield shrinkage, <sup>a</sup> cm/m	moderate 1.56	moderate 1.56	moderate 1.56	moderate 1.56–1.82	moderate 1.56–1.82	high 1.56–1.82	high 1.56	high 1.04–1.56	high 1.56	high 1.56

<sup>a</sup> Pattern maker's shrinkage.

#### 6.4. Manganese Bronze Alloys

The melt should be heated to the highest temperature without causing excessive zinc boil or flare, and pouring temperature is important enough to be measured. Zinc losses can substantially change the composition of the casting. Manganese bronze alloys are dross formers and therefore tend to develop their own melt covers. However, if open flame melting is practiced, a flux cover can be used. Because the alloys form dross (oxidation of zinc, aluminum, and manganese) readily, choke gates, strainer cores, and pouring basins should be arranged to cause the melt to enter the mold with as little turbulence as possible.

Manganese bronze alloys have high shrink characteristics, and special attention must be given to gating and risering systems for individual castings. Hot tops and insulated sleeves are often used in casting manganese bronze because of an insulating effect on the riser, thus promoting better feeding to the casting. Good castings can be produced if the composition is controlled and good melting, gating, and risering practices are followed.

The alloys in this series have been cast using centrifugal, continuous, die, investment, permanent, plaster, and sand molding systems. Table 11 lists properties and characteristics of manganese-bronze alloys. The minimum tensile strength for leaded high strength yellow brass is 413 MPa (60,000 psi) for sand-cast test bars, and the minimum tensile strength for high strength yellow brasses varies from 448 to 758 MPa (65,000–110,000 psi).

##### 6.4.1. Uses

The general uses for the manganese alloy group are alloy UNS C 86200, as marine fittings, gears, and gun mounts; alloy UNS C 86300 as bearings and bushings; and alloy UNS C 86400, leaded manganese bronze, as free-machining manganese bronze, valve stems, marine fittings, light duty gears, and propellers.

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**Table 11. Properties of High Strength Yellow Brass<sup>a</sup>**

Property	Leaded C 86400	Nonleaded		
		C 86200	C 86500	C 86300
melting point, °C	860–880	899–927	862–880	885–923
pouring temperature, °C				
light castings	1038–1121	1066–1177	1038–1093	1066–1177
heavy castings	954–1038	982–1066	954–1038	982–1066
specific gravity	8.0–8.4	7.9	8.0–8.5	7.7–8.0
dross generation	high	high	high	high
gassing	low	low	low	low
cast yield	low	low	low	low
pattern maker's shrinkage, cm/m	1.82–2.08	2.08–2.60	1.82–2.34	2.08–2.60

<sup>a</sup> Manganese-bronze alloys.

**Table 12. Properties of Aluminum Bronze Alloys**

Property	C 95200	C 95300	C 95400	C 95500
melting point, °C	1038–1043	1038–1052	1027–1038	1038–1054
pouring temperature, °C				
light castings	1121–1204	1121–1204	1260	1232
heavy castings	1093–1149	1066–1149	1777	1066
specific gravity	7.3–7.5	7.3–7.65	7.50	7.49–7.66
dross generation	high	high	high	high
gassing	moderate	moderate	moderate	moderate
shrinkage, <sup>a</sup> cm/m	2.60–2.86	1.82–2.60	1.82–2.60	2.08

<sup>a</sup> Pattern maker's shrinkage.

### 6.5. Aluminum Bronze Alloys

The melting precautions for aluminum bronzes are basically the same as those for the other copper-base alloys. The danger of gas absorption is not as great as with tin bronze alloys because of the protective film of aluminum oxide on the surface of the melt. Nevertheless, the alloys do dissolve gas and therefore precautions must be taken to prevent this. Although pouring temperatures are not as critical, temperature control is needed. The pouring range is 1065–1260°C, depending on casting size and section; ladle surfaces should be kept well skimmed during pouring, and the melt should be exposed to air as little as possible. The shortest distance from the pouring ladle to the mold should be used to hold turbulence to an absolute minimum. Every precaution to eliminate dross should be taken.

The gating and risering system for cast aluminum bronze is extremely important and must be arranged to introduce the metal quietly at the lowest portion of the mold. The alloys shrink well; hence the gating and risering must be well adapted to the particular casting. See Table 12 for properties of these alloys. Alloys C 95300, C 95400, and C 95500 are heat-treatable for increased mechanical properties and the last two should be temper-annealed if used in a corrosive environment.

Aluminum bronze alloys have been successfully cast in the centrifugal, continuous, permanent, plaster, and sand molding methods. Depending on the alloy, the minimum tensile strengths of sand-cast test bars are 448–620 MPa (65,000–90,000 psi).

#### 6.5.1. Uses

Aluminum bronze alloy UNS C 95200 is used as acid-resistant pumps, pump rods, bushings, and gears; alloy UNS C 95300, as pickling baskets, gears, and marine equipment; alloy UNS C 95400, as bearings, gears, valve



**Table 13. Properties of Silicon Bronze and Silicon Brass Alloys**

Property	Silicon-bronze C 87200	Silicon-brass	
		C 87400	C 87500
melting point, °C	860–971	821–916	821–917
pouring temperature, °C			
light castings	1093–1177	1093–1177	1093–1177
heavy castings	1038–1066	1038–1066	1038–1066
specific gravity	8.30–8.44	8.30–8.44	8.30–8.44
dross generation	low	low	low
gassing	high	moderate to high	moderate to high
casting yield	moderate	moderate	moderate
pattern maker's shrinkage, cm/m	1.82	1.82	1.82

seats, valve guides, and pickling hooks; and alloy UNS C 95500, as valve guides and seats, corrosion-resistant parts, bushings, gears, and worms.

## 6.6. Silicon Bronze and Silicon Brass Alloys

For silicon-containing alloys best casting results are obtained if the melting is accomplished using slightly oxidizing conditions. Rapid heating to the melting point is required to control dissolved gases in the melt. Superheating the melt to ca 85°C above the pouring temperature is desired. Undisturbed cooling to the pouring temperature allows the dross to float on the melt surface. Both melting and pouring temperatures are important and should be measured. Pouring temperatures for these alloys are 1040–1175°C, depending on size and section thickness of the casting. Prolonged holding of the melt at pouring temperature should be avoided. Molds should be ready to receive the melt as soon as it is at the proper temperature. Melting oily scrap should be avoided. Silicon is a powerful deoxidizing element and can easily be lost from the melt in the form of dross.

Covers for the melt can be used. Preburned charcoal has been successfully used as a cover and is applied hot directly from the preburner. Fluxing and deoxidation is not necessary because of the strong affinity silicon has for oxygen. Silicon-bearing scrap must be kept segregated from other scrap, because silicon as an impurity in other alloys can promote a very coarse dendritic structure and weak porous castings.

If gas has been absorbed, some degassing treatment is necessary. The melt may be flushed using dry nitrogen or a degassing flux may be used. Copper–silicon alloys shrink less than manganese bronze and aluminum bronze but more than tin bronze. Good gating and risering systems are required. The properties of these alloys are listed in Table 13.

The alloys in the copper–silicon group have been cast using centrifugal, investment, die, permanent, plaster, and sand molding methods. The minimum tensile strengths for sand-cast test bars are 310–413 MPa (45,000–60,000 psi).

### 6.6.1. Uses

Uses for copper–silicon alloys are silicon bronze, UNS C 87200, as bearings, pumps, valve parts, marine fittings, and corrosion-resistant castings; silicon brass UNS C 87400 as bearings, gears, impellers, valve stems, and clamps; and silicon brass UNS C 87500 as small propellers, valve stems, gears, and bearings.

**Table 14. Properties of Copper–Nickel Alloys and Leaded Nickel Bronze and Brass**

Property	Copper–nickel		Leaded nickel bronze		Leaded nickel brass C 97300
	C 96200	C 96400	C 97600	C 97800	
melting point, °C	1099–1149	1171–1238	1108–1143	1140–1180	1010–1040
pouring temperature, °C					
light castings	1316–1427	1371–1483	1260–1427	1316–1427	1204–1316
heavy castings	1204–1316	1316–1399	1232–1316	1260–1316	1993–1204
specific gravity	8.94	8.94	8.8–8.9	8.8–8.9	8.9–8.95
dross generation	low	moderate	moderate to high	moderate to high	high
gassing	high	high	moderate to high	moderate to high	moderate
cast yield	low	low	moderate	moderate	moderate
pattern maker's shrinkage, cm/m	1.56	1.82	1.56	1.56	1.04–1.56

### 6.7. Copper–Nickel and Leaded Nickel Bronze and Brass Alloys

High pouring temperatures cause most casting troubles with this group. The temperatures make a sand mold of low permeability practically unusable because the steam generated may exceed the venting power of the sand. Gases dissolve more readily at the higher temperatures and should be removed before pouring the melt. Degasifiers are used as a matter of standard practice. Copper–nickel alloys should be melted under slightly oxidizing conditions. Scrap must be clean. Cutting oils or compounds or other organic matter must be removed before melting to control dissolved gases in the melt that can lead to inferior castings.

Time must be allowed for the degasifier to be effective, and the treated melt should be tested with a so-called pitch test to determine the condition of the melt.

An accurate and rapid method for evaluating the gas content of melts has been developed. The method consists of solidifying a sample of the melt in a vacuum and measuring the degree of swelling in the solidified sample. Melting and pouring temperatures must be controlled by measurement and the melt poured at 1095–1425°C, depending on the alloy, casting size, and section thickness. Gating and risering are especially important, and careful consideration of the particular casting must be made.

Properties of copper–nickel alloys are listed in Table 14. The alloys in the copper–nickel group have been successfully cast using the centrifugal, investment, permanent, and sand molding methods. The minimum tensile strengths on test bars cast in sand molds are 207–310 MPa (30,000–45,000 psi).

#### 6.7.1. Uses

Copper–nickel–iron alloys, UNS C 96200 (90:10 copper:nickel) and UNS C 96400 (70:30 copper:nickel), are used in corrosion-resistant marine (seawater) applications. UNS C 96400 is used for corrosion-resistant marine elbows, flanges, valves, and pumps. Leaded nickel–brass, UNS C 97300 (12% nickel–silver), is used for hardware fittings, valves, and statuary and ornamental castings.

The leaded nickel bronzes, UNS 97600 (20% nickel–silver) and UNS C 97800 (25% nickel–silver), are used for marine, ornamental, and sanitary castings, and valves and pumps, and for ornamental hardware, sanitary castings, valves, and musical instrument parts, respectively.

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