

# Aluminum Bronzes

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## Introduction

The aluminum bronzes are a family of copper-based alloys offering a combination of mechanical and chemical properties unmatched by any other alloy series. This feature often makes aluminum bronzes the first choice — and sometimes the only logical choice — for demanding applications. What are these attributes?

**Excellent strength**, similar to that of low alloy steels

**Excellent corrosion resistance**, especially in seawater and similar environments, where the alloys often outperform many stainless steels

**Favorable high temperature properties**, for short or long term usage

**Good resistance to fatigue**, ensuring a long service life

**Good resistance to creep**, making the alloys useful at elevated temperatures

**Oxidation resistance**, for exposure at elevated temperatures and in oxidizing environments

**Ease of casting and fabrication**, when compared to many materials used for similar purposes

**High hardness and wear resistance**, providing excellent bearing properties in arduous applications

**Ductility**, which, like that for all copper alloys, is not diminished at low temperatures;

**Good weldability**, making fabrication economical

**Readily machined**, when compared with other high-duty alloys

**Low magnetic susceptibility**, useful for many special applications, and

**Ready availability**, in cast or wrought forms.

## Applications

The aluminum bronzes comprise a wide range of compositions, and alloys can be chosen with a correspondingly wide range of properties to suit many types of duty. In fact, the mix of properties available is so varied that alloy selection needs to be carefully considered, and expert advice is always useful.



**Photo 1.** Centrifugally cast nickel-aluminum bronze high-pressure flange for a sub-sea weapons ejection system. Alloy C95800 was selected for this application for its combination of high yield strength (35 ksi, 241 Mpa minimum as cast), excellent seawater corrosion resistance and galvanic compatibility with mating materials. (Photo courtesy MetalTek, Inc., [www.metaltelkint.com](http://www.metaltelkint.com).)



**Photo 2.** Clutch components for a shipboard winch, centrifugally cast in aluminum bronze alloy C95400. The inside diameter surfaces of these castings are actually metal-matrix composite structures containing non-metallic anti-wear particles, while the outer diameter is cast to net shape. Application of the continuous casting process to produce this innovative technique extended the life of the clutch component by 20-fold, and near net shape casting reduced the cost of finish machining. (Photo courtesy MetalTek, Inc., [www.metaltelkint.com](http://www.metaltelkint.com).)



**Photo 3.** Propeller shaft seal, centrifugally cast in nickel-aluminum bronze. Alloy C95800 was specified for this application for its seawater corrosion resistance, non-magnetic properties and good anti-galling characteristics against steel (the propeller shaft). Small flats were intentionally cast into the blank, which was then cut transversely and finish machined to the proper inside diameter. Note that the outside diameter is cast to net shape and does not require further machining. (Photo courtesy MetalTek, Inc., [www.metalttekint.com](http://www.metalttekint.com).)

Where are all these properties best employed?

Simply put, aluminum bronzes are used where other materials might fail prematurely or would be more expensive to buy or fabricate. For example, the alloys find widespread applications in chemical, petrochemical and desalination plants; in marine, offshore and shipboard hardware and equipment (**Photos 1-4**); in power generation (**Photo 5**), aircraft, automotive and railway engineering; and in the iron and steel-making, electrical manufacturing and building industries (**Photo 6**).

These areas of application are best discussed with reference to the primary service property required of the alloy, allowing for the fact that it is normally a combination of several properties that finally governs the selection of a particular material. As to the choice of product form, it is worth noting that the excellent mechanical properties obtainable from both cast and wrought aluminum bronzes makes it possible in many applications to interchange the manufacturing method in order to achieve maximum economy.



**Photo 4.** Nickel-aluminum bronze (alloy C95800) hub for a variable pitch naval propeller. The alloy was selected for its high strength, non-magnetic properties, cavitation resistance and galvanic compatibility with the propeller blades. Nickel-aluminum bronze exhibits good anti-galling characteristics against itself, an important property in this application since the propeller blades, which are also cast in nickel-aluminum bronze, rotate within the cylindrical openings on the sides of the hub. (Photo courtesy MetalTek, Inc., [www.metalttekint.com](http://www.metalttekint.com))



**Photo 5.** Wear rings for a large hydroturbine, centrifugally cast in nickel-aluminum bronze, alloy C95800. Nickel-aluminum bronze was selected for these rings, which operate under a hydrostatic head as large as 400 ft (122 m), for the alloy's proven anti-galling properties and excellent galvanic corrosion resistance with respect to the austenitic stainless steel (Type 304 and Nitonic 60) rotating runner components against which the rings operate. Passive nickel-aluminum bronzes are galvanically compatible with several corrosion-resistant ferrous materials, including titanium and its alloys. Rings of the type illustrated here have achieved more than 20 years of service in the Hoover, Grand Coulee, and other dams, and

in numerous hydroturbine installations around the world. (Photo courtesy MetalTek, Inc., [www.metaltekint.com](http://www.metaltekint.com).)



**Photo 6.** Continuous cast gear-wheel blanks, aluminum bronze, alloy C95400. This alloy, like other aluminum bronzes, is known for its high as-cast strength (35 ksi, 221 MPa YS; 85 ksi, 586 MPa UTS) and favorable anti-wear properties. Note that the gear-wheel spokes are cast as part of the blank, thereby reducing the extent of finish machining operations. (Photo courtesy MetalTek, Inc., [www.metaltekint.com](http://www.metaltekint.com).)

**Table 1** contains a list of typical products, both cast and wrought, manufactured from aluminum bronzes. It is by no means an exhaustive list as new applications are constantly being developed. Note that many applications are related to marine environments because of the outstanding performance of aluminum bronzes in seawater.

**Table 1. Typical Applications for Aluminum Bronzes**

| <b>FOUNDRY PRODUCTS</b>                 |                              |
|---|------------------------------|
| Impellers                               | Bearings                     |
| Propellers                              | Gear selector forks          |
| Shafts                                  | Synchronizing rings          |
| Pumps & valves                          | Non-sparking tools           |
| Water cooled compressors                | Glass moulds                 |
| Tubesheets & other heat exchanger parts | Pipe fittings                |
| Channel covers                          | Rudders & Propeller brackets |
| Gears & Gear blanks                     | Die-cast components          |
| Deep drawing dies                       | Continuous cast bar & shapes |
| Pickling equipment                      | Centrifugal castings         |
| Rolling Mill equipment                  |                              |
| Bushes                                  |                              |

| <b>WROUGHT PRODUCTS</b>         |                        |
|---------------------------------|------------------------|
| Drop forgings                   | Chain                  |
| Tubesheets                      | Impellers              |
| Tubes & Shells                  | Compressor blades      |
| Pressure vessels                | Shafting               |
| Reaction & Distillation vessels | Gears                  |
| Pipe work                       | Non-sparking tools     |
| Wear plates                     | Non-magnetic equipment |
| Springs                         | Masonry fixings        |
| Bearings                        | Rod, bar & shapes      |
| Fasteners                       | Free hammer forgings   |
| Valve spindles                  |                        |

In addition, aluminum bronzes are extensively used as metal-sprayed or weld-deposited surfacing materials, generally over steel substrates, in order to provide wear, corrosion and sparking resistance.

### **Effect of Alloying Elements**

In addition to aluminum, which ranges from 5% to 14% in these alloys, the alloying elements most commonly used in aluminum bronzes are nickel, iron, manganese, silicon and tin. The mechanical properties of aluminum bronze depend primarily on aluminum content; however, varying proportions of these secondary additions result in sub-classifications of the family, as described below.

The four principal types of aluminum bronzes are:

1. *The low alloy, single-phase (face-centered cubic) alpha alloys containing less than 8% aluminum.* These alloys have a good ductility, both hot and cold, and are well suited for cold working into tube, sheet, strip and wire. Alloys of this type containing 3% iron are single-phase at compositions exceeding 9% aluminum.

- *The more highly alloyed, two-phase (duplex) alloys containing from 8% to 11% aluminum and, usually, additions of iron and nickel, for higher strength.* As aluminum content is increased to between 8% and 10%, the alloys are progressively strengthened by appearance of the harder body-centered cubic beta phase, which additionally makes the bronzes more suitable for hot working and casting. Even greater strength and hardness is developed in alloys containing more than 10% Al. Such alloys are favored for specialized applications requiring superior wear resistance.

The other alloying elements mentioned earlier also modify the structure and thereby increase strength and corrosion resistance: iron improves tensile strength and acts as a grain refiner; nickel improves yield (proof) stress and corrosion resistance and has a beneficial stabilizing effect on the metallurgical structure; manganese also performs a stabilizing function.

- *The copper-aluminum-silicon alloys, or silicon-aluminum bronzes.* These are mainly alpha-phase alloys and therefore have good strength and ductility: Alloys having silicon contents ranging up to about 2% and aluminum to about 6% are known as aluminum-silicon bronzes; these alloys are stronger than unmodified single-phase aluminum bronzes and can be cast and hot-worked more readily. Like other aluminum bronzes, they have a low magnetic permeability and excellent resistance to shock loading. Silicon also improves machinability. The alloys are available in wrought and cast forms.
- *The copper-manganese-aluminum alloys, or manganese-aluminum bronzes.* These alloys have good castability and were, in fact, developed primarily for the manufacture of propellers. Manganese, at about 13%, is the major alloying addition in a series of manganese-aluminum bronzes in which aluminum levels range between 8 and 9%. Although not so strong as other aluminum bronzes, the alloys' foundry properties are better. They also have good resistance to impingement and cavitation and can be heat treated to give low magnetic permeability. They have excellent weldability.

## **Mechanical Properties**

### **Tensile Strength**

Some aluminum bronzes exhibit strengths comparable to low alloy steels and many are stronger than most stainless steels. Furthermore, the alloys retain a substantial proportion of their strength at elevated temperature, and at low temperatures, they gain strength slightly while retaining ductility. Shear strength can be estimated as being two thirds of the tensile strength.

### **Yield (Proof) Strength**

Yield (proof) strength is a more useful property than tensile strength since it is a measure of the stress needed to cause a measurable permanent (non-elastic) deformation, *i.e.*, far lower than the stress needed to cause failure. However, yield strength is not quite so easy to measure as is tensile strength in this case because, unlike steels, copper alloys do not show a sudden "yield" deformation when stress is



increased past a critical value, so "proof strength" is a more appropriate term. Values may be given with respect to various percentages of permanent deformation; in the U.S.A., for example, yield stress for most copper alloys is expressed as the stress corresponding to 0.5% extension under load, whereas for certain high-strength alloys such as C63020, it is given as the stress corresponding to a 0.2% strain offset to the linear (Hooke's Law) portion of the engineering stress-strain curve. Comparison of values therefore needs care.

### Hardness

The hardness of aluminum bronzes increases with aluminum (and other alloy) content as well as with stresses caused through cold working. Some manganese- and manganese-nickel-aluminum bronzes exhibit martensitic transformations similar to those seen in steels, but while these reactions produce higher mechanical properties, they are not generally thought of as primary strengthening mechanisms.

### Ductility

Most aluminum bronzes show ample ductility to provide adequate service life and to resist fatigue. Again, values attainable vary with alloy content and amount of prior cold work. Elongation figures decrease as the alloys get harder, the ranges shown in the table below reflect this.

**Table 2. Typical Mechanical Property Ranges for Commercial Wrought Aluminum Bronzes**

| Product Form    | Tensile strength |          | Yield Strength, 0.5% Extension |          | Elongation % | Hardness, HR <sub>B</sub> |
|-----------------|------------------|----------|--------------------------------|----------|--------------|---------------------------|
|                 | ksi              | MPa      | Ksi                            | MPa      |              |                           |
| <b>Plate</b>    | 50-65            | 350-450  | 17-27                          | 117-165  | 30           | 85                        |
| <b>Sheet</b>    | 50-120           | 360-830  | 17-27                          | 117-700  | 25-8         | 60-100                    |
| <b>Strip</b>    | 50-145           | 360-1000 | 17-135*                        | 117-930* | 45-1         | 60-72**                   |
| <b>Bar</b>      | 75-100           | 520-690  | 35-50                          | 240-350  | 92-80        | 85                        |
| <b>Rod</b>      | 60-120           | 410-810  | 30-75                          | 240-520  | 64-1         | 29-98                     |
| <b>Wire</b>     | 60-140           | 410-960  |                                |          | 67-1         |                           |
| <b>Tube</b>     | 60               | 410      | 27                             | 180      | 55           | 77 (HR <sub>F</sub> )     |
| <b>Forgings</b> | 80               | 540      | 40                             | 260      | 30           | 78                        |

\*(0.2% offset)

\*\* (HR<sub>30T</sub>)

*Note: These are generalizations based on most common uses. A comprehensive list of properties for UNS-listed alloys can be found at <http://properties.copper.org/>.*

**Table 3. Typical Mechanical Properties for Commercial Cast Aluminum Bronzes**



| Approx. alloy composition*:<br>Alloy Type                                      | Tensile Strength |                   | 0.5% Yield Strength |                   | Elongation | Hardness (Brinnell) |
|--|------------------|-------------------|---------------------|-------------------|------------|---------------------|
|  | kips             | N/mm <sup>2</sup> | kips                | N/mm <sup>2</sup> | %          | HB                  |
| <b>9% Al, 3%Fe<br/>Aluminum<br/>Bronze</b>                                     | 80               | 550               | 27                  | 190               | 35         | 125                 |
| <b>10%Al, 5%Ni,<br/>4%Fe, 1%Mn<br/>Nickel-<br/>Aluminum<br/>Bronze</b>         | 95               | 660               | 40                  | 260               | 25         | 160                 |
| <b>11%Al, 4%Ni,<br/>4%Fe, Nickel<br/>Aluminum<br/>Bronze, heat<br/>treated</b> | 120              | 830               | 70                  | 470               | 10         | 230                 |
| <b>18%Mn, 8%Al,<br/>3%Fe, 2%Ni<br/>Manganese<br/>Bronze</b>                    | 90               | 600               | 40                  | 270               | 15         | 220                 |
| <b>13%Al, 4%Fe<br/>(bearing<br/>material)</b>                                  |                  |                   |                     |                   |            | 250                 |

\*Balance Cu.

Note: These values are approximate for sand-cast specimens, and properties vary with composition, section thickness, casting conditions and other variables. Centrifugal castings will produce similar properties. Values for continuous castings will be higher and those for castings made in permanent molds (die castings) will be higher still. Mechanical and physical properties of UNS alloys can be accessed at <http://properties.copper.org>.

## Wear Resistance

From the standpoint of wear resistance, aluminum bronzes often provide excellent service in both cast and wrought forms. Metal-sprayed or welded overlay deposits of aluminum bronze on steel also provide effective wear-resistant surfaces. At the high end of the wear- and abrasion-resistance spectrum are special aluminum bronze alloys containing up to 14% aluminum, whose applications include dies for deep drawing and molds for die casting, casting of glass bottles and pressing of vinyl records. Such alloys are quite brittle and are exclusively used as overlays.

## Bearing and Frictional Properties

Aluminum bronzes are used as bearing materials and heavy-duty guides where other materials would fail quickly. They thrive on heavy loads, shocks and harsh working environments and so are found in steel works, in agricultural, mining and earthmoving equipment, and as bridge bearings and other structural and architectural applications. In rotating applications, best results are usually achieved when running aluminum bronzes

against hardened surfaces. When lubrication of sliding surfaces is less than ideal, aluminum bronzes are superior to ferrous materials. Both wrought and cast alloys are used. Permanent mold (also known as gravity or low-pressure die casting) provides an excellent production method for the quantity production of such low-friction items as selector forks for gearboxes. Additional information about bronze sleeve bearings can be found at [http://www.copper.org/industrial/bronze\\_bearing.htm](http://www.copper.org/industrial/bronze_bearing.htm).

### **Shock Resistance**

Aluminum bronze alloys, and in particular the wrought products, have excellent resistance to shock provided, as always, that the material is sound, and undue stress concentrations are avoided in design.

### **Fatigue Strength**

Aluminum bronzes possess exceptional resistance to fatigue, which is one of the most common causes of deterioration in marine engineering equipment. This property helps to give the alloys their excellent resistance to corrosion fatigue that makes them suitable for use as propellers and in pumps.

### **Damping Capacity**

Aluminum Bronzes are twice as effective as steel in their ability to dampen vibrations.

### **Magnetic Permeability**

Aluminum bronzes can be made with exceptionally low magnetic permeability and are therefore ideal for non-magnetic instrumentation, survey vessels, mine counter-measure craft and other marine parts where permeability must not exceed 1.05. The magnetic permeability of certain aluminum bronzes is often less than 1.01, whereas that of austenitic stainless steels can be higher than this value if excessive ferrite is present.

### **Non-Sparking Characteristics**

Excellent non-sparking characteristics make aluminum bronzes suitable for the manufacture of tools and equipment used in the handling of explosives, in mines, petroleum and chemical plants, gas-handling equipment and similar applications.

### **Corrosion resistance**

Aluminum bronzes can be used in environments that are far more aggressive than are tolerated by most other metals, including even copper and the brasses used for general purposes. They can provide heavy-duty service at higher temperatures, in seawater environments and in the presence of many chemicals and acids. Much useful work has been done to characterize the corrosion resistance of these alloys so that best use can be made of them.

Like many copper alloys, aluminum bronzes also resist biofouling in both fresh and saline waters. This property is useful in propellers and especially so in seawater piping

systems aboard ships and offshore platforms where, for example, fire safety systems depend on fouling-free piping for maximum flow.

**Table 4. Corrosion Resistance Guide**

*Aluminum Bronze alloys may be considered for service with the following chemicals, particularly where there is a combination of stress and erosion, but selection must take account of the anticipated temperature, concentration and other service conditions.*

|                   |                               |                       |                          |
|-------------------|-------------------------------|-----------------------|--------------------------|
| Acetic Acid       | Carbolic Acid                 | Glucose               | Sewage                   |
| Acetic Anhydride  | Carbon Dioxide<br>and         | Glycerin              | Soaps                    |
| Acetate Solvents  | Carbonic Acid                 | Glycerol              | Sodium Bisulphate        |
| Acetone           | Carbon<br>Tetrachloride       | Hydrocarbon<br>Gases  | Sodium Carbonate         |
| Alcohols          | Caustic Potash                | Hydrochloric Acid     | Sodium Chloride          |
| Aldehydes         | Caustic Soda                  | Hydrofluoric Acid     | Sodium<br>Hypochlorite   |
| Aluminum Chloride | Chlorine (dry)                | Hydrogen              | Sodium Nitrate           |
| Aluminum Fluoride | Chloroform                    | Inert Gases           | Sodium Silicate          |
| Aluminum          | Citric Acid                   | Lactic Acid           | Sodium Sulfate           |
| Hydroxide         |                               |                       |                          |
| Aluminum Sulfate  | Coal Tar                      | Magnesium<br>Chloride | Sodium Sulfide           |
| Ammonia (dry)     | Coal Tar Solvents             | Mineral Oils          | Sulfur                   |
| Amyl Chloride     | Copper Sulfate                | Naphthenic Acids      | Sulfuric Acid            |
| Asphalt           | Esters                        | Nickel Sulfate        | Sulfurous Acid           |
| Barium Chloride   | Ethers                        | Nitrogen              | (moist SO <sub>2</sub> ) |
| Benzole           | Fats                          | Oxalic Acid           | Tannic Acid              |
| Borax             | Fatty Acids                   | Oxygen                | Tartaric Acid            |
| Boric Acid        | (Oleic, Palmytic,<br>Stearic) | Paints                | Trichlorethylene         |
| Brine             | Fluosilicic Acid              | Petroleum products    | Tri-Sodium<br>Phosphate  |
| Bromine (dry)     | Formaldehyde                  | Phosphoric Acid       | Zinc Chloride            |
| Calcium Chloride  | Formic Acid                   | Pickling solutions    | Zinc Sulfate             |
| Calcium Hydroxide | Freon                         | Potassium Sulfate     |                          |
| Calcium           | Fuel Gases                    | Refrigeration         |                          |
| Hypochlorite      |                               | Gases                 |                          |
| Cane Sugar        | Gelatin                       | Seawater              |                          |
| Liquors           |                               |                       |                          |

**Freedom from Oxide Flaking**

The outstanding corrosion resistance of aluminum bronzes in marine and chemical processing environments is due to the formation of an intrinsic, thin but tough adherent film of aluminum oxide. This film is self-healing and, once formed, prevents further

oxidation and consequently eliminates the exfoliation of oxides so often encountered with ferrous alloys. This property, combined with the alloys' corrosion resistance and creep and fatigue properties at elevated temperature makes aluminum bronzes ideal for high temperature service. The aluminum bronzes have excellent resistance to stress corrosion cracking and corrosion fatigue; in fact, some alloys are especially chosen for these attributes. They are also rarely, if at all, susceptible to pitting and are generally far more resistant to selective attack than brasses.

Because strength is comparable to many ferrous alloys, it is possible, without radical re-design, to substitute aluminum bronzes where even mild corrosion of ferrous components is a potential problem. This applies particularly in critical areas of plant operation such as pumps and valves. **Table 5** gives a comparison of the resistance to corrosion of various ferrous and non-ferrous alloys.

**Table 5. Resistance to General Corrosion, Crevice Corrosion and Corrosion-Erosion in Flowing Seawater**

| Alloys                              | General Corrosion Rate |        | Crevice Corrosion |        | Erosion-Corrosion Resistance |     |
|-------------------------------------|------------------------|--------|-------------------|--------|------------------------------|-----|
|                                     | mil/yr                 | mm/yr  | mil/yr            | mm/yr  | ft/s                         | m/s |
| <b>Wrought Alloys</b>               |                        |        |                   |        |                              |     |
| <b>Phosphorus deoxidized copper</b> | 1.6                    | 0.04   | 0.9               | <0.025 | 6                            | 1.8 |
| <b>Admiralty brass</b>              | 2                      | 0.05   | <2                | <0.051 | 10                           | 3   |
| <b>Aluminum brass</b>               | 2                      | 0.05   | 2                 | 0.051  | 13                           | 3.9 |
| <b>Naval brass</b>                  | 2                      | 0.05   | 6                 | 0.15   | 10                           | 3   |
| <b>High tensile brass</b>           | 7                      | 0.18   | 29                | 0.74   | 10                           | 3   |
| <b>90/10 copper-nickel</b>          | 1.6                    | 0.04   | <1.6              | <0.04  | 12                           | 3.7 |
| <b>70/30 copper-nickel</b>          | 0.9                    | 0.023  | <0.9              | <0.023 | 15                           | 4.6 |
| <b>5% aluminum bronze</b>           | 2.3                    | 0.06   | <2.3              | <0.058 | 14                           | 4.3 |
| <b>8% aluminum bronze</b>           | 2                      | 0.05   | <2                | <0.051 | 14                           | 4.3 |
| <b>9% aluminum bronze</b>           | 2.3                    | 0.06   | 2.9               | 0.074  | 15                           | 4.6 |
| <b>Nickel aluminum bronze</b>       | 2.9                    | 0.074  | <20               | <0.5   |                              |     |
| <b>Aluminum-silicon bronze</b>      | 2.9                    | 0.074  | 2.9               | <0.074 | 8                            | 2.4 |
| <b>17% Cr stainless steel</b>       | <0.9                   | <0.023 | 200               | 5.1    | >30                          | >9  |

|                                       |      |        |      |        |     |     |
|---------------------------------------|------|--------|------|--------|-----|-----|
| <b>Austenitic stainless steel 304</b> | <0.9 | <0.023 | 0.9  | 0.23   | >30 | >9  |
| <b>Austenitic stainless steel 316</b> | 0.9  | 0.023  | 0.4  | 0.1    | >30 | >9  |
| <b>Monel</b>                          | 0.9  | 0.023  | 1.8  | 0.5    | >30 | >9  |
| <b>Cast Alloys:</b>                   |      |        |      |        |     |     |
| <b>Leaded Red Brass</b>               | 1.6  | 0.04   | <1.6 | <0.04  | 12  | 3.7 |
| <b>Red Brass (Gunmetal)</b>           | 0.9  | 0.023  | <0.9 | <0.023 | 20  | 6.1 |
| <b>High tensile brass</b>             | 8.7  | 0.22   | 0.9  | 0.23   | 8   | 2.4 |
| <b>Aluminum bronze</b>                | 2.9  | 0.074  | <2.9 | <0.074 | 15  | 4.6 |
| <b>Nickel-aluminum bronze</b>         | 2.9  | 0.074  | 2    | <0.51  | 14  | 4.3 |
| <b>Manganese-aluminum bronzes</b>     | 2.1  | 0.053  | 140  | 3.6    | 14  | 4.3 |
| <b>Austenitic cast iron (AUS 202)</b> | 2.7  | 0.069  | 0    | 0      | >20 | >6  |
| <b>Austenitic stainless steel 304</b> | 0.9  | <0.023 | 9    | 0.23   | >30 | >9  |
| <b>Austenitic stainless steel 316</b> | 0.9  | <0.023 | 4.5  | 0.11   | >30 | >9  |
| <b>3% or 4% Si Monel</b>              | 0.9  | 0.023  | 1.8  | 0.5    | >30 | >9  |

Notes:

*Self-corrosion rate:* For general long-term use over several years, a reasonable design value is 0.2 mil (0.05 mm) per year, but, under ideal conditions for nickel-aluminum bronze in seawater, a black film slowly forms, which reduces the corrosion rate in accordance with an equation of the form:

$$\text{Corrosion rate} = kt^{-0.2}$$

*Impingement resistance:* a maximum of 14 ft/s (4.3 m/s) is an appropriate design value for aluminum bronzes used in pipe systems carrying clean flowing seawater.

When *Crevice corrosion* occurs in nickel aluminum bronze, it takes the form of selective phase de-alloying and is usually of little practical significance since it has only a minimal effect on the surface finish. Crevice corrosion of austenitic stainless steels 304 and 316, although shallower, takes the form of pitting with consequent serious deterioration of surface finish.

The data in **Table 5** are taken from U.K. Defense Standard 01/2 *Guide to Engineering Alloys Used in Naval Service: Data Sheets*. The figures for general corrosion rate and crevice corrosion were determined using samples fully immersed beneath rafts in Langstone Harbor for one year. General corrosion results were provided by freely exposed specimens; crevice corrosion results by specimens held in Perspex jigs providing crevice conditions between the metal sample and the Perspex. The corrosion/erosion resistance tests were carried out using the Brownsdon and Bannister test, the specimens were fully immersed in natural sea water and supported at 140°F (60°C) to a submerged jet, 0.016 in (0.4 mm) diameter placed 0.04-0.08 in (1-2 mm) away, through which air was forced at high velocity. The minimum sea water velocity required to produce erosion-corrosion under service conditions was estimated from the minimum air jet velocity required to produce erosion-corrosion in a fourteen-day test, and on the basis of known service behavior of some of the materials.

### **Cavitation Erosion**

Nickel-aluminum bronze has a greater resistance to cavitation erosion than cast steel, Monel alloys and the 400 and 300 series stainless steels. By the same token, it has excellent resistance to impingement attack by gas bubbles. These characteristics make it particularly suitable for propellers, pump impellers, casings and turbine runners, enabling long service lives and optimum operating efficiency. Although more resistant to impingement attack by abrasive substances than gray cast iron and gunmetal, the aluminum bronzes are more vulnerable in this regard than cast steel and stainless steels. Filtration is sometimes necessary, therefore, in the case of high-speed pumps requiring the otherwise good corrosion and cavitation-erosion resistance properties of aluminum bronze but which have to handle water badly contaminated by suspended solids such as sand or other abrasives.

Tables 6 and 7 present comparisons of cavitation erosion of various ferrous and non-ferrous alloys in fresh water and in 3% NaCl (salt) solution.

**Table 6. Cavitation Erosion in 3% NaCl (Salt) Solution**

| <b>Material</b>                | <b>Depth of Attack</b>         |
|--------------------------------|--------------------------------|
| Nickel-aluminum bronze         | 0.01 mil (0.025 mm) in 7 hours |
| Austenitic stainless steel 321 | 0.12 mil (0.305 mm) in 7 hours |
| High-tensile brass             | 0.11 mil (0.280 mm) in 6 hours |

**Table 7. Cavitation Erosion Rates in Fresh Water**

| Material                             | Cavitation-Erosion Rate |                    |
|--------------------------------------|-------------------------|--------------------|
|                                      | in <sup>3</sup> /h      | mm <sup>3</sup> /h |
| Nickel-aluminum bronze               | 0.0037                  | 0.6                |
| Aluminum bronze                      | 0.0049                  | 0.8                |
| Manganese-aluminum bronze            | 0.0092                  | 1.5                |
| High tensile brass                   | 0.0287                  | 4.7                |
| Gunmetal                             | 0.0299                  | 4.9                |
| Monel K500 (cold drawn)              | 0.0171                  | 2.8                |
| Monel K500 (aged)                    | 0.0073                  | 1.2                |
| Austenitic stainless steel 321       | 0.0104                  | 1.7                |
| Austenitic stainless steel 316       | 0.0104                  | 1.7                |
| Cast martensitic stainless steel 420 | 0.0104                  | 1.7                |
| Cast austenitic stainless steel 347  | 0.0061                  | 1.0                |
| Spheroidal-graphite cast iron        | 0.0079                  | 1.3                |
| Ni-resist iron                       | 0.0269                  | 4.4                |

**Cast Aluminum Bronze**

Aluminum bronze castings are produced by the recognized techniques of sand, shell, permanent mold (low-pressure die), ceramic, investment, centrifugal and continuous casting. The size of castings ranges from tiny investment cast components to very large propellers weighing 70 tons. Standard compositions of cast aluminum bronzes are shown in **Table 12**.

One of the very attractive characteristics of aluminum bronzes is that, due to their short cooling range, they solidify compactly, as do pure metals. This means that, provided defects are avoided, the metal is inherently sound, more so than alloys such as gunmetal (tin bronze, UNS C90500) which may be porous unless cooled very rapidly.

The alloy's short freezing range means that adequate feeding is required as the metal solidifies. It is also essential to prevent the aluminum oxide dross on top of the liquid metal from becoming entrapped in the castings during pouring. Avoiding internal defects therefore requires a certain degree of care, although foundries with the required expertise routinely produce castings of very high integrity.

Because aluminum bronze is often selected for critical applications, it is important that casting be well designed so as to achieve best results. Consultation with an experienced founder is essential at a relatively early stage of design development. Publications are available that are helpful in the initial design work and give a good basis for consultation between the designer and the founder.

Many duplex alloy castings may be heat treated to improve the microstructure of the alloy, giving better corrosion resistance and higher strength for only a slight reduction in ductility. The treatment recommended is to soak at 1220°F (660°C) and cool in still air.



The time at temperature depends on casting size and section thickness but is on the order of two hours. This treatment is used only for the most critical of applications.

### Wrought Aluminum Bronze

A wide variety of wrought products are made in aluminum bronze alloys, including forgings, rod, bar, section (profile), flat, sheet, strip and plate, filler rod and wire. An indication of this variety is given in **Table 8**. Material can be chosen from the compositions that are given in **Table 14** but manufacturers or distributors will advise the most suitable alloy for selection.

**Table 8. Availability of Wrought Aluminum Bronzes**

| Product Form                              | English   | Metric   |
|---|---|--|
| <b>Plate, sheet, strip, up to 4000 kg</b> | 0.02 to 5 in  | 0.5 to 127 mm  |
| <b>Bar, rod, section</b>                  | 0.3-8 in diameter   | 7 to 200 mm diameter   |
| <b>Wire</b>                               |   | Size and weight per spool by arrangement                                       |
| <b>Tube and hollow bar</b>                | Up to 4 in diameter, 0.4 in wall thickness. Hollow bar up to 20 in diameter | Up to 108 mm diameter, 9.5 mm wall thickness. Hollow bar up to 500 mm diameter |
| <b>Welded tube</b>                        | By arrangement  | By arrangement   |
| <b>Forgings</b>                           | Size and maximum weight by arrangement                                      | Size and maximum weight by arrangement   |

Billets from which wrought products are made continuously to ensure freedom from entrapped oxide defects, which would carry through to the final product. These billets are then hot worked by conventional methods such as extrusion, rolling or forging. Rolling, extrusion and rotary forging produce sections that are to final or near final dimensions and reduce the need for costly machining. This provides very useful design flexibility.

Forgings are produced either freehand in simple shapes and to relatively wide tolerances, or in closed dies to close tolerances if the quantity required justifies the initial cost of the die. Hot pressing, stamping and other methods are used to produce flanged shafts, nuts and bolts.

### Fabrication and Welding of Aluminum Bronze

The ductility and weldability of aluminum bronzes lends it to weld fabrication of preformed sections to produce items such as pressure vessels and pipes. One attractive feature of the aluminum bronzes is that it is possible to incorporate castings

as well as forgings in a fabricated assembly. The single-phase alloys are easier to cold work than the complex alloys and are therefore less expensive to roll into shape. The complex alloys are, however, stronger and are less sensitive to the stresses resulting from the heating and cooling cycles caused by welding.

Gas shielded arc welding (GTAW, GMAW) is the most popular method for welding aluminum bronze. Depending on strength requirements, filler metals will either conform to AWS 5.7 grades ER CuAl-A1 (moderate strength, used for weld overlay and metallizing to repair bearing and corrosion-resistant surfaces, and not intended for joining); ER CuAl-A2 (intermediate strength, for joining aluminum bronze fabrications, joining a wide variety of dissimilar metals, casting repair, general maintenance and galvanized sheet fabrication), or ER CuAl-A3, (high strength, mainly used to weld aluminum bronze castings of similar composition and for build-up and repair of bearing surfaces).

To avoid possible effects of mixed microstructures in the weld bead and heat affected zone, post weld heat treatment may be recommended for complex alloys. There will, for example, be an improvement in corrosion resistance after soaking weld fabrications at 1220°F (660°C) and cooling in still air.

### **The Machining of Aluminum Bronzes**

Aluminum bronze should be considered as a bronze with mechanical properties similar to those of a high-grade steel. While the alloys are not free cutting (Type I chip behavior), they do not present inordinate machining difficulties. It will be appreciated that to ensure the most economical production, materials of this caliber require correct machining methods. Although many machine shops have developed their own standard practice to suit their particular requirements, the following notes will serve as a general guide for machining aluminum bronzes.

Most duplex aluminum bronzes (including UNS C61800, C62300, C62400, C62500, C63000, C63020 and C63200) exhibit Type II chip-forming behavior. Type II chips are short and curled or serrated, and metals that produce them can be processed on automatic screw machines and high-speed machining centers in many instances. Deep drilling and tapping may require greater care.

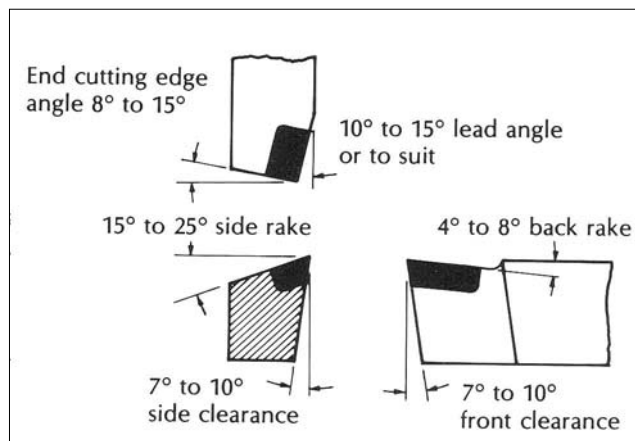
The alpha aluminum bronzes (C61000, C61300, C61400) generate Type III chips, which are long and stringy or tangled, and somewhat "gummy". Metals of this type are generally not recommended for automatic screw machine production.

Definite values for maximum feeds, speeds and depth-of-cut cannot be stated since these are influenced by several factors; the equipment being used, the operator, and his experience in handling the material. On the other hand, the various recommendations given below may be taken as representing a reliable average, offering maximum production with reasonable tool life and efficiency. Little distortion normally occurs on machining, but in cases where dimensions are critical it may be useful to carry out a stress relief heat treatment of one hour at 660°F (350°C) prior to final machining.

## Turning

The use of tungsten carbide tipped tools is considered desirable. It is most important that the work should be held rigidly and that tools should be properly supported, with minimum overhang from the tool post. To obtain the best results, equipment must be kept in good condition, as excessively worn headstock bearings and slides will give rise to tool chatter and rapid tool breakdown. The first roughing cut on a casting should be deep enough to penetrate the skin, and a steady flow of soluble oil is essential for both roughing and finishing cuts. The work must be kept cool during precision machining; if it is allowed to heat up, difficulty will be experienced in maintaining accuracy.

Suitable designs for tungsten carbide roughing and finishing tools are illustrated in **Figure 1**, and speeds and feeds recommended for use with these tools are given in **Table 9**. High efficiency with carbide tipped tools is attained by using a light feed, a moderately heavy depth of cut and the highest cutting speed consistent with satisfactory tool life.



**Figure 1. Cutting Tool Geometry for Machining Aluminum Bronzes**

**Table 9. Turning Speeds and Feed Rates for Aluminum Bronzes (Type II Chips)**

|                        | Surface Speed                | Roughing Feed                                  | Finishing Feed                                |
|------------------------|------------------------------|--|---|
| <b>HSS Tooling</b>     | 150-300 sfm<br>46-92 m/min   | 2-8 mil/rev<br>51-203 $\mu\text{m}/\text{rev}$ | 2-3 mil/rev<br>51-76 $\mu\text{m}/\text{rev}$ |
| <b>Carbide Tooling</b> | 400-600 sfm<br>122-183 m/min | 2-8 mil/rev<br>51-203 $\mu\text{m}/\text{rev}$ | 2-3 mil/rev<br>51-76 $\mu\text{m}/\text{rev}$ |

## Drilling

Since aluminum bronze is hard, close grained and (except for some alpha alloys) free from the "stringy" characteristics of copper, a fine quality drilled finish is obtainable. The best results are achieved with high-speed steel (HSS) drills ground with negative rake at an included angle of  $100^\circ$  to  $110^\circ$ . Straight-fluted drills will give a fine surface finish. Binding in the hole can be overcome by grinding the drill very slightly off center, thereby providing additional clearance. Where countersinking is required, a counterboring tool will give the best results. If a counterboring tool is not available, it may be preferable to carry out countersinking before drilling. A coolant must be used, especially with the harder grades, and overheating must be avoided. Medium speeds and moderate feeds give the best results.

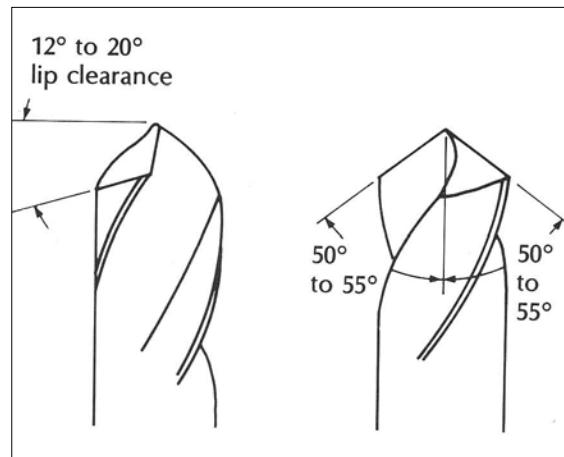


Figure 2. Drill Geometry for Aluminum Bronzes

Table 10. Drilling Speeds And Feeds For Aluminum Bronzes

| Material       | Clearance Angle         | Drill Point Angle | Cutting Edge                 | Speed       | Feed             |
|----------------|-------------------------|-------------------|------------------------------|-------------|------------------|
| Type II Alloys | $12^\circ$ - $15^\circ$ | $118^\circ$       | Flatten to $0^\circ$<br>Rake | 75-250 sfm  | 2-30 mil/rev     |
|                |                         |                   |                              | 23-76 m/min | 0.05-0.76 mm/rev |

## Reaming

Normal reaming practice is not suitable for aluminum bronze, although excellent results can be obtained. A simple "D" bit made up with a tungsten carbide insert will maintain the closest limits and produce a highly finished bore. Approximately 0.005 in (0.12mm) of metal should be removed. Adjustable-type reamers with carbide inserts can also be used, and it will be found that chatter is eliminated if a reamer having an odd number of inserts is chosen. Fluted reamers are less prone to chatter, an important consideration with tough short-chip (Type II) alloys. A rake angle (hook) of 5° is used for both Types II and III alloys. It is important that cutting tools be lapped to a fine finish. Avoid undue heating and use coolant. A left-hand spiral type is to be preferred for hand reaming.

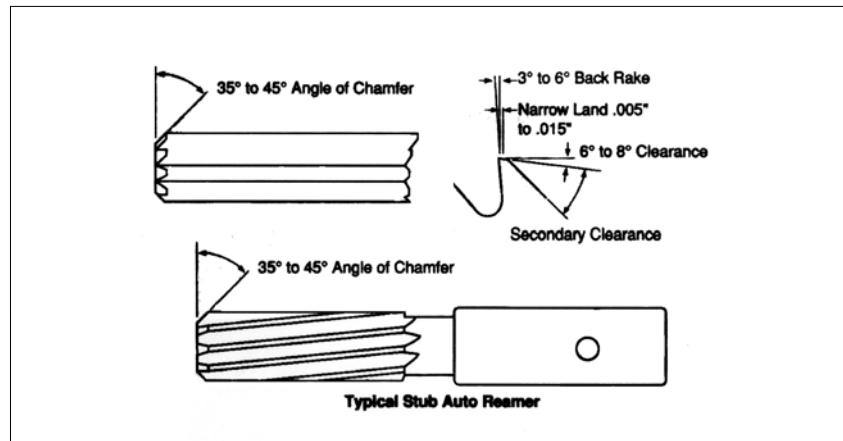


Figure 3. Reaming Geometries for Aluminum Bronzes

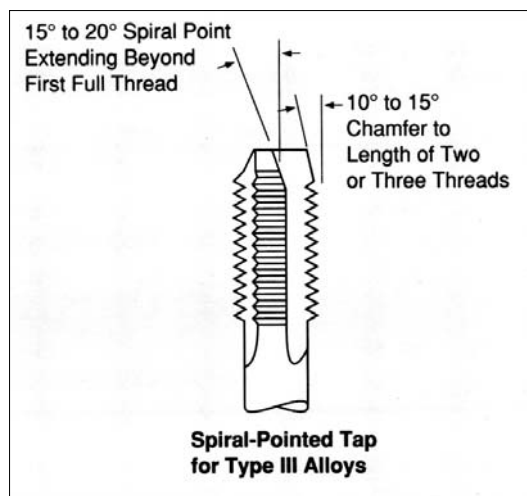
Table 11. Recommended Reaming Feeds for Aluminum Bronzes

| Hole Diameter  | Feed               | Depth of Cut   |
|----------------|--------------------|----------------|
| <0.125 in      | 0.010 in/rev       | 0.003-0.004 in |
| <3.2 mm        | 0.25 mm/rev        | 0.08-0.10 mm   |
| 0.125-0.375 in | 0.010-0.016 in/rev | 0.004-0.007 in |
| 3.2-9.5 mm     | 0.25-0.41 mm/rev   | 0.08-0.18 mm   |
| >0.375 in      | 0.016 in/rev       | 0.007-0.015 in |
| >9.5 mm        | 0.41-0.91 mm/rev   | 0.18-0.38 mm   |

## Tapping

For hand tapping where the quantity of work or nature of the part does not permit use of a tapping machine, regular commercial two- and three-flute high-speed steel taps should prove satisfactory. The rake should be correct for the metal being cut and the chamfer should be relatively short, so that work-hardening or excess stresses do not result from too many threads being cut at the same time.

High-speed steel taps with ground threads are used in machine tapping. In instances where the threads tend to tear as the tap is being backed out, a rake angle should be ground on both sides of the flute.



*Fig 4. Recommended Tap Geometry for Aluminum Bronzes*

**Table 12. Threading and Tapping Data for Aluminum Bronzes**

| Material       | Tap Rake Angle | Die Chamfer          | Lineal Threading or Tapping Speed |
|----------------|----------------|----------------------|-----------------------------------|
| Type II Alloys | 5°-8°          | 10°-15°              | 50-90 sfm                         |
|                |                | two or three threads | 15-27 m/min                       |

Hard, multiphase (Type II) aluminum bronzes require intermediate rake angles (12° to 17°). For aluminum bronzes that produce tough, stringy chips, spiral pointed taps with two or three flutes are preferred for tapping through holes or blind holes drilled sufficiently deep for chip clearance. These taps produce long, curling chips, which are forced ahead of the tap. Larger (17° to 25°) rake angles are required for these Type III alloys. Spiral fluted bottoming taps can be used for machine (and hand) tapping of blind holes. The speeds indicated in **Table 12** are based on the use of taps to produce fine

to moderate pitch threads. Appreciably lower speeds should be used for coarse pitch threads, and speeds should be reduced by about 50% if carbon steel taps are used.

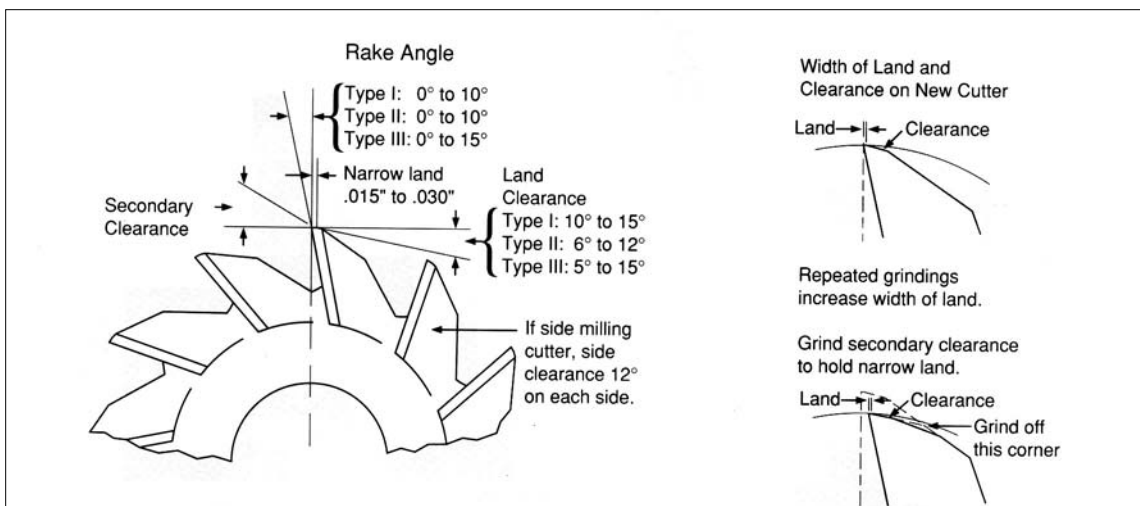
If the work is allowed to overheat, a re-tapping operation may be necessary. The use of a tapping compound having a high tallow content will prevent binding in the case of softer grades, and will prevent cracking of the work in the harder grades.

## Milling

Milling data for aluminum bronzes is given in **Table 13** and are depicted graphically in **Figure 5**. Hard (Type II) aluminum bronzes generally require smaller rake angles from those used with ductile Type III alloys. Small-diameter cutters should be ground with radial teeth ( $0^\circ$  rake) for these alloys. Recommended milling speeds can be as high as 200 sfm (61 m/min). Recommended feeds range from 0.016 to 0.022 in/rev (0.4 to 0.56 mm/rev) per tooth for spiral cutters and from 0.010 to 0.022 in/rev (0.25 to 0.56 mm/rev) per tooth for end mills. Speeds and feeds will depend upon the job and machining conditions, but the work must not be "forced", or tearing and chipping may result.

For long-chip Type III alloys, milling cutters with tooth spacing no finer than four to eight teeth per inch will facilitate chip removal. Combined cutters can also be used, but teeth should be interlocked to prevent chips from collecting between cutter elements. Generous rake angles and adequate clearance should be provided on face-, side- and end-milling cutters to prevent burnishing of the workpiece. Up to  $15^\circ$  clearance can be incorporated on tooth sides in side and face cutters and on tooth ends in end cutters. A radial undercut will prevent tooth edges from dragging along the workpiece. Cutting edges should be finely polished and/or coated to reduce loading.

Undue heating must be avoided and a coolant should be used. Good results can be achieved by employing standard steel practice. Soluble-oil coolants are satisfactory for these alloys. Mineral oils containing about 5% lard oil can also be used.



**Fig 5. Recommended Milling Cutter Geometries for Aluminum Bronzes**



**Table 13. Milling Data for Aluminum Bronzes**

| Alloy          | Rake Angle | Clearance Angle | Land           | Surface Speed |
|----------------|------------|-----------------|----------------|---------------|
| Type II Alloys | 0°-10°     | 5°-15°          | 1.015-0.030 in | 150-200 sfm   |
|                |            |                 | 0.38-0.76 mm   | 46-61 m/min   |

### Grinding

All grades of aluminum bronze can readily be given an excellent ground finish, and even the softer grades will not clog the grinding wheel. Again, a coolant must be used and overheating must be avoided. A bauxite type wheel gives satisfactory results and the grades recommended for particular operations are 30 grit for roughing; 46 grit for general purposes; and 60 grit for fine finish work. Since aluminum bronze is non-magnetic, it cannot be finished using a magnetic chuck.

Further information on the machining of aluminum bronzes and other copper alloys is available in the CDA publication, *Copper Rod Alloys for Machined Products* and in CDA-UK [Technical Note TN44 Machining Copper and Its Alloys](#).

### Scrap Values

The scrap value of aluminum bronze chips (swarf) is relatively high provided that it is kept clean and segregated from other alloys, particularly steels. As with all copper alloys, high scrap value helps offset machining costs and should be considered when costing component manufacture.

**Table 11. Aluminum Bronzes for Cold Working**

**Wrought UNS Alloys with less than 8% aluminum**

| UNS No.               | Cu (Incl. Ag) | Pb   | Fe      | Ni (Incl. Co)          | Al       | Mn  | Si  | Zn                 | Sn      | Other Named Elements |
|-----------------------|---------------|------|---------|------------------------|----------|-----|-----|--------------------|---------|----------------------|
| C60800 <sup>(1)</sup> | Rem.          | .10  | .10     | —                      | 5.0–6.5  | —   | —   | —                  | —       | .02–.35As            |
| C61000 <sup>(1)</sup> | Rem.          | .02  | .50     | —                      | 6.0–8.5  | —   | .10 | .20                | —       | —                    |
| C61300 <sup>(2)</sup> | Rem.          | .01  | 2.0–3.0 | .15                    | 6.0–7.5  | .20 | .10 | .10 <sup>(3)</sup> | .20–.50 | .015P                |
| C61400 <sup>(1)</sup> | Rem.          | .01  | 1.5–3.5 | —                      | 6.0–8.0  | 1.0 | —   | .20                | —       | .015P                |
| C61500 <sup>(1)</sup> | Rem.          | .015 | —       | 1.8–2.2 <sup>(4)</sup> | 7.7–8.3  | —   | —   | —                  | —       | —                    |
| C61550 <sup>(1)</sup> | Rem.          | .05  | .20     | 1.5–2.5 <sup>(4)</sup> | 5.5–6.5  | 1.0 | —   | —                  | .05     | .8Zn                 |
| C61800 <sup>(1)</sup> | Rem.          | .02  | .50–1.5 | —                      | 8.5–11.0 | —   | .10 | .02                | —       | —                    |
| C61900 <sup>(1)</sup> | Rem.          | .02  | 3.0–4.5 | —                      | 8.5–10.0 | —   | —   | .8                 | .6      | —                    |

## European Alloys

|                 |     |         |  |         |  |  |  |  |  |           |
|-----------------|-----|---------|--|---------|--|--|--|--|--|-----------|
| <b>CuAl5As</b>  | Rem |         |  | 4.0-6.5 |  |  |  |  |  | 0.1-0.4As |
| <b>CuAl8Fe3</b> | Rem | 1.5-3.5 |  | 6.5-8.5 |  |  |  |  |  |           |

<sup>(1)</sup> Cu + Sum of Named Elements, 99.5% min.

<sup>(2)</sup> Cu + Sum of Named Elements, 99.8% min.

<sup>(3)</sup> When the product is for subsequent welding applications and is so specified by the purchaser, Cr, Cd, Zr and Zn shall each be .05% max.

<sup>(4)</sup> Fe content shall not exceed Ni content.

**Table 12. Aluminum Bronzes for Casting**

### UNS Alloys

| Copper Alloy No. | Cu                      | Pb  | Fe      | Ni (incl. Co) | Al        | Mn  | Mg  | Si  | Zn  | Sn  |
|------------------|-------------------------|-----|---------|---------------|-----------|-----|-----|-----|-----|-----|
| <b>C95200</b>    | 86.0 min <sup>(1)</sup> | —   | 2.5–4.0 | —             | 8.5–9.5   | —   | —   | —   | —   | —   |
| <b>C95210</b>    | 86.0 min <sup>(1)</sup> | .05 | 2.5–4.0 | 1.0           | 8.5–9.5   | 1.0 | .05 | .25 | .50 | .10 |
| <b>C95220</b>    | Rem <sup>(2)</sup>      | —   | 2.5–4.0 | 2.5           | 9.5–10.5  | .50 | —   | —   | —   | —   |
| <b>C95300</b>    | 86.0 min <sup>(1)</sup> | —   | .8–1.5  | —             | 9.0–11.0  | —   | —   | —   | —   | —   |
| <b>C95900</b>    | Rem. <sup>(2)</sup>     | —   | 3.0–5.0 | .50           | 12.0–13.5 | 1.5 | —   | —   | —   | —   |

### European

|                    |           |  |         |     |          |      |  |  |  |  |
|--------------------|-----------|--|---------|-----|----------|------|--|--|--|--|
| <b>CuAl9-C</b>     | 88.0-92.0 |  | 1.2     | 1.0 | 8.0-10.5 | 0.50 |  |  |  |  |
| <b>CuAl10Fe2-C</b> | 83.0-89.5 |  | 1.5-3.5 | 1.5 | 8.5-10.5 | 1.0  |  |  |  |  |

<sup>(1)</sup> Cu + sum of named elements, 99.0% min.

<sup>(2)</sup> Cu + sum of named elements, 99.5% min.

**Table 13. High Strength Aluminum Bronzes — Wrought**

### UNS Alloys

| UNS Alloy No.               | Cu <sup>(1)</sup> (Incl. Ag) | Pb  | Fe      | Ni (Incl. Co) | Al        | Mn  | Mg | Si  | Zn  | Sn  |
|-----------------------------|------------------------------|-----|---------|---------------|-----------|-----|----|-----|-----|-----|
| <b>C62200<sup>(1)</sup></b> | Rem.                         | .02 | 3.0–4.2 | —             | 11.0–12.0 | —   |    | .10 | .02 | —   |
| <b>C62300<sup>(1)</sup></b> | Rem.                         | —   | 2.0–4.0 | 1.0           | 8.5–10.0  | .50 |    | .25 | —   | .6  |
| <b>C62400<sup>(1)</sup></b> | Rem.                         | —   | 2.0–4.5 | —             | 10.0–11.5 | .30 |    | .25 | —   | .20 |
| <b>C62500<sup>(1)</sup></b> | Rem.                         | —   | 3.5–5.5 | —             | 12.5–13.5 | 2.0 |    | —   | —   | —   |
| <b>C62580<sup>(1)</sup></b> | Rem.                         | .02 | 3.0–5.0 | —             | 12.0–13.0 | —   |    | .04 | .02 | —   |
| <b>C62581<sup>(1)</sup></b> | Rem.                         | .02 | 3.0–5.0 | —             | 13.0–14.0 | —   |    | .04 | .02 | —   |
| <b>C62582<sup>(1)</sup></b> | Rem.                         | .02 | 3.0–5.0 | —             | 14.0–15.0 | —   |    | .04 | .02 | —   |

## European

|                     |     |   |         |   |          |         |   |   |   |   |
|---------------------|-----|---|---------|---|----------|---------|---|---|---|---|
| <b>CuAl10Fe1</b>    | Rem | — | 0.5-1.5 | — | 9.0-10.0 | —       | — | — | — | — |
| <b>CuAl10Fe3Mn2</b> | Rem | — | 2.0-4.0 | — | 9.0-11.0 | 1.5-3.5 | — | — | — | — |

<sup>(1)</sup>Cu + Sum of Named Elements, 99.5% min.

**Table 14. High Strength Nickel-Aluminum Bronzes — Wrought**

### UNS

| Copper Alloy No.            | Cu <sup>(1)</sup><br>(Incl.Ag) | Pb  | Fe                     | Ni (Incl Co) | Al        | Mn        | Si  | Zn  | Sn  | Other Named Elements |
|-----------------------------|--------------------------------|-----|------------------------|--------------|-----------|-----------|-----|-----|-----|----------------------|
| <b>C63000<sup>(1)</sup></b> | Rem.                           | —   | 2.0-4.0                | 4.0-5.5      | 9.0-11.0  | 1.5       | .25 | .30 | .20 | —                    |
| <b>C63010</b>               | 78.0 min. <sup>(2)</sup>       | —   | 2.0-3.5                | 4.5-5.5      | 9.7-10.9  | 1.5       | —   | .30 | .20 | —                    |
| <b>C63020<sup>(1)</sup></b> | 74.5 min.                      | .03 | 4.0-5.5                | 4.2-6.0      | 10.0-11.0 | 1.5       | —   | .30 | .25 | 0.20Co,<br>0.05Cr    |
| <b>C63200<sup>(1)</sup></b> | Rem.                           | .02 | 3.5-4.3 <sup>(3)</sup> | 4.0-4.8      | 8.7-9.5   | 1.2-2.0   | .10 | —   | —   | —                    |
| <b>C63280</b>               | Rem.                           | .02 | 3.0-5.0                | 4.0-5.5      | 8.5-9.5   | .6-3.5    | —   | —   | —   | —                    |
| <b>C63380</b>               | Rem.                           | .02 | 2.0-4.0                | 1.5-3.0      | 7.0-8.5   | 11.0-14.0 | .10 | .15 | —   | —                    |

## European

|                     |      |   |         |         |           |   |   |   |   |   |
|---------------------|------|---|---------|---------|-----------|---|---|---|---|---|
| <b>CuAl9Ni3Fe2</b>  | Rem  | — | 1.0-3.0 | 2.0-4.0 | 8.0-9.5   | — | — | — | — | — |
| <b>CuAl10Ni5Fe4</b> | Rem  | — | 3.0-5.0 | 4.0-6.0 | 8.5-11.0  | — | — | — | — | — |
| <b>CuAl11Fe6Ni6</b> | Rem. | — | 5.0-7.0 | 5.0-7.0 | 10.5-12.5 | — | — | — | — | — |

<sup>(1)</sup> Cu + Sum of Named Elements, 99.5% min.

<sup>(2)</sup> Cu + Sum of Named Elements, 99.8% min.

<sup>(3)</sup> Fe content shall not exceed Ni content.

**Table 15. High Strength Nickel-Aluminum Bronzes — Cast**

### UNS

| UNS Alloy No. | Cu                      | Pb  | Fe                     | Ni (incl. Co)          | Al        | Mn     | Mg  | Si  | Zn  | Sn  | Other Named Elements |
|---------------|-------------------------|-----|------------------------|------------------------|-----------|--------|-----|-----|-----|-----|----------------------|
| <b>C95400</b> | 83.0 min <sup>(1)</sup> | —   | 3.0-5.0                | 1.5                    | 10.0-11.5 | .50    | —   | —   | —   | —   | —                    |
| <b>C95410</b> | 83.0 min <sup>(1)</sup> | —   | 3.0-5.0                | 1.5-2.5                | 10.0-11.5 | .50    | —   | —   | —   | —   | —                    |
| <b>C95420</b> | 83.5 min <sup>(1)</sup> | —   | 3.0-4.3                | .50                    | 10.5-12.0 | .50    | —   | —   | —   | —   | —                    |
| <b>C95500</b> | 78.0 min <sup>(1)</sup> | —   | 3.0-5.0                | 3.0-5.5                | 10.0-11.5 | 3.5    | —   | —   | —   | —   | —                    |
| <b>C95510</b> | 78.0 min <sup>(2)</sup> | —   | 2.0-3.5                | 4.5-5.5                | 9.7-10.9  | 1.5    | —   | —   | .30 | .20 | —                    |
| <b>C95520</b> | 74.5 min <sup>(1)</sup> | .03 | 4.0-5.5                | 4.2-6.0                | 10.5-11.5 | 1.5    | —   | .15 | .30 | .25 | .20Co<br>.05Cr       |
| <b>C95800</b> | 79.0 min <sup>(1)</sup> | .03 | 3.5-4.5 <sup>(3)</sup> | 4.0-5.0 <sup>(3)</sup> | 8.5-9.5   | .8-1.5 | —   | .10 | —   | —   | —                    |
| <b>C95810</b> | 79.0 min <sup>(1)</sup> | .10 | 3.5-4.5 <sup>(3)</sup> | 4.0-5.0 <sup>(3)</sup> | 8.5-9.5   | .8-1.5 | .05 | .10 | .50 | —   | —                    |
| <b>C95820</b> | 77.5 min <sup>(4)</sup> | .02 | 4.0-5.0                | 4.5-5.8                | 9.0-10.0  | 1.5    | —   | .10 | .20 | .20 | —                    |

## European

|                       |           |  |         |         |           |     |  |  |  |  |  |
|-----------------------|-----------|--|---------|---------|-----------|-----|--|--|--|--|--|
| <b>CuAl10Ni3Fe2-C</b> | 80.0-86.0 |  | 1.0-3.0 | 1.5-4.0 | 8.5-10.5  | 2.0 |  |  |  |  |  |
| <b>CuAl10Ni5Fe5-C</b> | 76.0-83.0 |  | 4.0-5.5 | 4.0-6.0 | 8.5-10.5  | 3.0 |  |  |  |  |  |
| <b>CuAl11Fe6Ni6-C</b> | 72.0-78.0 |  | 4.0-7.0 | 4.0-7.5 | 10.0-12.0 | 2.5 |  |  |  |  |  |

(1) Cu + sum of named elements, 99.5% min.

(2) Cu + sum of named elements, 99.8% min.

(3) Fe content shall not exceed Ni content.

(4) Cu + sum of named elements, 99.2% min.

**Table 16 Aluminum Bronzes With Silicon for Low Magnetic Permeability — Wrought**

**UNS**

| UNS Alloy No. | Cu <sup>(1)</sup><br>(Incl.Ag) | Pb  | Fe  | Ni<br>(Incl.<br>Co) | Al      | Mn  | Si      | Zn  | Sn  | Other<br>Named<br>Elements |
|---------------|--------------------------------|-----|-----|---------------------|---------|-----|---------|-----|-----|----------------------------|
| <b>C63400</b> | Rem.                           | .05 | .15 | .15                 | 2.6–3.2 | —   | .25–.45 | .50 | .20 | .15As                      |
| <b>C63600</b> | Rem.                           | .05 | .15 | .15                 | 3.0–4.0 | —   | .7–1.3  | .50 | .20 | .15As                      |
| <b>C63800</b> | Rem.                           | .05 | .20 | .20                 | 2.5–3.1 | .10 | 1.5–2.1 | .8  | —   | .25–.55Co                  |
| <b>C64200</b> | Rem.                           | .05 | .30 | .25                 | 6.3–7.6 | .10 | 1.5–2.2 | .50 | .20 | .15As                      |
| <b>C64210</b> | Rem.                           | .05 | .30 | .25                 | 6.3–7.0 | .10 | 1.5–2.0 | .50 | .20 | .15As                      |

**European**

|                   |     |   |         |   |         |   |         |   |   |   |
|-------------------|-----|---|---------|---|---------|---|---------|---|---|---|
| <b>CuAl6Si2Fe</b> | Rem | — | 0.5-0.7 | — | 6.0-6.4 | — | 2.0-2.4 | — | — | — |
| <b>CuAl7Si2</b>   | Rem | — | 1.0-3.0 | — | 7.3-7.6 | — | 1.5-2.2 | — | — | — |

(1) Cu + sum of named elements, 99.5% min.

(2) Not including Co.

**Table 20 Aluminum Bronzes with silicon for low magnetic permeability - Cast**

**UNS**

| UNS Alloy No. | Cu                      | Pb | Fe | Ni<br>(incl.<br>Co) | Al      | Mn | Si      | Zn | Sn | Other<br>Named<br>Elements |
|---------------|-------------------------|----|----|---------------------|---------|----|---------|----|----|----------------------------|
| <b>C95600</b> | 88.0 min <sup>(1)</sup> | —  | —  | .25                 | 6.0–8.0 | —  | 1.8–3.2 | —  | —  | —                          |

(1) Cu + sum of named elements, 99.0% min.

**Table 21 Manganese Aluminum Bronzes, Cast**

**UNS**

| UNS Alloy No. | Cu                      | Pb  | Fe      | Ni<br>(incl.<br>Co) | Al      | Mn        | Si  | Zn  | Sn  | Other<br>Named<br>Elements |
|---------------|-------------------------|-----|---------|---------------------|---------|-----------|-----|-----|-----|----------------------------|
| <b>C95700</b> | 71.0min. <sup>(2)</sup> | —   | 2.0–4.0 | 1.5–3.0             | 7.0–8.5 | 11.0–14.0 | .10 | —   | —   | —                          |
| <b>C95710</b> | 71.0min. <sup>(2)</sup> | .05 | 2.0–4.0 | 1.5–3.0             | 7.0–8.5 | 11.0–14.0 | .15 | .50 | 1.0 | .05P                       |
| <b>C95720</b> | 73.0min. <sup>(2)</sup> | .03 | 1.5–3.5 | 3.0–6.0             | 6.0–8.0 | 12.0–15.0 | .10 | .10 | .10 | .20Cr                      |

**European**

|                       |           |  |         |  |         |          |  |  |  |  |
|-----------------------|-----------|--|---------|--|---------|----------|--|--|--|--|
| <b>CuMn10Fe3Ni3-C</b> | 68.0-77.0 |  | 2.0-4.0 |  | 7.0-9.0 | 8.0-15.0 |  |  |  |  |
|-----------------------|-----------|--|---------|--|---------|----------|--|--|--|--|

(1) Cu + sum of named elements, 99.0% min.

(2) Cu + sum of named elements, 99.5% min.

## **Available Publications on Aluminum Bronzes, including help available on websites.**

H. J Meigh, 'Cast and Wrought Aluminum Bronzes - Properties, Processes and Structure', Institute of Materials, London, 2000, 404pp.

P J Macken and A A Smith, 'The Aluminum Bronzes - Properties and Production Processes' CDA Publication No 31, second edition 1966, Copper Development Association, St Albans, 263pp.

<http://www.cda.org.uk/Megab2/corrs/pub31/default.htm>

### **Corrosion**

Aluminum Bronze Alloys - Corrosion Resistance Guide, Publication No 80, 26 pages of invaluable data on recommended service environments.

<http://www.cda.org.uk/Megab2/corrs/pub80/default.htm>

Copper & Copper Alloy Corrosion Resistance Database

<http://protection.copper.org/>

Corrosion Resistance of Copper and Copper Alloys (Large Table), CDA No 106

<http://www.cda.org.uk/Megab2/corrs/corrosio.htm>

### **Properties**

<http://properties.copper.org/servlet/com.copper.servlet.CDAPropertiesSelectionServlet>

Aluminum Bronze Alloys - Technical Data, Publication No 82, 90 pages of tabulated mechanical and physical properties.

<http://www.cda.org.uk/Megab2/corrs/pub82/default.htm>

Property Data - Wrought Alloys

<http://www.cda.org.uk/Megab2/corrs/pub82/sec2.htm>

Property Data - Cast Alloys

<http://www.cda.org.uk/Megab2/corrs/pub82/casts1.htm>

Collation of Data Comparing Properties of Aluminum Bronze with Cast Stainless Steels and Ni-Resist in Offshore Sea Water Environments

<http://www.cda.org.uk/Megab2/corrs/pub115/default.htm>

Welding Aluminum Bronzes, Publication No 85, 8 pages of useful guidance.

<http://www.cda.org.uk/Megab2/corrs/pub85/default.htm>

### **Suitability of joining techniques**

<http://properties.copper.org/servlet/com.copper.servlet.CDAFabPracticesSelectionServlet>

### **Microstructures**

[http://microstructure.copper.org/al\\_bronzes.htm](http://microstructure.copper.org/al_bronzes.htm)

Designing Aluminum Bronze Castings, a 7-page reprint of data from an article by H. J. Meigh

[http://www.cda.org.uk/Megab2/corr\\_rs/pub81/default.htm](http://www.cda.org.uk/Megab2/corr_rs/pub81/default.htm)

### **Wear Resistance**

Resistance to Wear of Aluminium Bronzes, H J Meigh

[http://www.cda.org.uk/Megab2/corr\\_rs/allybrwe/default.htm](http://www.cda.org.uk/Megab2/corr_rs/allybrwe/default.htm)

### **Uses**

<http://properties.copper.org/servlet/com.copper.servlet.CDACategoryUsesServlet>

Corrosion Resistant Fasteners

[http://www.cda.org.uk/Megab2/corr\\_rs/is34/default.htm](http://www.cda.org.uk/Megab2/corr_rs/is34/default.htm)

### **Search the Copper Data Center Database**

<http://www.csa.com/copperdata/>

### **Other Information**

<http://www.copperinfo.com/>

### **Aluminum Bronze References**

[http://www.cda.org.uk/Megab2/corr\\_rs/allyb4in/aluminiu.htm](http://www.cda.org.uk/Megab2/corr_rs/allyb4in/aluminiu.htm)

(Also included in full, below)

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