Copper Specifications, Grades & Properties

Introduction

Copper is the oldest metal used by man. It's use dates back to prehistoric times. Copper has been mined for more than 10,000 years with a Copper pendant found in current day Iraq being dated to 8700BC. By 5000BC Copper was being smelted from simple Copper Oxides.

Copper is found as native metal and in minerals cuprite, malachite, azurite, chalcopyrite and bornite. It is also often a by-product of silver production. Sulphides, oxides and carbonates are the most important ores.

Copper and Copper alloys are some of the most versatile engineering materials available. The combination of physical properties such as strength, conductivity, corrosion resistance, machinability and ductility make copper suitable for a wide range of applications. These properties can be further enhanced with variations in composition and manufacturing methods.

The largest end use for Copper is in the building industry. Within the building industry the use of copper based materials is broad. Construction industry related applications for copper include:

- Roofing
- Cladding
- Rainwater systems
- Heating systems
- Water pipes and fittings
- Oil and gas lines
- Electrical wiring

The building industry is the largest single consumer of copper alloys. The following list is a breakdown of copper consumption by industry on an annual basis:

- **Building industry – 47%**
- **Electronic products - 23%**
- **Transportation - 10%**
- **Consumer products - 11%**
- **Industrial machinery - 9%**

There are around 370 commercial compositions for copper alloys. The most common grade tends to be C106 / CW024A - the standard water tube grade of copper.

World consumption of copper and copper alloys now exceeds 18 million tonnes per annum.

Applications

Copper and copper alloys can be used in an extraordinary range of applications. Some of these applications include:

- Power transmission lines
- Architectural applications
- Cooking utensils
- Spark plugs
- Electrical wiring, cables and busbars
- High conductivity wires
- Electrodes
- Heat exchangers
- Refrigeration tubing
- Plumbing
- Water-cooled copper crucibles

Structure

Copper has a face centred cubic crystal structure. It is yellowish red in physical appearance and when polished develops a bright metallic lustre.

Key Properties of Copper Alloys

Copper is a tough, ductile and malleable material. These properties make copper extremely suitable for tube forming, wire drawing, spinning and deep drawing. The other key properties exhibited by copper and its alloys include:

- Excellent heat conductivity
- Excellent electrical conductivity
- Good corrosion resistance
- Good biofouling resistance
- Good machinability
- Retention of mechanical and electrical properties at cryogenic temperatures
- Non-magnetic

Other Properties

- Copper and Copper alloys have a peculiar smell and disagreeable taste. These may be transferred by contact and therefore Copper should be kept clear of foodstuffs.
- Most commercially used metals have a metallic white colour. Copper is a yellowish red.

Melting Point

The melting point for pure copper is 1083°C.

Electrical Conductivity

The electrical conductivity of copper is second only to silver. The conductivity of copper is 97% that of silver. Due to its much lower cost and greater abundance, copper has traditionally been the standard material used for electricity transmission applications.

However, weight considerations mean that a large proportion of overhead high voltage power lines now use aluminium rather than copper. By weight, the conductivity of aluminium is around twice that of copper. The aluminium alloys used do have a low strength and need to be reinforced with a galvanised or aluminium coated high tensile steel wire in each strand.

Although additions of other elements will improve properties like strength, there will be some loss in electrical conductivity. As an example a 1% addition of cadmium can increase strength by 50%. However, this will result in a corresponding decrease in electrical conductivity of 15%.

Corrosion Resistance

All Copper alloys resist corrosion by fresh water and steam. In most rural, marine and industrial atmospheres Copper alloys also resistant to corrosion. Copper is resistant to saline solutions, soils, non-oxidising minerals, organic acids and caustic solutions. Moist ammonia, halogens, sulphides, solutions containing ammonia ions and oxidising acids, like nitric acid, will attack Copper. Copper alloys also have poor resistance to inorganic acids.

The corrosion resistance of Copper alloys comes from the formation of adherent films on the material surface. These films are relatively impervious to corrosion therefore protecting the base metal from further attack.

Copper Nickel alloys, Aluminium Brass, and Aluminium Bronzes demonstrate superior resistance to saltwater corrosion.

Surface Oxidation of Copper

Most Copper alloys will develop a blue-green patina when exposed to the elements outdoors. Typical of this is the colour of the Copper Statue of Liberty in New York. Some Copper alloys will darken after prolonged exposure to the elements and take on a brown to black colour.

Lacquer coatings can be used to protect the surface and retain the original alloy colour. An acrylic coating with benzotriazole as an additive will last several years under most outdoor, abrasion-free conditions.

Yield Strength

The yield point for Copper alloys is not sharply defined. As a result it tends to be reported as either a 0.5% extension under load or as 0.2% offset.

Most commonly the 0.5% extension yield strength of annealed material registers as approximately one-third the tensile strength. Hardening by cold working means the material becomes less ductile, and yield strength approaches the tensile strength.

Joining

Commonly employed processes such as brazing, welding and soldering can be used to join most copper alloys. Soldering is often used for electrical connections. High Lead content alloys are unsuitable for welding.

Copper and Copper alloys can also be joined using mechanical means such as rivets and screws.

Hot and Cold Working

Although able to be work hardened, Copper and Copper alloys can be both hot and cold worked.

Ductility can be restored by annealing. This can be done either by a specific annealing process or by incidental annealing through welding or brazing procedures.

Temper

Copper alloys can be specified according to temper levels. The temper is imparted by cold working and subsequent degrees of annealing.

Typical tempers for Copper alloys are

- Soft
- Half-hard
- Hard, spring
- Extra-spring.

Yield strength of a hard-temper Copper alloy is approximately two-thirds of the materials' tensile strength.

Copper Designations

Designation systems for Copper are not specifications, but methods for identifying chemical compositions. Property requirements are covered in EN, ASTM, government and military standards for each composition.

The alloy designation system used in the Uk and across Europe uses a 6 character alpha-numeric series.

The 1st letter is C for copper-based material

The second letter indicates the product form:

- B = Ingot for re-melting to produce cast products
- C = Cast products
- F = Filler materials for brazing and welding
- M = Master Alloys
- R = Refined unwrought Copper
- S = Scrap
- W = Wrought products
- X = Non-standard materials

There is then a 3 digit number between 001 and 999 with the numbers being in groups as shown in the table below

There is then a letter indicating the copper or alloy grouping, also shown in the table

Number Series	Letters	Materials
001 - 099	A or B	Copper
100 - 199	C or D	Copper Alloys, Min. 95% Cu
200 - 299	E or F	Copper Alloys, <95% Cu
300 - 349	G	Copper-Aluminium Alloys
350 - 399	H	Copper-Nickel Alloys
400 - 449	J	Copper-Nickel-Zinc Alloys
450 - 499	K	Copper-Tin Alloys
500 - 599	L or M	Copper-Zinc Alloys - Binary
600 - 699	N or P	Copper-Zinc-Lead Alloys
700 - 799	R or S	Copper-Zinc Alloys - Complex

UNS Designations

The method for designating Copper alloys is an expansion upon the system developed by the U.S. copper and brass industry using five digits preceded by the letter C.

UNS Numbers	Types	Alloy Names
C10000-C19999	Wrought	Coppers, High-Copper Alloys
C20000-C49999	Wrought	Brasses
C50000-C59999	Wrought	Phosphor Bronzes
C60600-C64200	Wrought	Aluminium Bronzes
C64700-C66100	Wrought	Silicon Bronzes
C66400-C69800	Wrought	Brasses
C70000-C79999	Wrought	Copper nickels, nickel silvers
C80000-C82800	Cast	Coppers, High-Copper Alloys
C83300-C85800	Cast	Brasses
C86100-C86800	Cast	Manganese Bronzes
C87200-C87900	Cast	Silicon Bronzes and Brasses
C90200-C94800	Cast	Tin Bronzes
C95200-C95800	Cast	Aluminium Bronzes
C96200-C97800	Cast	Copper Nickels, Nickel Silvers
C98200-C98800	Cast	Leaded Copper
C99300-C99750	Cast	Special Alloys

Cast Copper Alloys

The nature of the casting process means that most cast Copper alloys have a greater range of alloying elements than wrought alloys.

Wrought Copper Alloys

Wrought copper alloys are produced using a variety of different production methods. These methods including processes such as annealing, cold working, hardening by heat treatments or stress relieving.

Copper Alloy Families

Within the wrought and cast categories for Copper alloys, the compositions can be divided into the following main families:

- Pure Coppers
- High Copper Alloys
- Brasses
- Bronzes

Coppers

The Pure Coppers have a Copper content of 99.3% or higher.

High Copper Alloys

Wrought high Copper alloys have Copper contents of less than 99.3% but more than 95% but don't fall into another Copper alloy group. Cast high Copper alloys have Copper contents in excess of 94%. Silver may be added to impart special properties.

Brasses

Brasses contain Zinc as the principal alloying element.

Other alloying elements may also be present to impart advantageous properties. These elements include Iron, Aluminium, Nickel and Silicon.

Brasses are most commonly characterised by their free machining grades by which

machining standards are set for all other metals.

Brasses can also have high corrosion resistance and high tensile strength. Some brasses are also suited to hot forging.

Brass Additives

Adding Lead to a brass composition can result in a brass with the ability to be rapidly machined. It will also produce less tool wear. Adding Aluminium, Iron and Manganese to brass improves strength. Silicon additions improve wear resistance.

Brasses are divided into two classes and three families.

Brass Classes

Brasses are divided into two classes. These are:

- The alpha alloys, with less than 37% Zinc. These alloys are ductile and can be cold worked.
- The alpha/beta or duplex alloys with 37-45% Zinc. These alloys have limited cold ductility and are typically harder and stronger.

Brass Families

There are three main families of wrought alloy brasses:

- Copper-Zinc alloys
- Copper-Zinc-Lead alloys (Leaded brasses)
- Copper-Zinc-Tin alloys (Tin brasses)

Cast brass alloys can be broken into four main families:

- Copper-Tin-Zinc alloys
- Manganese Bronze (high strength brasses) and Leaded Manganese Bronze (high tensile brasses)
- Copper-Zinc-Silicon alloys (Silicon brasses and bronzes)
- Cast Copper-Bismuth and Copper-Bismuth-Selenium alloys.

Bronzes

The term bronze originally described alloys with Tin as the only or principal alloying element.

Modern day bronzes tend to be Copper alloys in which the major alloying element is not Nickel or Zinc.

Bronzes can be further broken down into four families for both wrought and cast alloys.

Bronze Families

The wrought bronze alloy families are:

- Copper-Tin-Phosphorus alloys (Phosphor Bronzes)
- Copper-Tin-Lead-Phosphorus alloys (Leaded Phosphor Bronzes)
- Copper-Aluminium alloys (Aluminium Bronzes)
- Copper-Silicon alloys (Silicon Bronzes)

The cast bronze alloy families are:

- Copper-Tin alloys (Tin Bronzes)
- Copper-Tin-Lead alloys (Leaded and high leaded Tin Bronzes)
- Copper-Tin-Nickel alloys (nickel-tin bronzes)
- Copper-Aluminium alloys (Aluminium Bronzes)

Other Alloy Groups

Copper-Nickel Alloys

As the name suggests, the principal alloying element is Nickel. They can contain other alloying elements or simply have Nickel alone.

Copper-Nickel-Zinc Alloys

These alloys are commonly known as "Nickel Silvers" due to the colour of the alloy. They contain Zinc and Nickel as the principal alloying elements and may also contain other alloying elements.

Leaded Coppers

Leaded Coppers are cast Copper alloys with 20% or more Lead added. They may also contain a small amount of Silver but have no Tin or Zinc. Due to the toxity of Lead these are no longer in widespread use.

Special Alloys

When alloys have chemical compositions that do not fall into any of the other categories mentioned, they are grouped together as "special alloys".

Free Machining Coppers

Free machining properties are imparted upon Copper alloys by the addition of Sulphur and Tellurium.

Recycling

Copper alloys are highly suited to recycling. Around 40% of the annual consumption of Copper alloys is derived from recycled Copper materials.