Copper Alloys

Copper occurs in nature as sulfides and also as elemental copper. Copper is typically produced by a pyro-metallurgical (high-temperature) process. The copper ore containing high-sulfur contents is concentrated, then converted into a molten immiscible liquid containing copper sulfide-iron sulfide and is known as a copper matte. This is done in a flash smelter. In a separate reactor, known as a copper converter, oxygen introduced to the matte, converts the iron sulfide to iron oxide and the copper sulfide to an impure copper called blister copper, which is then purified electrolytically. Other methods for copper extraction include leaching copper from low-sulfur ores with an acid, then electrolytically extracting the copper from the solution.

Copper-based alloys have higher densities than that for steels. Although the yield strength of some alloys is high, their specific strength is typically less than that of aluminium or magnesium alloys. These alloys have better resistance to fatigue, creep, and wear than the lightweight aluminum and magnesium alloys. Many of these alloys have excellent ductility, corrosion resistance, electrical and thermal conductivity, and most can easily be joined or fabricated into useful shapes. **Applications for copper-based alloys** include electrical components (such as wire), pumps, valves, and plumbing parts, where these properties are used to advantage.

Copper alloys are also unusual in that they may be selected to produce an appropriate decorative color. Pure copper is red; zinc additions produce a yellow color, and nickel produces a silver color. Copper can corrode easily; forming a basic copper sulfate ($CuSO_4.3Cu(OH)_2$). This is a green compound that is insoluble in water (but soluble in acids). This green patina provides an attractive finish for many applications. The statue of Liberty is green because of the green patina of the oxidized copper skin that covers the steel structure.

Table 1. Properties of typical copper alloys obtained by different strengthening mechanisms.

Material	Tensile Strength (psi)	Yield Strength (psi)	% Elongation	Strengthening Mechanism
Pure Cu, annealed	30,300	4,800	60	None
Commercially pure Cu, annealed to coarse grain size	32,000	10,000	55	Solid solution
Commercially pure Cu, annealed to fine grain size	34,000	11,000	55	Grain size
Commercially pure Cu, cold-worked 70%	57,000	53,000	4	Strain hardening
Annealed Cu-35% Zn	47,000	15,000	62	Solid solution
Annealed Cu-10% Sn	66,000	28,000	68	Solid solution
Cold-worked Cu-35% Zn	98,000	63,000	3	Solid solution + strain hardening
Age-hardened Cu-2% Be	190,000	175,000	4	Age hardening
Quenched and tempered Cu-Al	110,000	60,000	5	Martensitic reaction
Cast manganese bronze	71,000	28,000	30	Eutectoid reaction

The wide variety of copper-based alloys take advantage of all of the strengthening mechanisms that we have discussed. The effects of these strengthening mechanisms on the mechanical properties are summarized in Table 1. Copper containing less than (**0.1%**) impurities is used for electrical and microelectronics applications. Small amounts of **Cadmium**, **Silver**, and **Al_2O_3** improve their hardness without significantly impairing conductivity. The single-phase copper alloys are strengthened by cold working. Examples of this effect are shown in Table 1. The FCC structure of copper provides for excellent ductility and a high strain-hardening coefficient.

Solid-Solution-Strengthened Alloys: A number of copper-based alloys contain large quantities of alloying elements, yet remain single phase. Important binary phase diagrams are shown in figure 1. The Copper-Zinc (Cu-Zn), or **Brass**, alloys with less than **40% Zn** form single-phase solid solutions of zinc in copper. The **Mechanical Properties** even elongation increase as the zinc content increases. These alloys can be cold formed into rather complicated yet corrosion-resistant components. **Bronzes** are alloys of copper containing tin (**Cu-Sn**) and can certainly contain other elements. Manganese bronze (**Cu-Mg**) is a particularly high-strength alloy containing manganese as well as zinc for solid-solution strengthening.

Tin bronzes (**Cu-Sn**), often called phosphor bronzes, may contain up to **10% Sn** and remain single phase. The phase diagram predicts that the alloy will contain the **Cu_3Sn** (ε) compound. However, the kinetics of the reaction are so slow that the precipitate particles often do not form.

Alloys containing less than about 9% Al or less than 3% Si are also single phase. These aluminum bronzes and silicon bronzes have good forming characteristics and are often selected for their good strength and excellent toughness.

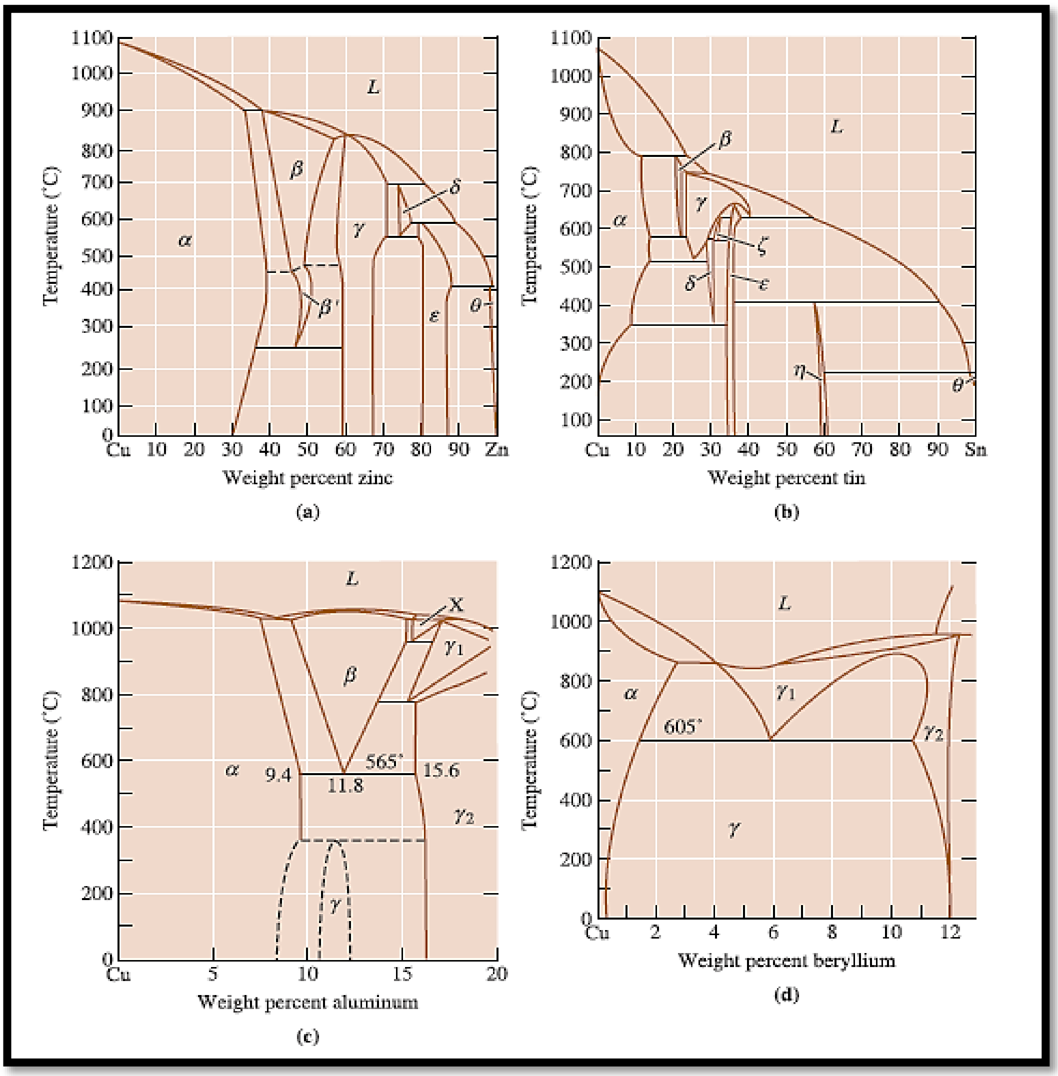

Figure 1. Binary phase diagrams for the (a) Copper-Zinc, (b) Copper-Tin, (c) Copper-Aluminum, and (d) Copper-Beryllium systems.

Age-Hardenable Alloys A number of copper-base alloys display an age-hardening response, including zirconium-copper, chromium-copper, and beryllium-copper. The **Copper-Beryllium alloys** are used for their high strength, their high stiffness (making them useful as springs and fine wires), and their non-sparking qualities (making them useful for tools to be used near flammable gases and liquids).

Phase Transformations Aluminium bronzes that contain over **9% Al** can form b phase on heating above 565°C, the eutectoid temperature. On subsequent cooling, the eutectoid reaction produces a lamellar structure (like pearlite) that contains a brittle **γ2** compound. The low temperature peritectoid reaction, a **γ2**! g, normally does not occur. The eutectoid product is relatively weak and brittle, but we can rapidly quench the b to produce martensite, or b_0, which has high strength and low ductility. When b_0 is subsequently tempered, a combination of high strength, good ductility, and excellent toughness is obtained as fine platelets of a precipitate from the b_0.

Leaded-Copper Alloys Virtually any of the wrought alloys may contain up to 4.5% Pb. The lead forms a monotectic reaction with copper and produces tiny lead spheres as the last liquid to solidify. The lead improves machining characteristics. Use of leaded-copper alloys, however, has a major environmental impact and, consequently, new alloys that are lead free have been developed. The following two examples illustrate the use of copper-based alloys.