Copper and Copper Alloys: Casting, Classification and Characteristic Microstructures

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1. Introduction

1.1 Copper

Copper is non-polymorphous metal with face centered cubic lattice (FCC, Fig. 1). Pure copper is a reddish color (Fig. 2); zinc addition produces a yellow color, and nickel addition produces a silver color. Melting temperature is 1083 °C and density is 8900 kg.m^{-3}, which is three times heavier than aluminum. The heat and electric conductivity of copper is lower compared to the silver, but it is 1.5 times larger compared to the aluminum. Pure copper

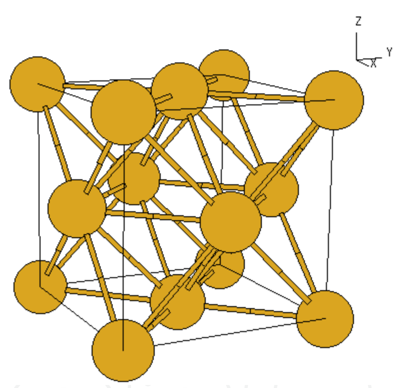


Fig. 1. FCC lattice (http://cst-www.nrl.navy.mil/lattice/struk/a1.html)

Fig. 2. Natural copper (http://jeanes.webnode.sk/prvky/med/)

electric conductivity is used like a basic value for other metals evaluation and electric conductivity alloys characterization (Skočovský et al., 2000, 2006). Copper conductivity standard (IASC) is determined as 58 Mss^{-1}. The pure metal alloying decreased its conductivity (Skočovský et al., 2000).

Before the copper products usage it has to pass through a number of stages. When recycled, it can pass through some stages over and over again. In nature, copper in its pure metal form occurs very often. Metallurgically from ores, where the chemical compound of copper with oxygen, sulphur or other elements occurs, copper is produced:

- chalcopyrite ($CuFeS_2$) – contains around 34.5 % of copper;
- azurite ($Cu_3[OH\text{-}Co_3]_2$) and malachite ($Cu_2[OH\text{-}Co_3]_2$) – alkaline copper carbonates;
- cuprite (Cu_2O) – copper oxide.

The beginning for all copper is to mine sulfide and oxide ores through digging or blasting and then crushing these to walnut-sized pieces. Crushed ore is ball or rod-milled in large, rotating, cylindrical machines until it becomes a powder, usually containing less than 1 % copper. Sulfide ores are moved to a concentrating stage, while oxide ores are routed to leaching tanks.

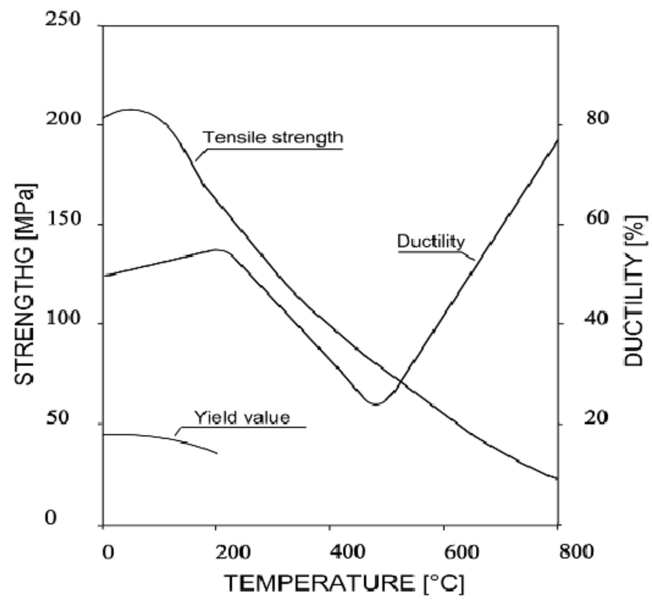
Minerals are concentrated into slurry that is about 15 % of copper. Waste slag is removed. Water is recycled. Tailings (left-over earth) containing copper oxide are routed to leaching tanks or are returned to the surrounding terrain. Once copper has been concentrated, it can be turned into pure copper cathode in two different ways: leaching & electrowinning or smelting and electrolytic refining.

Oxide ore and tailings are leached by a weak acid solution, producing a weak copper sulfate solution. The copper-laden solution is treated and transferred to an electrolytic process tank. When electrically charged, pure copper ions migrate directly from the solution to starter cathodes made from pure copper foil. Precious metals can be extracted from the solution.

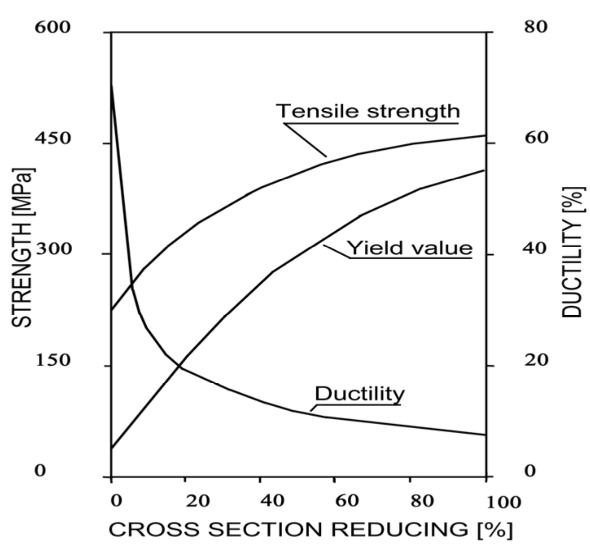
Several stages of melting and purifying the copper content result, successively, in matte, blister and, finally, 99% pure copper. Recycled copper begins its journey to finding another use by being remelted. Anodes cast from the nearly pure copper are immersed in an acid bath. Pure copper ions migrate electrolytically from the anodes to "starter sheets" made from pure copper foil where they deposit and build up into a 300-pound cathode. Gold, silver and platinum may be recovered from the used bath.

Cathodes of 99.9% purity may be shipped as melting stock to mills or foundries. Cathodes may also be cast into wire rod, billets, cakes or ingots, generally, as pure copper or alloyed with other metals (http://www.mtfdca.szm.com/subory/med-zliatiny.pdf, http://www.copper.org/education/production.html).

Coppers mechanical properties (Fig. 3) depend on its state and are defined by its lattice structure. Copper has good formability and toughness at room temperature and also at reduced temperature. Increasing the temperature steadily decreases coppers strength properties. Also at around 500 °C the coppers technical plastic properties decrease. Due to this behavior, cold forming or hot forming at 800 to 900 °C of copper is proper. Cold forming increases the strength properties but results in ductility decreasing. In the as cast state, the copper has strength of 160 MPa. Hot rolling increases coppers strength to 220 MPa. Copper has a good ductility and by cold deformation it is possible to reach the strength values close to the strength values of soft steel (Skočovský et al., 2000, 2006).



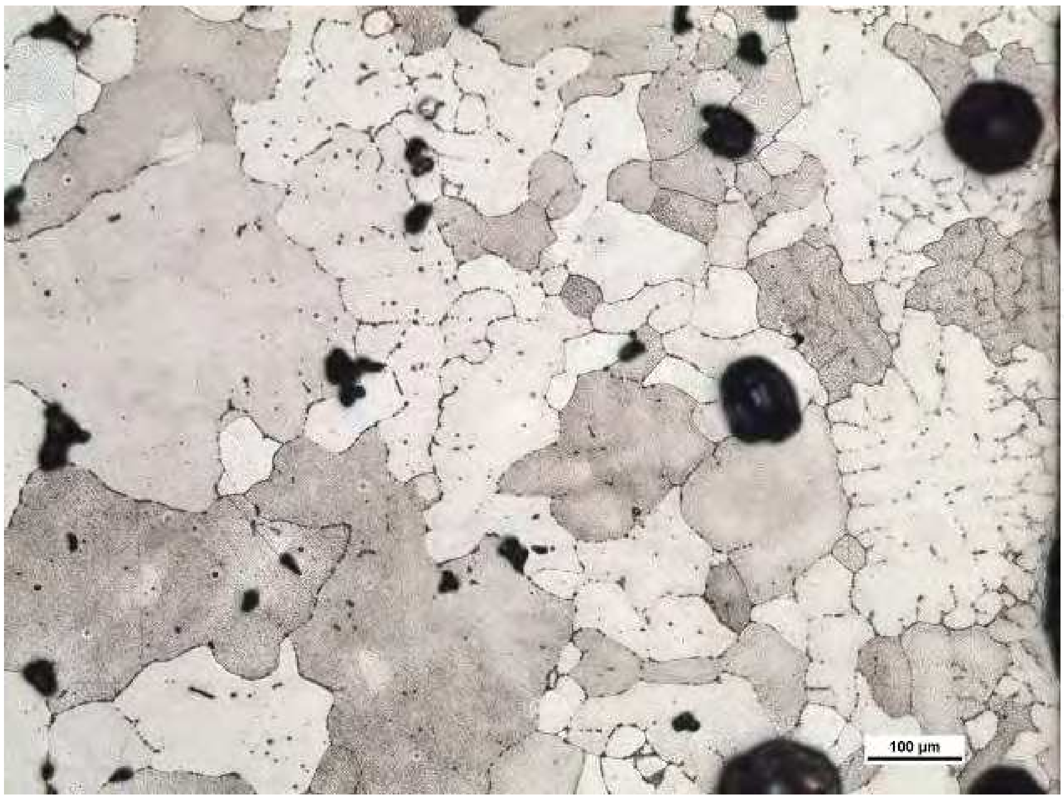
a) temperature influence on tensile strength, yield value and ductility



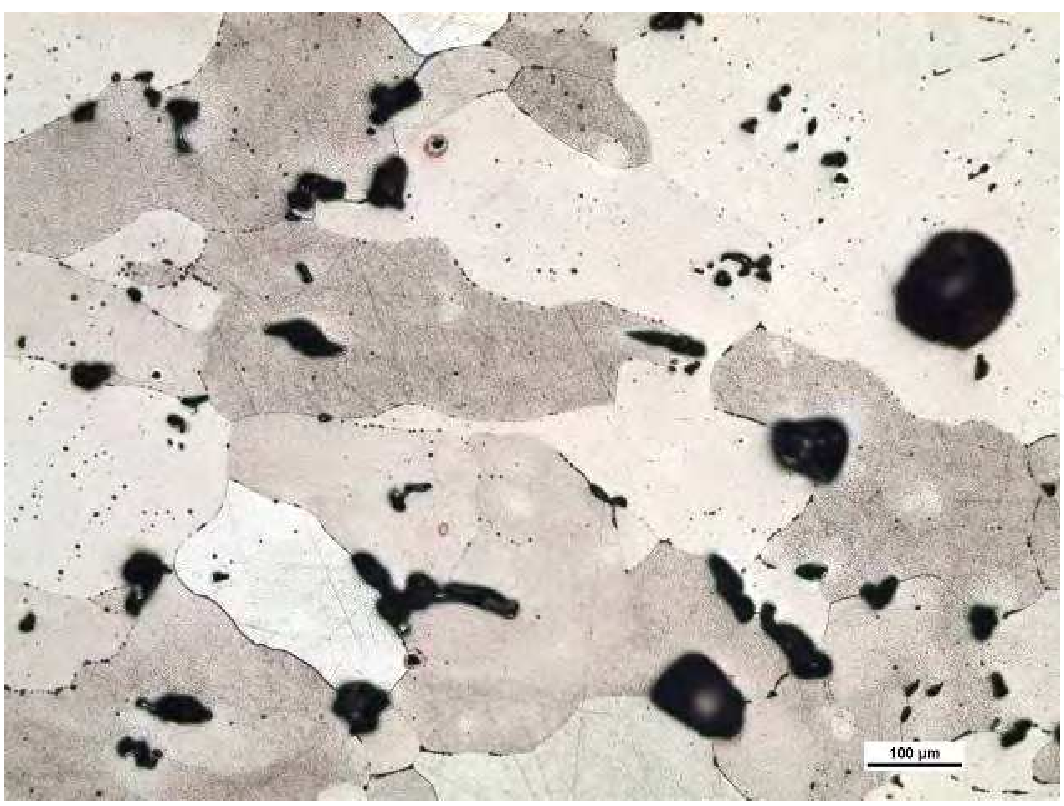
b) change properties due to the cold forming

Fig. 3. Copper mechanical properties (Skočovský et al., 2006).

Copper resists oxidation, however, it is reactive with sulphur and its chemical compounds, and during this reaction copper sulphide is created. Besides oxygen, the main contaminant, phosphor and iron are the significant copper contaminants. It is difficult to cast pure copper because large shrinkages during the solidification occur (1.5 %), and is the dissolving of a large amount of gasses at high temperatures disengaged during the solidification process and resulting in the melted metal gassing and the casting porosity (Fig. 4a, b). Cast copper microstructure is formed by non-uniform grains with very different sizes. Wrought copper microstructure consists of uniform polyhedral grains with similar grain size and it is also possible to observe annealing twins (Fig. 4c-e). Because of coppers reactivity, the dangers of surface cracking, porosity, and the formation of internal cavities are high.

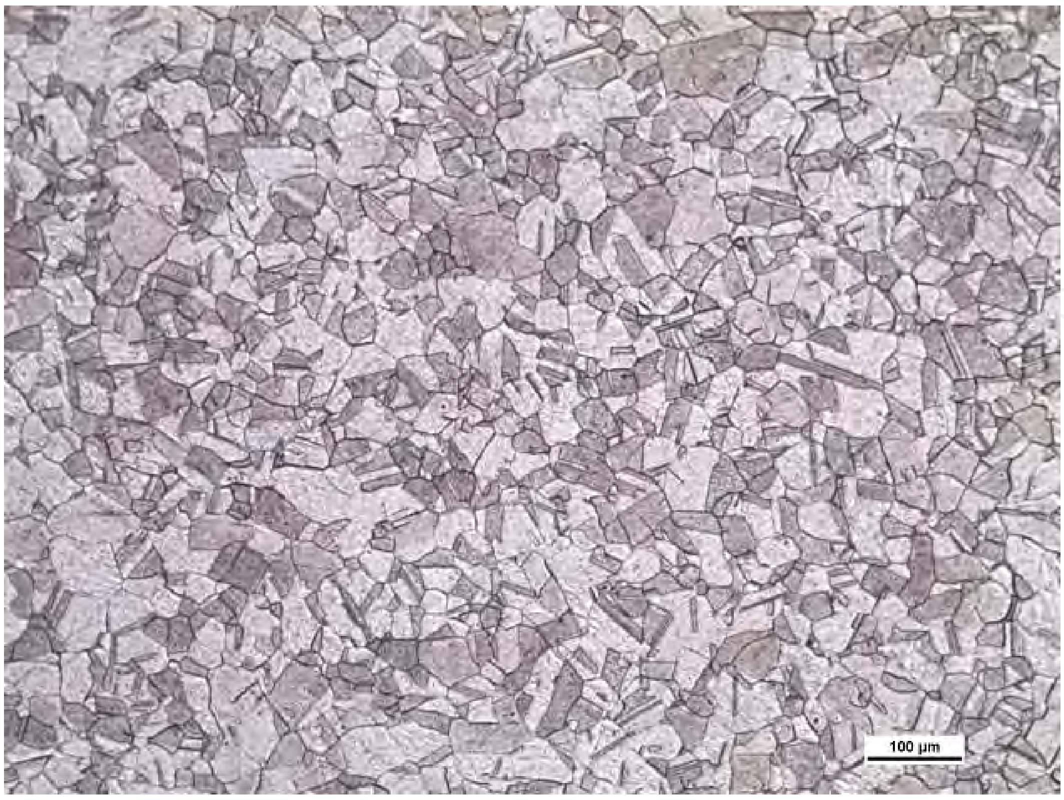


a) microstructure of cast Cu; specimens edge on the right, where is different grain size due to high cooling rate on the surface

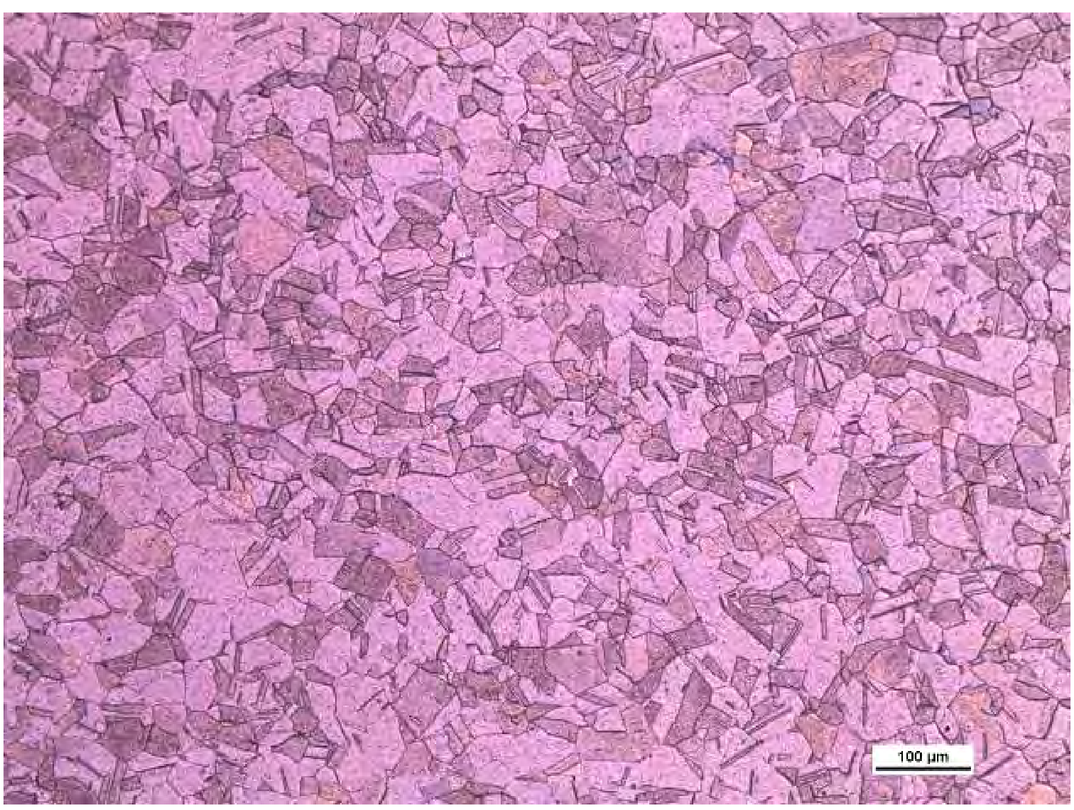


b) cast Cu; specimens middle part with big grains at low cooling rate

Fig. 4. Pure copper, chemically polished

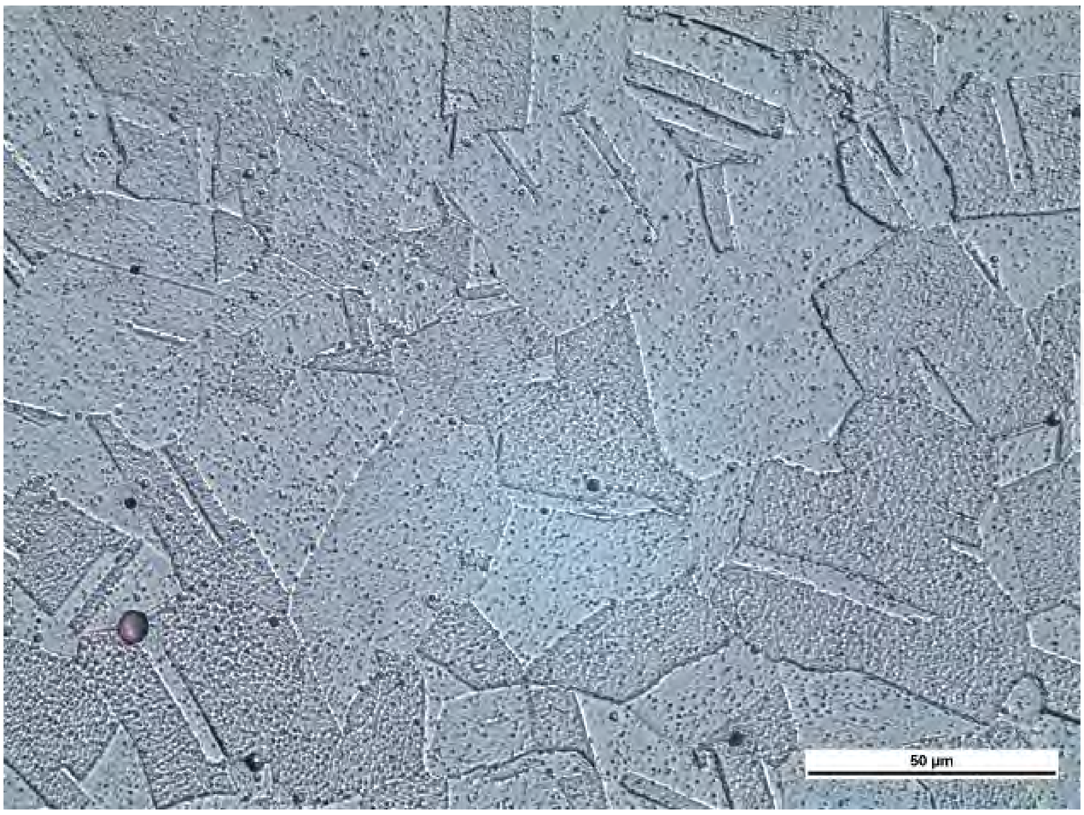


c) microstructure of wrought Cu with uniform polyhedral grains and annealing twins, white light

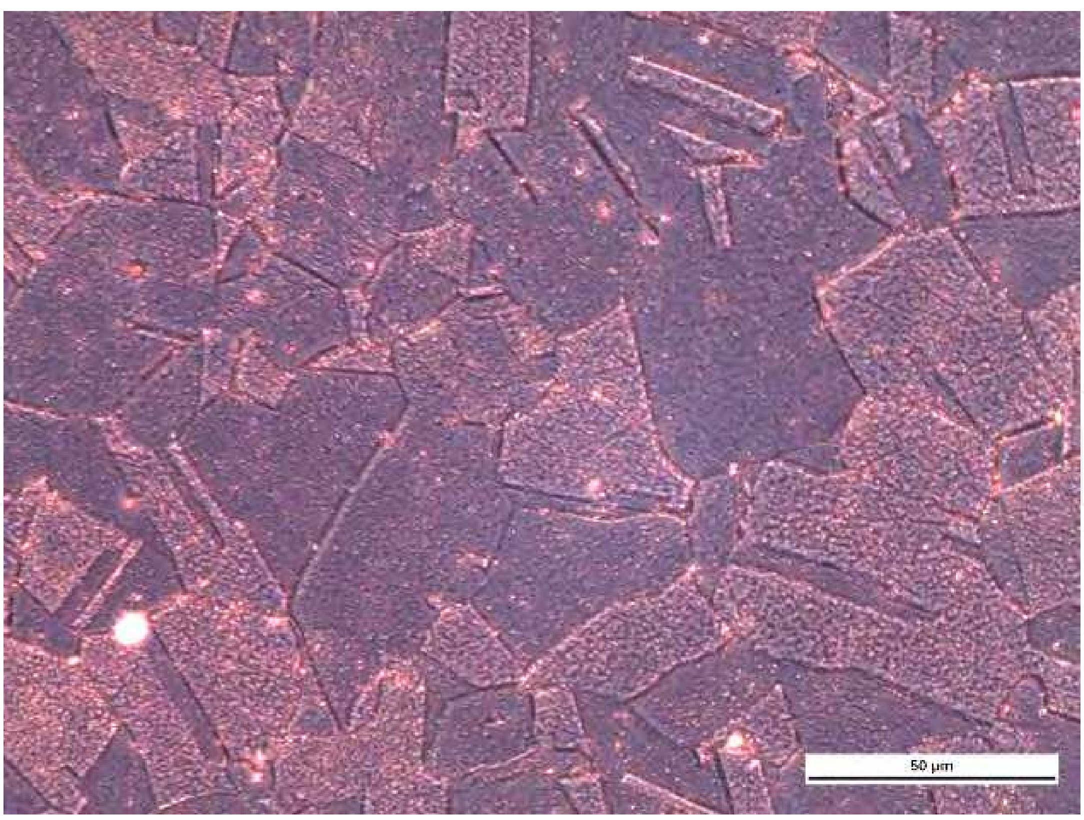


d) the same microstructure of wrought Cu, polarized light

Fig. 4. Pure copper, chemically polished



e) detail of wrought Cu grains, white light



f) detail of wrought Cu grains, polarized light

Fig. 4. Pure copper, chemically polished

The casting characteristics of copper can be improved by the addition of small amounts of elements like beryllium, silicon, nickel, tin, zinc, chromium, and silver. In copper based alloys 14 alloying elements, almost always in the solid solution dissolving area, are used. Most of the industrial alloys are monophasic and they do not show allotropic changes during heating or cooling. For some copper-base alloys precipitation hardening is possible. For the alloys with allotropic recrystallization heat treatment is possible. Single-phase copper alloys are strengthened by cold-working. The FCC copper has excellent ductility and a high strain-hardening coefficient.

Copper and copper based alloys can be divided into 3 groups according to the chemical composition:

- copper and high copper alloys,
- brasses (Cu-Zn + other alloying elements),
- bronzes (Cu + other elements except Zn).

The copper based alloys, according to the application can be divided into two groups, as copper alloys for casting and wrought alloys subsequently. Copper-base alloys are heavier than iron (Skočovský et al., 2006).

Although the yield strength of some alloys is high, their specific strength is typically less than that of aluminum or magnesium alloys. The alloys have better resistance to fatigue, creep, and wear than the lightweight aluminum and magnesium alloys. Many of the alloys have excellent ductility, corrosion resistance, and electrical and thermal conductivity, and they are easily joined or fabricated into useful shapes. The wide varieties of copper-based alloys take advantage of all of the straightening mechanisms on the mechanical properties (Skočovský et al., 2000).

1.2 Copper and copper alloys casting

From the casting point of view, especially the solidification (freezing range) Cu cast alloys can be divided into three groups:

Group I alloys - alloys that have a narrow freezing range, that is, a range of 50 °C between the liquidus and solidus curves. These are the yellow brasses, manganese and aluminum bronzes, nickel bronze, manganese bronze alloys, chromium copper, and copper.

Group II alloys – alloys that have an intermediate freezing range, that is, a freezing range of 50 to 110 °C between the liquidus and the solidus curves. These are the beryllium coppers, silicon bronzes, silicon brass, and copper-nickel alloys.

Group III alloys – alloys that have a wide freezing range. These alloys have a freezing range of well over 110 °C, even up to 170 °C. These are the leaded red and semi-red brasses, tin and leaded tin bronzes, and high leaded tin bronze alloys (R. F. Schmidt, D. G. Schmidt & Sahoo 1998).

According to the cast products quality the Cu based foundry alloys can be classified as high-shrinkage or low-shrinkage alloys. The former class includes the manganese bronzes, aluminum bronzes, silicon bronzes, silicon brasses, and some nickel-silvers. They are more fluid than the low-shrinkage red brasses, more easily poured, and give high-grade castings in the sand, permanent mold, plaster, die, and centrifugal casting processes. With high-shrinkage alloys, careful design is necessary to promote directional solidification, avoid abrupt changes in cross section, avoid notches (by using generous fillets), and properly place gates and risers; all of these design precautions help avoid internal shrinks and cracks (R. F. Schmidt & D. G. Schmidt, 1997).

1.2.1 Casting

To obtain good results from the product quality point of view, the casting processes technological specifications are the most important factor. The lowest possible pouring temperature needed to suit the size and form of the solid metal should be used to encourage as small a grain size as possible, as well as to create a minimum of turbulence of the metal during pouring to prevent the casting defects formation (R. F. Schmidt, D. G. Schmidt & Sahoo, 1988). Liberal use of risers or exothermic compounds ensures adequate molten metal to feed all sections of the casting.

Many types of castings for Cu and its alloys casting, such as sand, shell, investment, permanent mold, chemical sand, centrifugal, and die, can be used (R. F. Schmidt, D. G. Schmidt & Sahoo, 1988). Of course each of them has its advantages and disadvantages. If only a few castings are made and flexibility in casting size and shape is required, the most economical casting method is sand casting. For tin, silicon, aluminum and manganese bronzes, and also yellow brasses, permanent mold casting is best suited. For yellow brasses die casting is well suited, but increasing amounts of permanent mold alloys are also being die cast. Definite limitation for both methods is the casting size, due to the reducing the mold life with larger castings.

All copper alloys can be cast successfully by the centrifugal casting process. Because of their low lead contents, aluminum bronzes, yellow brasses, manganese bronzes, low-nickel bronzes, and silicon brasses and bronzes are best adapted to plaster mold casting. Lead should be held to a minimum for most of these alloys because lead reacts with the calcium sulfate in the plaster, resulting in discoloration of the surface of the casting and increased cleaning and machining costs.

1.2.2 Furnaces

The copper based alloys are melted mainly in Fuel-Fired Furnaces and Electric Induction Furnaces.

From Fuel-Fired Furnaces, oil- and gas-fired furnaces are the most important. However open-flame furnaces are able to melt large amounts of metal quickly; there is a need for operator skill to control the melting atmosphere within the furnace at present this kind of furnaces are not often used. Also, the refractory furnace walls become impregnated with the melting metal causing a contamination problem when switching from one alloy family to another.

When melting leaded red and semi-red brasses, tin and leaded tin bronzes, and high leaded tin bronze alloys, lead and zinc fumes are given off during melting and superheating. These harmful oxides emissions are much lower when the charge is melted in an induction furnace. This is caused by the duration of the melting cycle is only about 25 % of the cycle in a fuel-fired furnace.

The core type, better known as the channel furnace, and the coreless type of electric induction furnaces for Cu and its alloys melting are also used. Because core type furnaces are very efficient and simple to operate with lining life in the millions of pounds poured, they are best suited for continuous production runs in foundries making plumbing alloys of the leaded red and semi-red brasses, tin and leaded tin bronzes, and high leaded tin bronze alloys. They are not recommended for dross-forming alloys; yellow brasses, manganese and aluminum bronzes, nickel bronze, manganese bronze alloys, chromium copper, and copper. The channel furnace is at its best when an inert, floating, cover flux is used and charges of ingot, clean remelt, and clean and dry turnings are added periodically.

Coreless type furnaces have become the most popular melting unit in the Cu alloy foundry industry (R. F. Schmidt, D. G. Schmidt & Sahoo, 1988).

1.2.3 Pure copper and high copper alloys

Commercially pure copper and high copper alloys are very difficult to melt and they are very susceptible to gassing. Chromium copper melting is negatively linked with oxidation loss of chromium. To prevent both oxidation and the pickup of hydrogen from the atmosphere copper and chromium copper should be melted under a floating flux cover. In the case of pure copper crushed graphite should cover the melt. In the case of chromium copper, the cover should be a proprietary flux made for this alloy. It is necessary to deoxidize the melted metal. For this reason the calcium boride or lithium should be plunged into the molten bath when the melted metal reaches 1260 °C. The metal should then be poured without removing the floating cover.

Beryllium coppers can be very toxic and dangerous. This is caused by the beryllium content in cases where beryllium fumes are not captured and exhausted by proper ventilating equipment. To minimize beryllium losses beryllium coppers should be melted quickly under a slightly oxidizing atmosphere. They can be melted and poured successfully at relatively low temperatures. They are very fluid and pour well.

Copper-nickel alloys (90Cu-10Ni and 70Cu-30Ni) must also be carefully melted. Concern is caused by the presence of nickel in high percentages because this raises not only the melting point but also the susceptibility to hydrogen pickup. These alloys are melted in coreless electric induction furnaces, because the melting rate is much faster than it is with a fuel-fired furnace. The metal should be quickly heated to a temperature slightly above the pouring temperature and deoxidized either by the use of one of the proprietary degasifiers used with nickel bronzes or, better yet, by plunging 0.1 % Mg stick to the bottom of the ladle. This has to be done to prevent the of steam-reaction porosity from occurring by the oxygen removing. If the gates and risers are cleaned by shotblasting prior to melting there is a little need to use cover fluxes (R. F. Schmidt, D. G. Schmidt & Sahoo, 1988).

1.2.4 Brasses

Yellow Brasses (containing 23 - 41 % of zinc) as the major alloying element and may contain up to 3 % of lead and up to 1.5 % of tin as additional alloying elements. Due to vaporization these alloys flare, ore lose zinc close to the melting point. The zinc vaporization can be minimized by the addition of aluminum (0.15 to 0.35 %) which also increases the melted metals fluidity. In the case of larger aluminum amount shrinkages take place during freezing; this has to be solved by use of risers. Except for aluminum problems, yellow brass melting is simple and no fluxing is necessary. Zinc lost during the melting should be re-added before pouring.

Silicon brasses have excellent fluidity and can be poured slightly above their freezing range. If overheated, they can pick up hydrogen. In the case of the silicon brasses no cover fluxes are required.

Red brasses and leaded red brasses are copper alloys, containing 2 - 15 % of zinc as the major alloying element and up to 5 % of Sn and up to 8 % of Pb as additional alloying elements. Because of lengthy freezing range in the case of these alloys, chills and risers should be used in conjunction with each other. The best pouring temperature is the lowest one that will pour the molds without having misruns or cold shuts. For good casting, properties retaining these alloys should be melted from charges comprised of ingot and clean, sandfree gates and risers. The melting should be done quickly in a slightly oxidizing atmosphere. When at the proper furnace temperature to allow for handling and cooling to the proper pouring temperature, the crucible is removed or the metal is tapped into a ladle. At this point, a deoxidizer (15 % phosphorus copper) is added. The phosphorus is a reducing agent (deoxidizer) and must be carefully measured so that enough oxygen is removed, yet a small amount remains to improve fluidity. This residual level of phosphorus must be controlled by chemical analysis. Only amount in the range 0.010 and 0.020 % P is accepted, in the case of the larger phosphorus amount internal porosity may occur. Along with phosphorus copper pure zinc should also be added at the point at which skimming and temperature testing take place prior to pouring. This added zinc replaces the zinc lost during melting and superheating. With these alloys, cover fluxes are seldom used. In some foundries in which combustion cannot be properly controlled, oxidizing fluxes are added during melting, followed by final deoxidation by phosphor copper.

Leaded red brasses alloys have practically no feeding range, and it is extremely difficult to get fully sound castings. Leaded red brasses castings contain 1 to 2 % of porosity. Only small castings have porosity below 1 %. Experience has shown that success in achieving good quality castings depends on avoiding slow cooling rates. Directional solidification is the best for relatively large, thick castings and for smaller, thin wall castings, uniform solidification is recommended (R. F. Schmidt, D. G. Schmidt & Sahoo 1998).

1.2.5 Bronzes

Manganese bronzes are carefully compounded yellow brasses with measured quantities of iron, manganese, and aluminum. When the metal is heated at the flare temperature or to the point at which zinc oxide vapor can be detected, it should be removed from the furnace and poured. No fluxing is required with these alloys. The only required addition is zinc, which is caused by its vaporization. The necessary amount is the one which will bring the zinc content back to the original analysis. This varies from very little, if any, when an all-ingot heat is being poured, to several percent if the heat contains a high percentage of remelt.

White manganese bronzes. There are two alloys in this family, both of which are copper-zinc alloys containing a large amount of manganese and, in one case, nickel. They are manganese bronze type alloys, are simple to melt, and can be poured at low temperatures because they are very fluid. The alloy superheating resulting in the zinc vaporization and the chemistry of the alloy is changed. Normally, no fluxes are used with these alloys.

Aluminum bronzes must be melted carefully under an oxidizing atmosphere and heated to the proper furnace temperature. If needed, degasifiers removing the hydrogen and oxygen from the melted metal can be stirred into the melt as the furnace is being tapped. By pouring a blind sprue before tapping and examining the metal after freezing, it is possible to tell whether it shrank or exuded gas. If the sample purged or overflowed the blind sprue during solidification, degassing is necessary. For converting melted metal fluxes, are available, mainly in powder form, and usually fluorides. They are used for the elimination of oxides, which normally form on top of the melt during melting and superheating (R. F. Schmidt, D. G. Schmidt & Sahoo, 1988).

From the freezing range point of view, the manganese and aluminum bronzes are similar to steels. Their freezing ranges are quite narrow, about 40 and 14 °C, respectively. Large castings can be made by the same conventional methods used for steel. The attention has to be given to placement of gates and risers, both those for controlling directional solidification and those for feeding the primary central shrinkage cavity (R. F. Schmidt & D. G. Schmidt, 1997).

Nickel bronzes, also known as nickel silver, are difficult to melt because nickel increases the hydrogen solubility, if the alloy is not melted properly it gases readily. These alloys must be melted under an oxidizing atmosphere and they have to be quickly superheated to the proper furnace temperature to allow for temperature losses during fluxing and handling. After the furnace tapping the proprietary fluxes should be stirred into the metal for the hydrogen and oxygen removing. These fluxes contain manganese, calcium, silicon, magnesium, and phosphorus.

Silicon bronzes are relatively easy to melt and should be poured at the proper pouring temperatures. In the case of overheating the hydrogen, picking up can occur. For degassing, one of the proprietary degasifiers used with aluminum bronze can be successfully used. Normally no cover fluxes are used for these alloys.

Tin and leaded tin bronzes, and **high-leaded tin bronzes**, are treated the same in regard to melting and fluxing. Their treatment is the same as in the case of the red brasses and leaded red brasses, because of the similar freezing range which is long (R. F. Schmidt, D. G. Schmidt & Sahoo, 1988).

Tin bronzes have practically no feeding range, and it is extremely difficult to get fully sound castings. Alloys with such wide freezing ranges form a mushy zone during solidification, resulting in interdendritic shrinkages or microshrinkages. In overcoming this effect, design and riser placement, plus the use of chills, are important and also the solidification speed, for better results the rapid solidification should be ensured. As in the case of leaded red brasses, tin bronzes also have problems with porosity. The castings contain 1 to 2 % of porosity and only small castings have porosity below 1 %. Directional solidification is best for relatively large, thick castings and for smaller, thin wall castings, uniform solidification is recommended. Sections up to 25 mm in thickness are routinely cast. Sections up to 50 mm thick can be cast, but only with difficulty and under carefully controlled conditions (R. F. Schmidt & D. G. Schmidt, 1997).

2. Copper based alloys

2.1 Brasses

Brasses are copper based alloys where zinc is the main alloying element. Besides zinc, also some amount of impurities and very often some other alloying elements are present in the alloys. The used alloying elements can improve some properties, depending on their application. Due to the treatment, brasses can be divided into two groups: wrought brasses and cast brasses. One special group of brasses is brazing solder.

The binary diagram of the Cu-Zn system is quite difficult, Fig. 5. For the technical praxis only the area between the 0 to 50 % of Zn concentration is important. Alloys with higher Zn concentration have not convenient properties, as they are brittle.

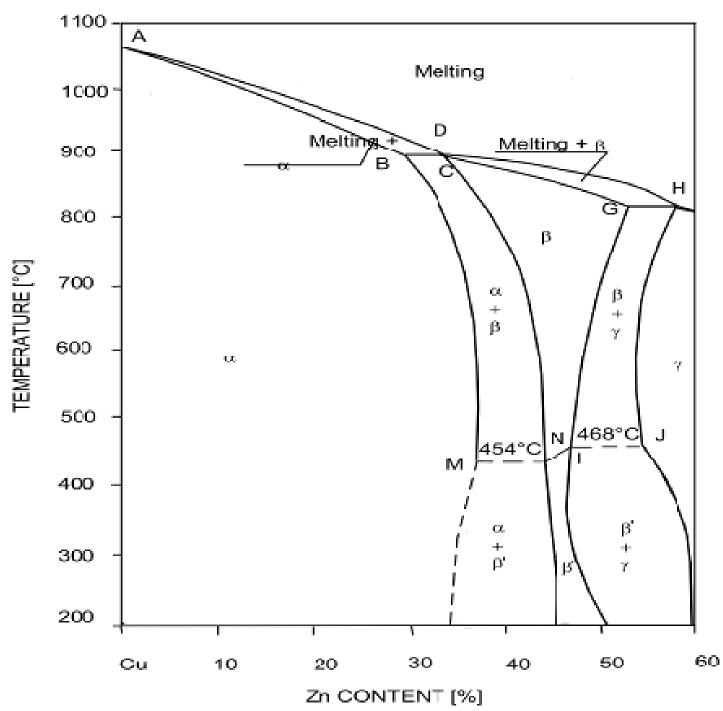


Fig. 5. Binary diagram copper-zinc

In the liquid state copper and zinc are absolutely soluble. In the solid state solubility is limited; copper has face centered cubic lattice and zinc has the hexagonal close-packed lattice (HCP). During solidification the α, β, γ, δ, ε and η phases are released. Most of the phases are intermediary phases characterized by the relation of valence electrons and amount of atoms. Primary solid solution α (Zn in Cu) has the same crystal lattice as pure copper and dissolves maximum 39 % of Zn at temperature 450 °C. Decreasing the temperature, also the zinc solubility in the α solution decreases ~ 33 %. In the alloys with higher content of Zn concentration the supersaturated α solid solution is retaining at room temperature. This is why alloys up to 39 % Zn concentration have homogenous structure consisting from the α solid solution crystals. After the forming and annealing the brass structure consists of the α solid solution polyhedral grains with annealed twins (Skočovský et al., 2000, 2006).

Alloys with Zn concentration from 32 % (point B, Fig. 5) to 36 % (point C) crystallize according to the peritectic reaction at temperature 902 °C. During this reaction the β phase is created by the reaction of formed primary α crystals and the liquid alloy. By decreasing the temperature in the solid state the ratio of both crystals is changed. This is caused by solubility changes and the resulting brass structure is created only by the α solid solution crystals. In the case of alloys with the concentration of Zn from 36 to 56 % the β phase exists after the solidification. β phase has a body centered cubic (BCC) lattice. The atoms of Cu and Zn are randomly distributed in the lattice. β phase has good ductility. By the next temperature decreasing the random β phase is changed to the ordered hard and brittle β´ phase; temperatures from 454 to 468 °C. The 39 to 45 % Zn containing brass resulting structure is heterogeneous, consisting of the α solid solution crystals and β´ phase crystals.

Only the alloys containing less than 45 % of Zn in the technical praxis, apart from small exceptions, are used. Brasses with less than 40 % Zn form single-phase solid solution of zinc in copper. The mechanical properties, even elongation, increase with increasing zinc content. These alloys can be cold-formed into rather complicated yet corrosion-resistant components. Brasses with higher Zn concentration, created by the β´ phases, or β´+γ phase, are excessively brittle. Mechanical properties of the brasses used in the technical praxis are shown in the Fig. 6 (Skočovský et al., 2000).

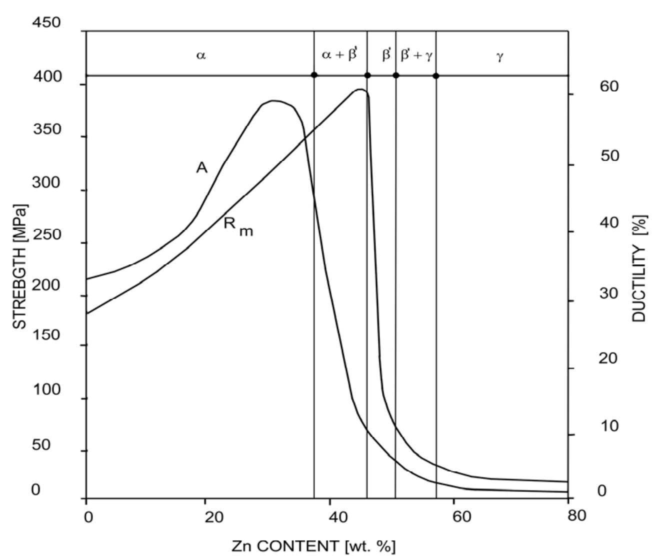


Fig. 6. Influence of the Zn content to the brass mechanical properties

Brasses used in technical praxis consist also of some other elements; impurities and alloying elements besides Zn, whose influence is the same as in the case of pure copper. Bismuth and sulphur, for example, decreases the ability of the metal to hot forming. Lead has a similar influence. On the other hand, lead improves the materials workability. For this reason, lead is used for heterogeneous brasses in an amount from 1 to 3 %. Homogenous brasses, for improving strength, contain tin, aluminum, silicon and nickel. Silicon improves the materials resistance against corrosion and nickel improves the materials ductility.

Brasses heat treatment. Recrystallization annealing is brasses basic heat treatment process. Combination of recrystallization annealing and forming allows to change the materials grain structure and to influence the hardening state reached by the plastic deformation. The lower limit of the recrystallizing temperatures for binary Cu-Zn alloys is ~ 425 °C and the upper limit is limited by the amount of Zn in the alloy.

Stress-relief annealing is the second possible heat treatment used for brasses. This heat treatment process, at temperatures from 250 – 300 °C, decreases the danger of corrosion cracking (Skočovský et al., 2000).

2.1.1 Wrought brasses

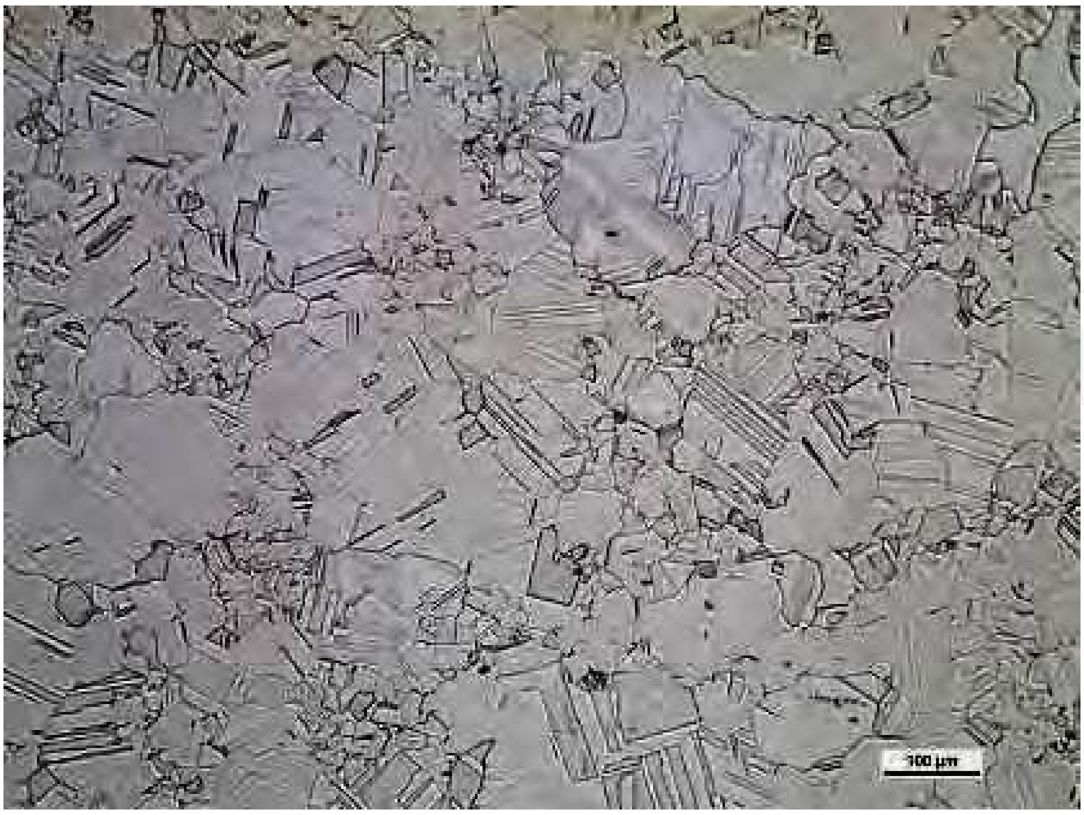
Wrought brasses are supplied in the form of metal sheets, strips, bars, tubes, wires, etc. in the soft (annealed) state, or in the state (medium, hard state) after cold forming (Skočovský et al., 2000, 2006).

Tombacs are brasses containing more than 80 % of copper. They are similar to the pure copper by theirs chemical and physical properties, but they have better mechanical properties. Tombac with higher copper content is used for coins, memorial tablets, medals, etc. (after production the products are gold-plated before distribution). Tombacs with medium or lower copper content are light yellow colored, close to the color of gold. Because of this, brass films are used like the gold substituent in the case of decorative, artistic, fake jewelry, architecture, armatures, in electrical engineering, for manometers, flexible metal tubes, sieves etc. plating. Tombac with 80 % Zn has lower chemical resistance due to the higher Zn content, and so its usage (same like for other Tombacs) is dependent on the working conditions.

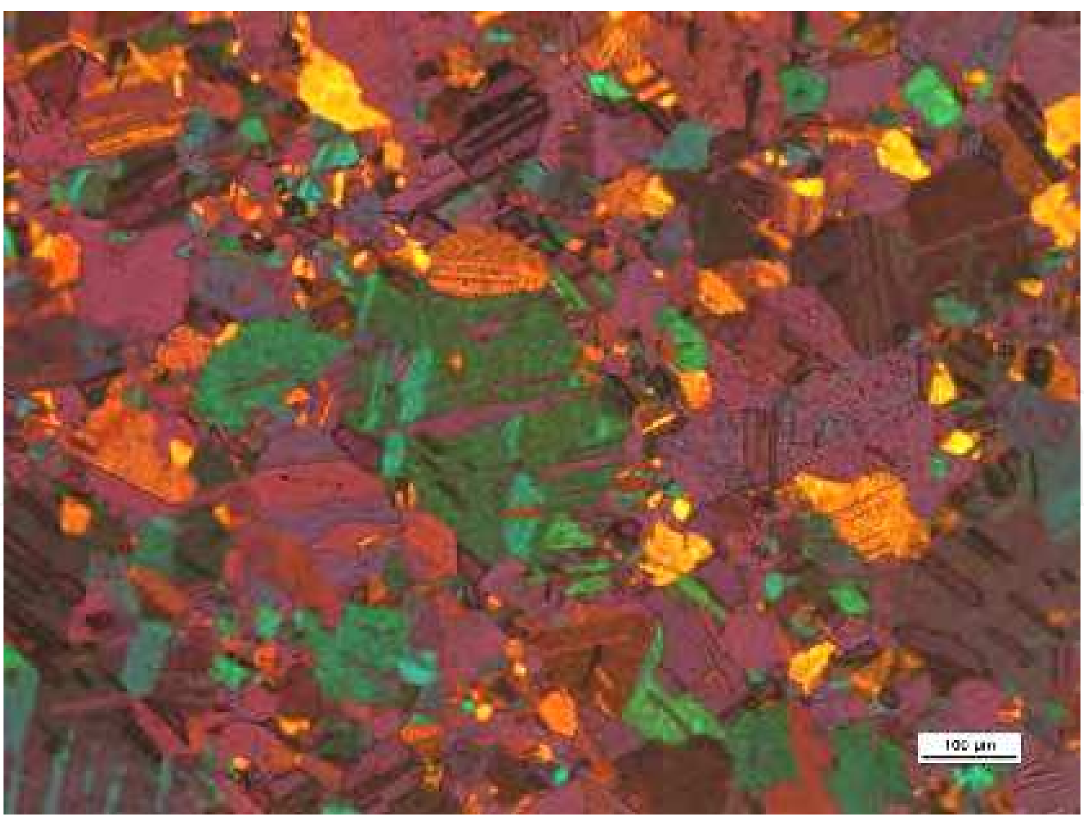
Deep-drawing brasses contain around 70 % of Cu (Fig. 7); for securing high ductility the impurities elements content has to be low. Cu-Zn alloys with the 32 % Zn content have the highest ductility at high strength which is why those alloys are used for deep-drawing. They are used, for example, for ball cartridges, musical equipment production and in the food industry (Skočovský et al., 2000).

Brass with higher Zn content (37 % of Zn) is quite cheap because of its lower Cu content. It is a heterogeneous alloy with small β´ phase content, with lower ductility and good ability for cold forming, Fig. 8. It is used for different not very hard loaded products; for example wiring material in electrical engineering, automotive coolers, etc. For improving the materials workability a small amount of lead is added to brasses with higher Zn content (Skočovský et al., 2000).

Brass with 40 % of Zn is heterogeneous alloy with (α+β´) microstructure. Compared to other brasses it has higher strength properties, but lower ductility and cold forming ability. This is caused by the β´ presence. It is suitable for forging and die pressing at higher temperatures (700 – 800 °C). This kind of brass is used in architecture, for different ship forging products, for tubes and welding electrodes. For this brass type, with 60 % of Cu, the tendency to dezincification corrosion and to corrosion cracking is typical. The crack tendency increases with the increasing Zn content and it is largest at 40 % Zn content. In the case of zinc content below 15 % this tendency is not present. Brasses alloying elements do not improve the crack tendency. Some of the used alloying elements can decrease this disadvantage; Mg, Sn, Be, Mn. Grain refinement has the same influence (Skočovský et al., 2000).

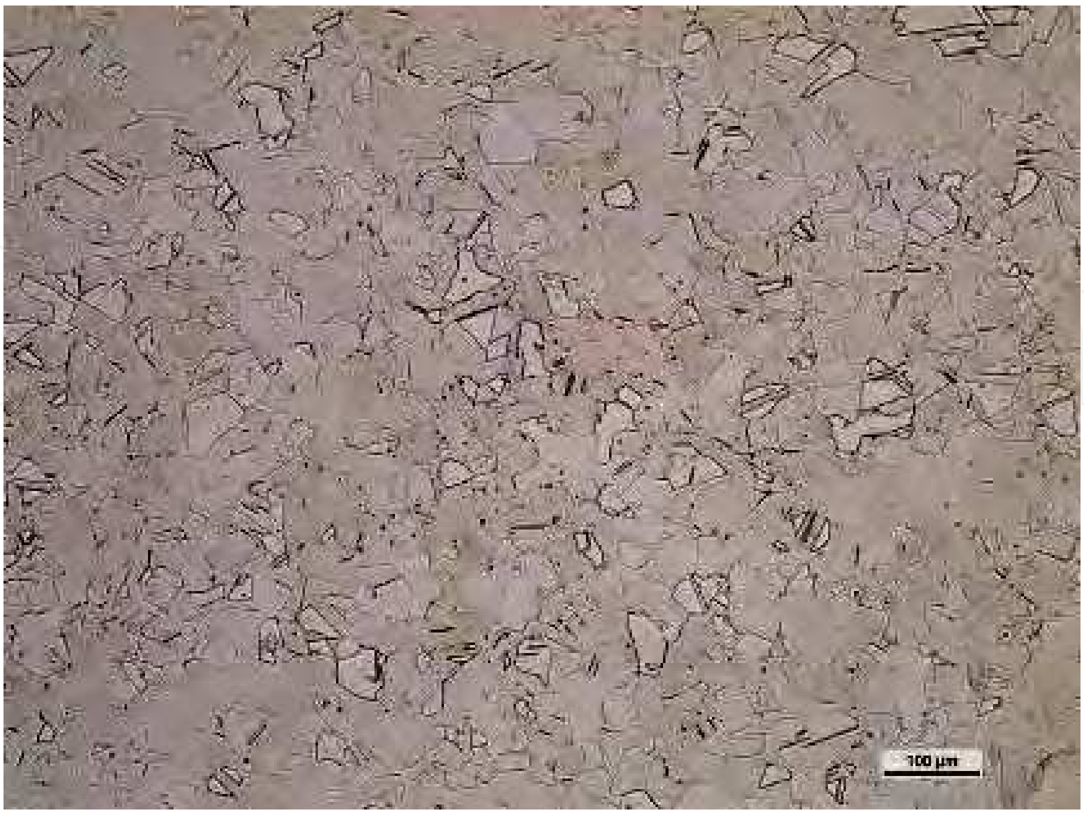


a) microstructure, polyhedral grains of α phase, chemically etched

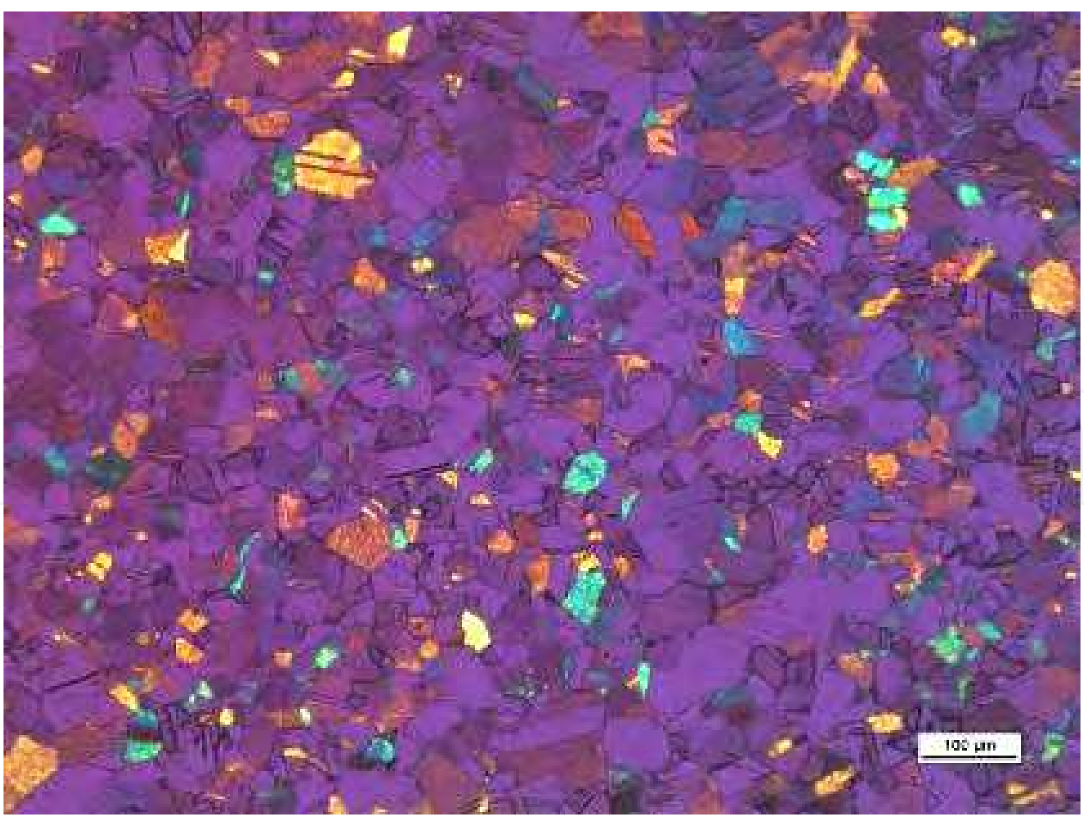


b) size and orientation of grains, polarized light, etched $K_2Cr_2O_7$

Fig. 7. Deep-drawing brass with 70 % Cu



a) (α+β´) microstructure, chemically etched



b) α phase is violet, polarized light, etched $K_2Cr_2O_7$

Fig. 8. Brass with 37 % of Zn

Brass CuZn40Mn3Fe1 is an alloy with a two phase microstructure (Fig. 9); α phase is light (in black and white color) or blue (with polarized light) and β´ phase is dark or a different color depending on the grains orientation. The microstructure shows polyhedral grains with different size and color of β´ phase (Fig. 9a). A direction of α phase is different according to the orientation of grains, as is shown in a detail of the microstructure (Fig. 9b).

Leaded brass. Brasses in this group contain ~ 60 % of copper and from 1 to 3 % of lead which improve the materials machinability (Skočovský et al., 2000). The microstructure is constituted by two phases, α and β´, where α phase is lighter than the second phase β´, (Fig. 10).

Lead is not soluble in copper and so its influence is the same as in the case of leaded steels. Lead should be finely dispersed as isolated particles in the final brass structure (Fig. 10). Smaller carburetor parts and seamless tubes are produced from leaded brasses.

Brasses with 58 or 59 % of Cu and lead are suitable for metal sheets, strips, bands, bars production and different shaped tubes. At higher temperatures it is possible apply forging and pressing to these brasses. They are difficult to cold form, but it is possible to strike them. They are used for different stroked product for watchmakers and small machines, especially in electrical engineering production. Leaded brass with 58 % of Cu and is used for screw production and for other in mass scale turned products (Skočovský et al., 2000).

The CuZn43Mn4Pb3Fe brass with higher content of Zn (43 %) has only one phase β´ microstructure (Fig. 11). This phase is constituted by polyhedral grains (different color according to the grains orientation) with very small black globular particles of the phase with high content of iron, and light colored regularly distributed small Pb particles.

2.1.2 Cast brasses

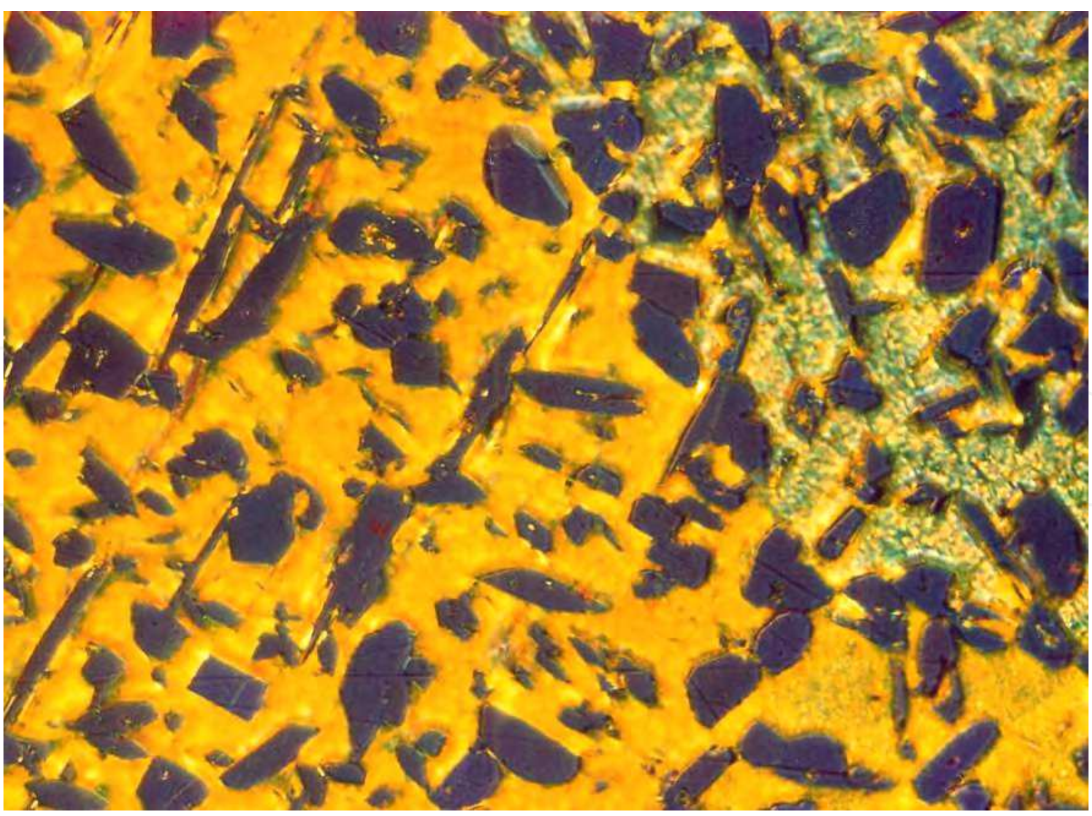
Cast brasses are heterogeneous alloys (α+β´) containing from 58 to 63 % of copper. For improving machinability they very often also contain lead (1 - 3 %). Cast brasses have good feeding, low tendency to chemical unmixing, but high shrinkage. Because of their structure cast brasses have lower mechanical properties compared to the mechanical properties of wrought brasses. These brasses are used mainly for low stressed castings; pumps parts, gas and water armatures, ironworks for furniture and building, etc. (Skočovský et al., 2000, 2006).

2.1.3 Special brasses

This alloy family consists of copper, zinc and one or more elements in addition (aluminum, tin, nickel, manganese, iron, silicon). The name of the alloy is usually formed according to the additional element (for example silicon brass is the Cu-Zn-Si alloy). Other elements addition improves the materials mechanical properties, corrosion resistance, castability and workability increasing. The change in properties is dependant on the element type and on its influence on the materials structure.

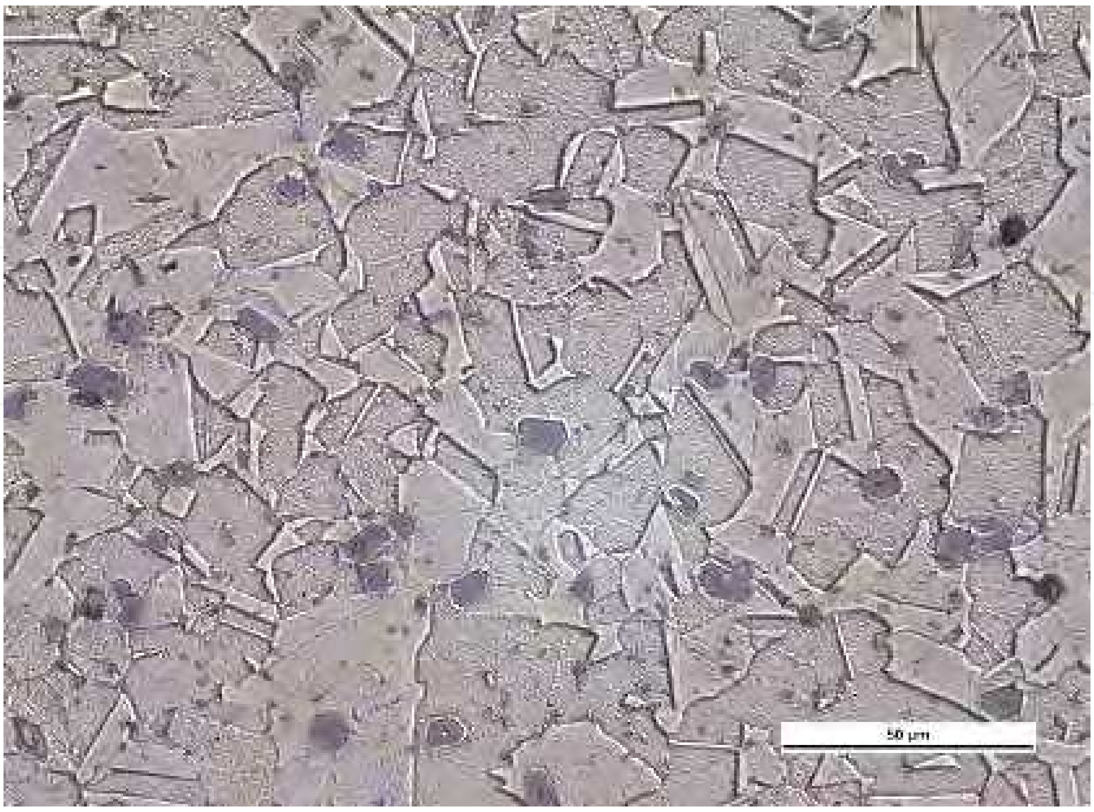
According to production technology special brasses can be divided into two groups: wrought and cast special brasses (Skočovský et al., 2000, 2006).

a) polyhedral microstructure, mag. 100 x

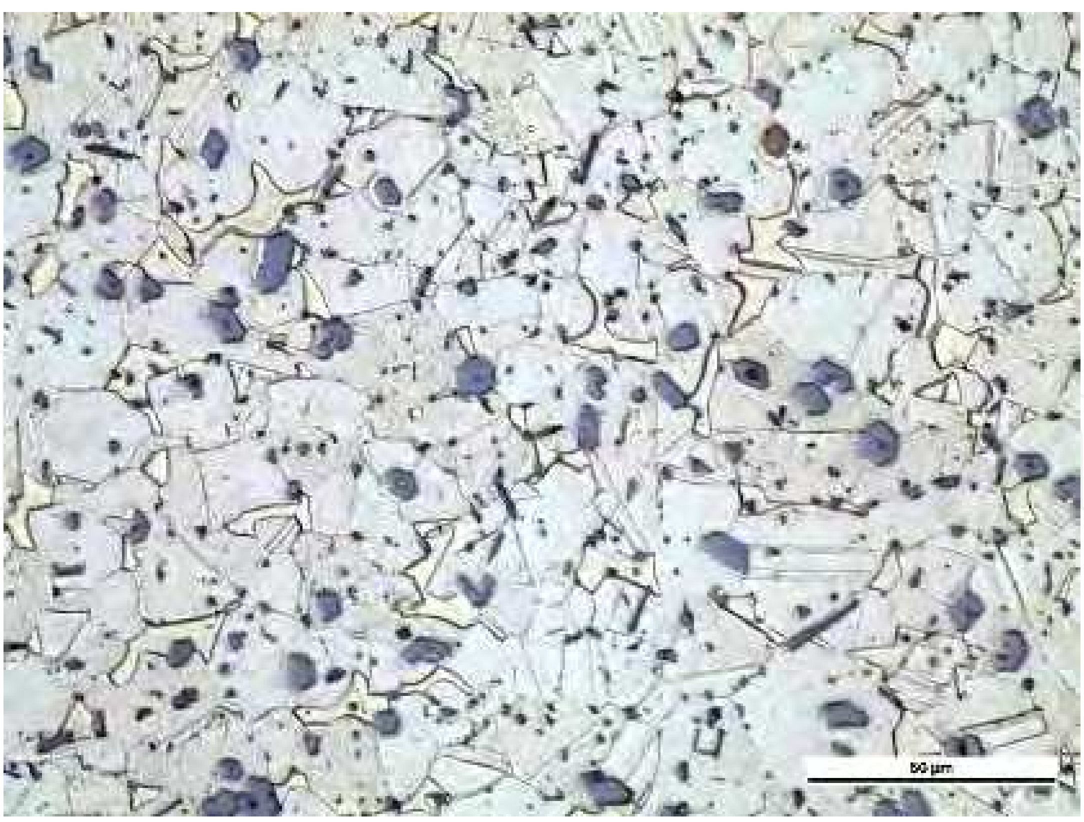


b) detail of two grains, mag. 500 x

Fig. 9. Brass CuZn40Mn3Fe1, polarized light, etched $K_2Cr_2O_7$

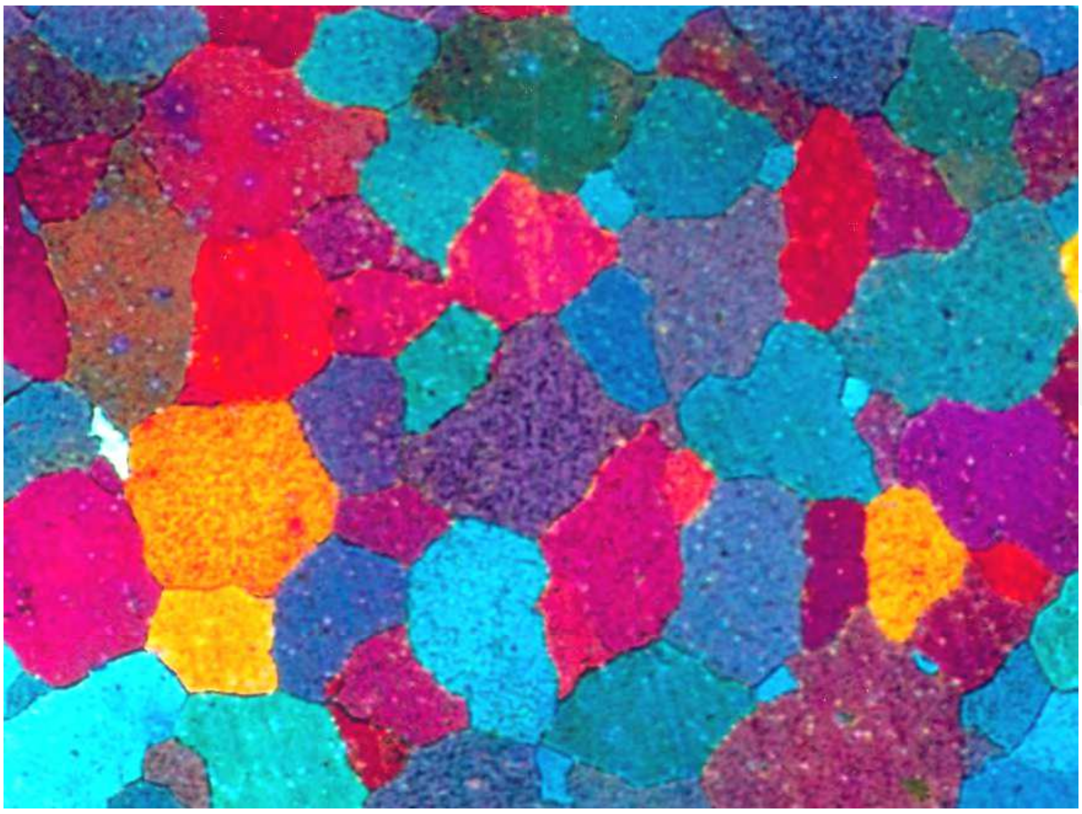


a) (α+β´) microstructure with Pb particles showed as dark gray, etched $K_2Cr_2O_7$

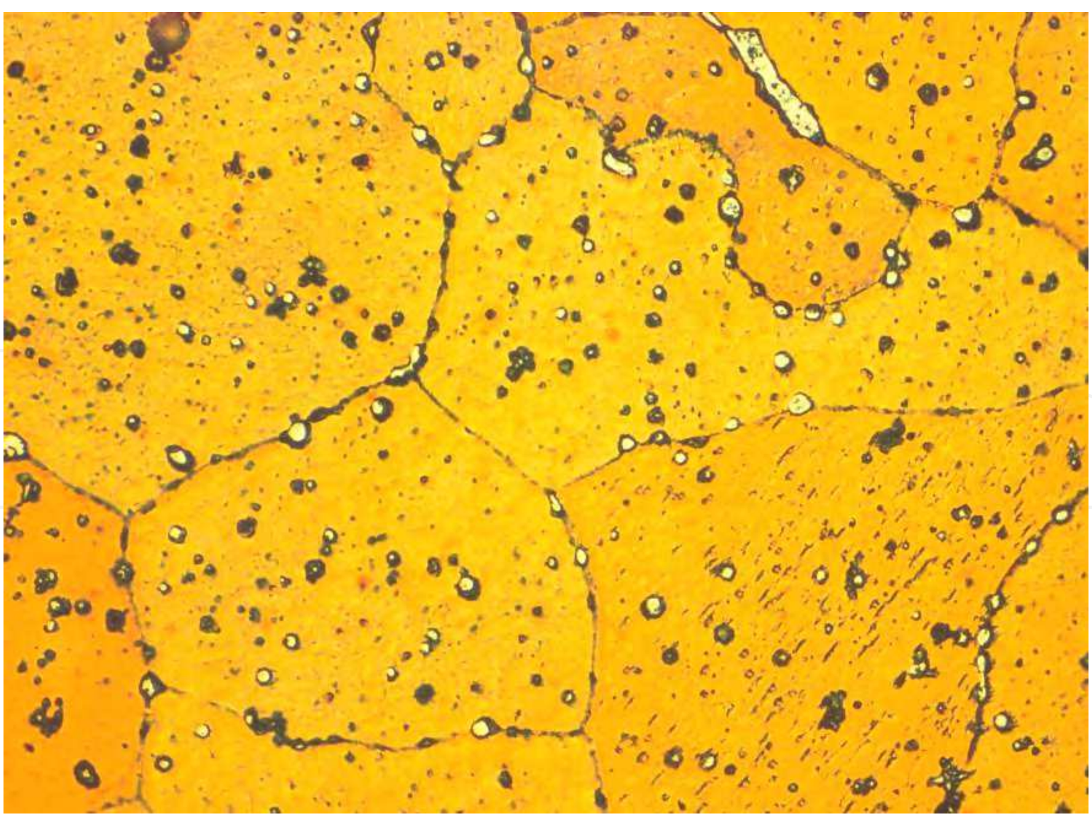


b) the same microstructure after chemical etching

Fig. 10. Leaded brass, 42 % of Zn and 2 % of Pb



a) polyhedral grains of β´phase, polarized light, mag. 100 x



b) detail, white light, mag. 500 x

Fig. 11. Brass CuZn43Mn4Pb3Fe, etched $K_2Cr_2O_7$

Aluminum brasses. Aluminum brasses contain from 69 to 79 % of copper; the aluminum additive content, in the case of wrought alloys, is below 3 to 3.5 % to keep the structure homogeneous. As well as this aluminum content, the structure is also formed by new phases as are $\beta + \gamma$ phases, which improve the materials hardness and strength, but decrease its ductility. Aluminum brass containing 70 % of Cu and 0.6 to 1.6 % Al, with Sn and Mn addition, is very corrosion resistant and is used for condenser tubes production. Al brass with higher content of Cu (77 %) and with Al from 1.7 to 2.5 %, whose application is the same as that of the previous brass, its corrosion resistance against the see water is higher because of the larger Al content.

The structure of cast aluminum brasses is heterogeneous. The copper content is in this case lower and the aluminum content is higher (below 7 %), which ensures good corrosion resistance of the material in sea water. They are used for very hard loaded cast parts; armatures, screw-cutting wheel, bearings and bearings cases.

Manganese brasses. Wrought manganese brasses contain from 3 to 4 % manganese and cast manganese brasses contain from 4 to 5 % manganese. This alloying family has high strength properties, and corrosion resistance. They are used usually in the heterogeneous structure. Wrought manganese brasses with 58 % of Cu or 57 % of Cu with addition of Al have quite good strength (in medium-hard state 400 to 500 MPa) at large toughness and corrosion resistance. They are used for armatures, valve seating, high-pressured tubes, etc. Mn brass with 58 % of Cu is also used for decorations (product surface is layered during hot oxidation process by attractive, durable brown verdigris). Cast manganese brasses have larger manganese and iron content and they are used for very hard loaded castings; weapons parts, screw propellers, turbine blades and armatures for the highest pressures.

Tin brasses. Tin brasses are mostly heterogeneous alloys containing tin below 2.5 %. Tin has a positive influence on mechanical properties and corrosion resistance. Some Sn alloys with 60 % of Cu have good acoustical properties and so they are used for the musical/sound instruments production. Sn brass alloy with 62 % of Cu is used for the strips, metal sheets and profiles used in the ships or boat constructions.

Silicon brasses. Silicon brasses contain maximum 5 % of Si at large copper content, from 79 to 81 %. As in the other brasses case, silicon brasses can be wrought (max. 4 % Si) or cast. They have very good corrosion resistance and mechanical properties also at low temperatures (- 183 °C). Over 230 °C their creeping is extensive, at a low stress level and at a temperature larger than 290 °C silicon brasses are also brittle. Lead addition, (3 to 3.5 %), positively affects the materials wear properties and so these alloys are suitable for bearings and bearings cases casting (Cu 80 %, Si 3 %, Pb 3 %). Silicon brasses are used in boats, locomotives and railway cars production. Silicon cast alloys with good feeding properties are used for armatures, bearings cases, geared pinions and cogwheels production.

Nickel brasses. Nickel brasses contain from 8 to 20 % nickel, which is absolutely soluble in homogeneous brasses α and nickel enlarges α area. Homogeneous alloys are good cold formed and are suitable for deep-drawing. Heterogeneous alloys (α+β) are good for hot forming. Nickel brasses have good mechanical properties, corrosion resistance and are easily polishable. One of the oldest alloys are alloys of 60 % of copper and from 14 to 18 % of nickel content; they were used for decorative and useful objects. These alloys have many different commercial names, for example "pakfong", "alpaca", "argentan" etc. they are used in the building industry, precise mechanics, and medical equipment production and for stressed springs (high modulus of elasticity).

Brazing solders. Brazing solders are either basic or special brasses with melting temperature higher than 600 °C. They are used for soldering of metals and alloys with higher melting temperatures like copper and its alloys, steels, cast irons etc. In the case of binary alloys Cu-Zn with other element addition (Ag or Ni), the solders are marked like silver or nickel solders. Brasses solders with Cu content from 42 to 45 % have the melting temperature 840 to 880 °C and they are used for brasses soldering. Silver solders contain from 30 to 50 % of copper, from 25 to 52 % of Zn and from 4 to 45 % of Ag. Lower the Ag content; lower the melting temperature (to 720 °C). Silver solders have good feeding and give strong soldering joints. Nickel solders (38 % Cu, 50 % Zn and 12 % Ni) have a melting temperature of around 900 °C. They are used for steels and nickel alloys soldering.

Solder with a very low Ag content (0.2 to 0.4 %) with upper melting temperature 900 °C has good electric conductivity and for this reason is used in electrical engineering. Solder with an upper melting temperature of 850 °C (60 % Cu and low content of Si, Sn) has high strength and it is suitable for steels, grey cast iron, copper and brasses soldering (Skočovský et al., 2000, 2006).

2.2 Bronzes

Bronzes are copper based alloys with other alloying elements except zinc. The name of bronzes is defined according to the main alloying element; tin bronzes, aluminum bronzes, etc. (Skočovský et al., 2000, 2006).

2.2.1 Tin bronzes

Tin bronzes are alloys of copper and tin, with a minimal Cu-Sn content 99.3 %. Equilibrium diagram of Cu-Sn is one of the very difficult binary diagrams and in some areas (especially between 20 to 40 % of Sn) it is not specified till now. For the technical praxis only alloys containing less than 20 % of Sn are important. Tin bronzes with higher Sn content are very brittle due to the intermetallic phases' presence. Cu and Sn are absolutely soluble in the liquid state. In the solid state the Cu and Sn solubility is limited.

Normally, the technical alloys crystallize differently as compared to the equilibrium diagram. Until 5 % of Sn, the alloys are homogenous and consist only of the α solid solution (solid solution of Sn in Cu) with face centered cubic lattice. In the cast state the alloy structure is dendritic and in the wrought and annealed state the structure is created by the regular polyhedral grains. The resulting structure of alloys with larger Sn content (from 5 to 20 %) is created by α solid solution crystals and eutectic $(\alpha + \delta)$. δ phase is an electron compound $Cu_{31}Sn_8$ (e/a = 21/13) with cubic lattice. δ phase is brittle phase, which has negative influence on the ductility and also decreases the materials strength in case of higher Sn content (above 20 %). Even though the solubility in the case of technical alloys decreases, the ε phase (Cu_3Sn with hexagonal lattice; e/a = 7/4) is not created. The ε phases do not occur because the diffusion ability of Sn atoms below 350 °C is low. ε phase also does not occur at normal temperature with higher Sn content in bronze.

Tin addition has a similar influence on bronzes properties as zinc addition in the case of brasses. For the forming, bronzes with around 9 % of Sn are used (it is possible to heat those alloys to single-phase state above 5 % Sn). Tin bronzes are used when bronzes are not sufficient in strength and corrosion resistance points of view. For casting, bronzes with higher Sn content are used; up to 20 % of Sn. Cast bronzes are used more often than wrought bronzes. Tin bronzes castings have good strength and toughness, high corrosion resistance and also good wear properties (the wear resistance is given by the heterogeneous structure ($\alpha + (\alpha + \delta)$)). Tin bronzes have small shrinkages during the solidification (1 %) but they have worst feeding properties and larger tendency to the creation of microshrinkages.

Wrought tin bronzes

Bronze CuSn1 contains from 0.8 to 2 % of Sn. In the soft state this bronze has tensile strength 250 MPa and 33 % ductility. It has good corrosion resistance and electric conductivity; it is used in electrical engineering. Bronze CuSn3 with 2.5 to 4 % of Sn has in its soft state tensile strength 280 MPa and ductility 40 %. It is used for the chemical industry and electric engineering equipment production. Bronze CuSn6 with tensile strength 350 MPa and ductility 40 % (in soft state) is used for applications where β´, a higher corrosion resistance is required for good strength properties and ductility; for example corrosion environment springs. CuSn8 bronze has, from all wrought tin bronzes the highest strength (380 MPa) and ductility (40 %). It is suitable for bearing sleeves production and in the hard state also for springs which are resistant to fatigue corrosion.

Cast tin bronzes

Bronze CuSn1 with low Sn content has sufficient electric conductivity and so it is used for the castings used in electric engineering. CuSn5 and CuSn10 bronzes have tensile strength 180 and 220 MPa, ductility 15 % and they have good corrosion resistance. They are used for the stressed parts of turbines, compressors, for armatures and for pumps runners' production. Bronze CuSn12 is used for parts used to large mechanical stress and wear frictional loading; spiral gears, gear rims. CuSn10 and CuSn12 bronzes are used in the same way as bearing bronzes. High Sn content (14 to 16 %) bronzes usage have been, because of their expense, replaced by lower Sn containing bronzes, around 6 %, with good sliding properties (Skočovský et al., 2000, 2006).

2.2.2 Leaded tin bronzes and leaded bronzes

Leaded tin bronzes and leaded bronzes are copper alloys where the Sn content is partially or absolutely replaced by Pb. The Pb addition to copper, improves the alloys sliding properties without the negative influence on their heat conductivity. Cu-Pb system is characteristic by only partial solubility in a liquid state and absolute insolubility in a solid state. The resulting structure, after solidification, consists of copper and lead crystals. At a high cooling rate both the alloy components are uniformly distributed and the alloys have very good sliding properties. Leaded bronzes are suitable for steel friction bearing shells casting. They endure high specific presses, quite high circumferential speeds and it is possible to use them at elevated temperatures (around 300 °C).

Two types of bearing bronzes are produced. Bronzes with lower Pb content (from 10 to 20 %) and Sn addition (from 5 to 10 %) and also high-leaded bronzes (from 25 to 30 %) without tin. At present, specially leaded bronzes CuSn10Pb and CuSn10Pb10 like bearing bronzes are used (Skočovský et al., 2000, 2006). Lead (additive from 4 to 25 %) improves bearing sliding properties, and tin (from 4 to 10 %) improves strength and fatigue resistance. These alloys are used especially for bearings in dusty and corrosive environments. Second group binary alloys have lower strength and hardness and they are used for steel shells coatings. With small additions of Mn, Ni, Sn and Zn (in total 2 %) it is possible to refine the structure and to decrease the materials tendency to exsolution. These are very often used for steel shells coated by thin leaded bronze layer for the main and the piston rod bearings of internal-combustion engine (Skočovský et al., 2000).

2.2.3 Aluminum bronzes

Aluminum bronzes are alloys of copper, where aluminum is the main alloying element. For the technical praxis alloys with Al content below 12 % are important. Equilibrium diagram of Cu-Al is complicated and it is similar to Cu-Sn equilibrium diagram. One part of Cu-Al system for alloys containing up to 14 % of Al is shown on Fig. 12.

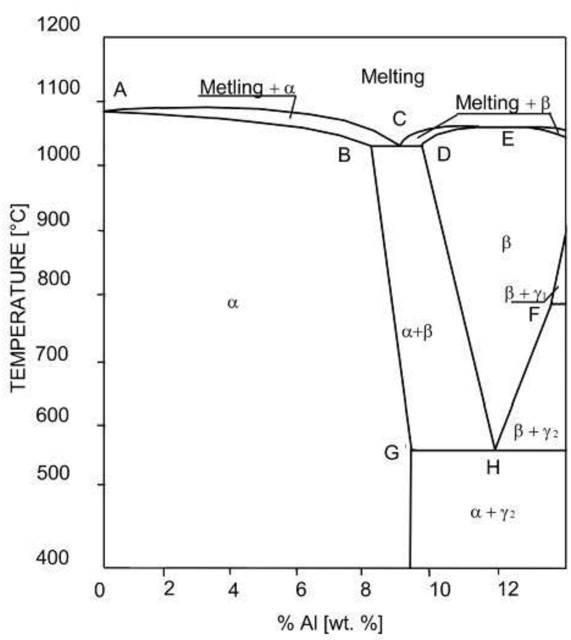


Fig. 12. Part of Cu-Al system equilibrium diagram

The solubility of Al in copper is maximum 7.3 % but it grows with temperature increasing to 9.4 % Al. Homogeneous alloys structure is created by α solid solution crystals (substituted solid solution of Al in Cu) with body centered cubic lattice with similar properties as has the α solid solution in brasses. It is relatively soft and plastic phase. In the real alloys the absolutely equilibrium state does not occur. In the case of Al content close to the solubility limit some portion of β phase in the structure will occur. The upper limit of Al in α homogeneous structure alloys is dependent on the cooling rate and it is in the range of 7.5 to 8.5 % of Al.

Alloys with Al content in the range of 7.3 to 9.4 % solidify at eutectic reaction (α + β) and close to the eutectic line they contain primary released phase α or β and eutectic. (After the changed at lower temperatures the eutectic disappears and so its influence in the structure cannot be proven.) By decreasing the temperature the composition, of α and β crystals changes according to the time of solubility change. β phase is a disordered solid solution of electron compound Cu_3Al (e/a = 3/2) with face centered cubic lattice. It is a hard and brittle phase. β phase, from which the α solid solution is created at lower temperatures, is precipitated from liquid metal at the Al content from 9.5 to 12 % alloys during the crystallization process. During the slow cooling rate the β phase is transformed at eutectoid temperature 565 °C to the lamellar eutectoid ($\alpha + \gamma_2$). For this reason the eutectoid reaction of β phase is sometimes called "pearlitic transformation".

Phase γ_2 is solid solution of hard and brittle electron compound Cu_9Al_4 with complicated cubic lattice. After the recrystallization in solid state the slowly cooled alloys with Al content from 9.4 to 12 % are heterogeneous. Their structure is created with α solid solution crystals and eutectoid ($\alpha + \gamma_2$).

Because of the possibility to improve the mechanical properties by heat treatment heterogeneous alloys are used more often than homogeneous alloys. From 10 to 12 % Al content alloys can be heat treated with a similarly process as in the case of steels. The martensitic transformation can be reached in the case when the eutectoid transformation is limited by fast alloys cooling rate from the temperatures in the β or (α + β) areas (Fig. 12). After this process the microstructure with very fine and hard needles β_1 phase with a body centered cubic lattice will be reached. By the β phase undercooling below the martensitic transformation temperature M_s, a needle-like martensitic supersaturated disordered solid solution β´ phase with body centered cubic lattice is created.

Due to the chemical composition aluminum bronzes can be divided into two basic groups:

- elementary (binary) alloys; i.e. Cu-Al alloys without any other alloying elements,
- complex (multicomponent) alloys; besides the Al these alloys contain also other alloying elements like Fe, Ni, Mg whose content does not exceeds 6 %.

Iron is frequently an aluminum bronzes alloying element. It is dissolved in α phase till 2 % and it improves its strength properties. With Al it creates $FeAl_3$ intermetallic phase which causes the structure fining.

Manganese is added to the multicomponent alloys because it has deoxidizing effect in the melted metal. It is dissolved in α phase, up to 12 % of Mn content, and it has an effect similar to iron.

Nickel is the most frequent alloying element in aluminum bronzes. It has positive influence on the corrosion resistance in aggressive water solutions and in sea water. Up to around 5 % nickel is soluble in α phase. Nickel with aluminum creates Ni_3Al intermetallic phase which has a precipitate hardening effect.

Homogeneous aluminum bronzes are tough and are suitable for cold and also hot forming. Heterogeneous alloys are stronger, harder, but they have lower cold forming properties compared to the homogeneous alloys. They are suitable for hot forming and have good cast properties. Aluminum bronzes are distinguished by good strength, even at elevated temperatures, and also very good corrosion resistance and wear resistance. Aluminum bronzes are used in the chemical and food industry for stressed components production.

These alloys are used in the mechanical engineering for much stressed gearwheels and worm wheels, armatures working at elevated temperatures etc. Production due to the treatment the aluminum bronzes are divided into two groups; cast and wrought aluminum bronzes.

Aluminum bronzes with Al content from 4.5 to 11 % are used for forming elementary or complex. Al content from 7.5 to 12 % are used for casting only complex aluminum bronzes

CuAl15 bronze is used for cold forming. It is supplied in the form of sheets, strips, bars, wires and pipes. In the soft state this alloy can reach the tensile strength 380 MPa, ductility 40 % and hardness 70 to 110 HB. It is used in the boats building, chemical, food and paper making industry.

Complex aluminum bronzes are normally used for hot forming. CuAl9Mn2 is used for the armatures (bellow 250 °C) production. CuAl9Fe3 is used for the bearings shells, valve seats production, etc. CuAl10Fe3Mn1.5 alloy has heightened hardness and strength; it is suitable for shells and bearings production; it is replacing leaded bronzes up to temperature 500 °C, sometimes also till 600 °C, the CuAl10Fe4Ni4 where Ni is replacing Mn is used. Nickel positively affects materials mechanical and corrosion properties. After the heat treatment the alloy has the tensile strength of 836 MPa and ductility 13.4 %. In the sea water corrosion environment this bronze reached better results compared to chrome-nickel corrosion steels. It is resistant against cavitational corrosion and stress corrosion. CuAl10Fe4Ni4 is used for castings, also used for water turbines and pumps construction, for valve seats, exhaust valves and other components working at elevated temperatures and also in the chemical industry. Besides CuAl19Ni5Fe1Mn1 the nickel alloy consists also a higher content of manganese. It is suitable for cars worm wheels, compressing rings of friction bearings for high pressures etc. (Skočovský et al., 2000, 2006).

2.2.4 Silicon bronzes

The silicon content in this type of alloys is in the range from 0.9 to 3.5 %. The Si content should not exceed 1 % when higher electric conductivity is required. Silicon bronzes more often in the form of complex alloys Cu-Si-Ni-Mn-Zn-Pb are produced; binary alloys Cu-Si only rarely are used. Manganese is dissolved in the solid solution; improving strength, hardness and corrosion properties. Zinc improves the casting properties and mechanical properties, as same as Mn. Nickel is dissolved in the solid solution but it also creates Ni_2Si phase with silicon, which has a positive influence on the materials warm strength properties. Lead addition secure sliding properties.

Silicon bronzes have good cold and hot forming properties and are also used for castings production. They are resistant against sulphuric acid, hydrochloric acid and against some alkalis. Because of their good mechanical, chemical and wear properties, silicon bronzes are used for tin bronzes replacing; they outperform tin bronzes with higher strength and higher working temperatures interval. Formed CuSi3Mn alloy has in the soft state tensile strength 380 MPa and ductility 40 %. It is used for bars, wires, sheets, strips, forgings and stampings production. Casting alloys have normally higher alloying elements content and Si content reaches 5 % very often (Skočovský et al., 2000).

2.2.5 Beryllium bronzes

Beryllium is in copper limitedly soluble (max. 2.7 %) and in the solid state the solubility decreases (0.2 % at room temperature). The binary alloys with low beryllium content (0.25 to 0.7 %) have good electric conductivity, but lower mechanical properties, they are used rarely. More often alloys with higher Be content and other alloying elements as Ni, Co, Mn and Ti are produced. Cobalt (0.2 to 0.3 %) improves heat resistance and creep properties; nickel improves toughness and titanium affects like grain finer. The main group of this alloy family is the beryllium bronzes with 2 % of Be content due to the highest mechanical properties after the precipitin hardening.

Beryllium bronzes thermal treatment consists of dissolved annealing (700 to 800 °C/1h) and water quenching. The alloy after heat treatment is soft, formable and it can be improved only by artificial aging. Hardening is in progress at temperature from 280 to 300 °C. After the hardening the tensile strength of the alloy is more than 1200 MPa and the hardness 400 HB. By cold forming, applied after the cooling from the annealing temperature, the materials tensile strength can be improved. Beryllium bronzes usage is given by their high tensile strength, hardness, and corrosion resistance which those alloys do not lose, even not in the hardened state. They are used for the good electric conductive springs production; for the equipment which should not sparkling in case of bumping (mining equipment) production; form dies, bearings, etc. (Skočovský et al., 2000, 2006).

2.2.6 Nickel bronzes

Copper and nickel are absolutely soluble in the liquid and in the solid state. Binary alloys are produced with minimal alloying elements content. Complex alloys, ternary or multi components, are suitable for hardening. Nickel bronzes have good strength at normal and also at elevated temperatures; good fatigue limit, they are resistant against corrosion and also against stress corrosion, and they have good wear resistance and large electric resistance.

Binary alloys Cu-Ni with low Ni content (bellow 10 %) are used only limitedly. They are replaced by cheaper Cu alloys. Alloys with middle Ni content (15 to 30 %) have good corrosion resistance and good cold formability. 15 to 20 % Ni containing alloys are used for deep-drawing. Alloys with 25 % Ni are used for coin production and alloys with 30 % Ni are used in the chemical and food industry.

Complex Cu-Ni alloys have a wider usage in the technical praxis compared to the binary alloys. CuNi30Mn with Ni content from 27 to 30 %, Mn content from 2 to 3 % and impurities content bellow 0.6 % is characterized by high strength and corrosion resistance also at elevated temperatures. Because of its electric resistance this alloy is suitable for usage as resistive material till 400 °C. CuNi45Mn constantan is alloy with Ni content form 40 to 46 %, Mn content from 1 to 3 % and impurities content below 0.5 %. From the Cu-Ni alloys, this one has the largest specific electric resistance and it is used for resistive and thermal element material.

Most often the Cu-Ni-Fe-Mn alloys are used. Iron and manganese addition improve the corrosion properties markedly, especially in the seas water and overheated water steam. CuNi30 alloy with iron content in the range from 0.4 to 1.5 % and manganese content from 0.5 to 1.5 % is used for seagoing ships condensers and condensers pipes production. In the new alloys also the niobium as an alloying element is used and the nickel content tends to be decreased because of its deficit. An alloy CuNi10Ge with nickel content from 9 to 10 % and Fe content from 1 to 1.75 % and maximally 0.75 % of Mn, which is used as the material for seagoing ships condensers (Skočovský et al., 2000, 2006).

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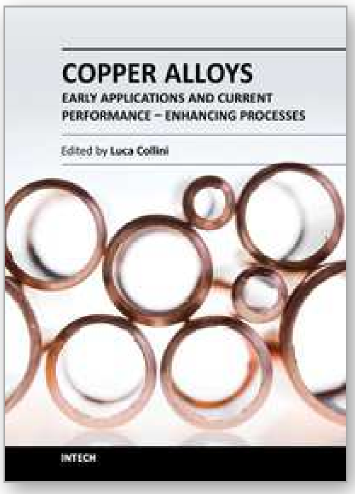

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Edited by Dr. Luca Collini

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Copper has been used for thousands of years. In the centuries, both handicraft and industry have taken advantage of its easy castability and remarkable ductility combined with good mechanical and corrosion resistance. Although its mechanical properties are now well known, the simple f.c.c. structure still makes copper a model material for basic studies of deformation and damage mechanism in metals. On the other hand, its increasing use in many industrial sectors stimulates the development of high-performance and high-efficiency copper-based alloys. After an introduction to classification and casting, this book presents modern techniques and trends in processing copper alloys, such as the developing of lead-free alloys and the role of severe plastic deformation in improving its tensile and fatigue strength. Finally, in a specific section, archaeometallurgy techniques are applied to ancient copper alloys. The book is addressed to engineering professionals, manufacturers and materials scientists.

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