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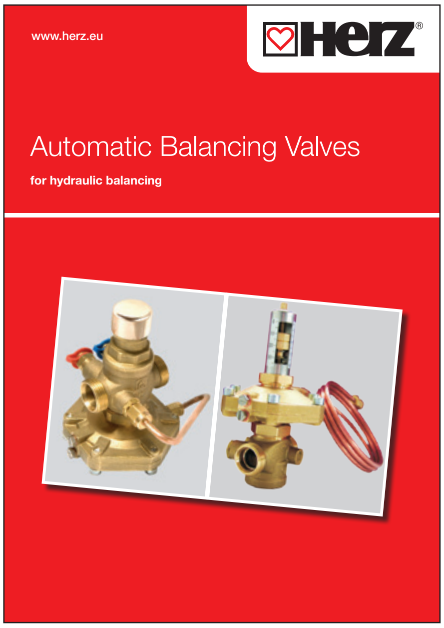

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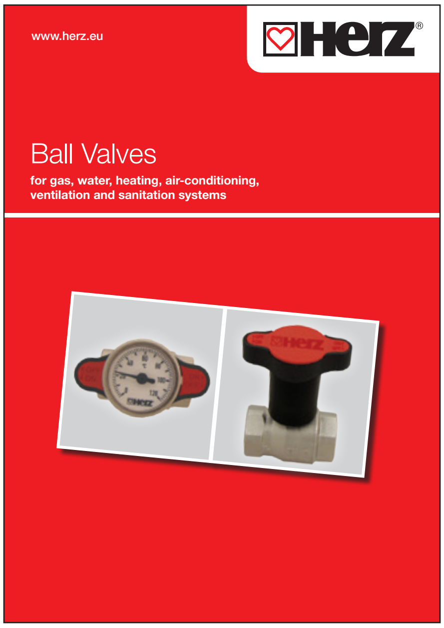

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*Information is provided by Copper Development Association (see the list of references for details)

Copper

Copper is one of the most widespreaded materials used in industry. It is soft, malleable and ductile with a specific gravity of 8.9 and a melting point of 1083°C. These properties make copper a good material to use in the manufacture of many items. Addtionally it has good conductive properties and is used in the production of electrical cables and wires for machinery, electropalting in coin production as well as in manufacturing household utilities. [3]

Figure 1: Native copper (~4 cm in size)
Source: https://en.wikipedia.org/wiki/Copper

It is possible to cast, forge and roll copper. It is non-corrosive under normal conditions and has good water resistant properties. Copper tubes are widely used in the mechanical industry. And copper is also used in ammunition production. Usually copper is utilised in alloys with tin, zinc, nickel etc., which are also used in industry. [3]

Copper alloys:

It is possible to highlight two main groups of copper alloys:
1. Copper-zinc alloys (Brasses), in which zinc is the principal alloying metal [3];
2. Copper-tin alloys (Bronzes), in which tin is the principal alloying metal [3];

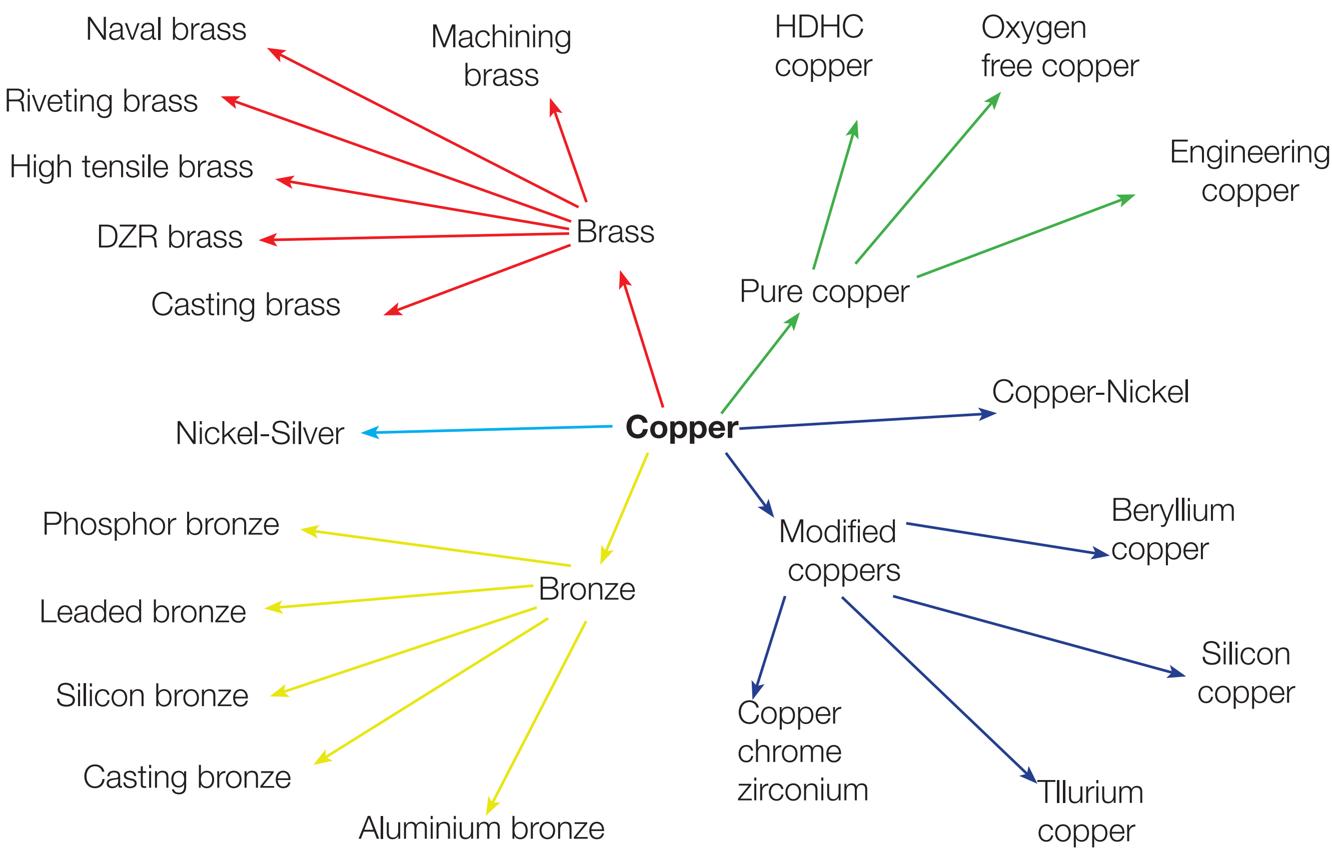


Figure 2. Classification

Source: http://www.aalco.co.uk/

Bronzes

Manganese 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
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. Fluorides are available, mainly in the powdered form, for converting melted metal fluxes. They are used for the elimination of oxides, which normally form on top of the melt during melting and superheating. 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

Nickel bronzes
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
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
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. 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.

Tin bronzes are alloys of copper and tin, with a minimal Cu-Sn content of 99.3 %. The equilibrium diagram of Cu-Sn is one of the most difficult binary diagrams and in some areas (especially between 20 to 40 % of Sn) it is not used. For the technical practice only alloys containing less than 20 % of Sn are important, except bell metal with 20-25% tin. Tin bronzes with higher Sn content are very brittle due to the intermetallic phases' presence. Cu and Sn are soluble in the liquid state but in the solid state the Cu and Sn solubility is limited.

The addition of Tin has a similar influence on the properties of bronzes as the addition of zinc 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 for the point of view of strength and corrosion resistance. 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). Tin bronzes have small shrinkages during the solidification (1 %) but they have worst feeding properties and have a larger tendency to the creation of microshrinkages.

Beryllium bronzes

Beryllium is limitedly soluble in copper (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, and are used rarely. More often alloys are produced with higher Be content and other alloying elements such 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 produces a finer grain. The main group of this alloy family is the beryllium bronzes with 2 % of Be content due to the highest mechanical properties after precipitation hardening.

The thermal treatment of beryllium bronzes 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 a 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. The materials tensile strength can be improved by cold forming, applied after the cooling from the annealing temperature. Beryllium bronzes usage is given by their high tensile strength, hardness, and corrosion resistance which those alloys do not lose, even not in the hardend state. They are used for the production of good electric conductive springs; for the production of equipment which does not create sparks in the case of contact (mining equipment); form dies, bearings, etc.

Usage of bronzes in past and nowadays

The true Bronze Age - featuring objects made from an alloy of copper and tin - begins in about 2800 BC, in the Middle East. There have been earlier periods when other naturally-occuring alloys of coper are used. The most common of these alternative 'bronzes' is an alloy of copper and arsenic. The age of tools made from pure copper (often called the Chalcolithic Period) goes back as far as about

7000 BC. Arsenical bronze objects have been found in south Iran dating back to at least 4000 BC. The term Bronze Age is sometimes extended back to include arsenical bronze.[1]

The introduction of bronze was significant for every civilization that encountered it. Tools, weapons, armour, and various building materials like decorative tiles made of bronze were harder and more durable than their stone and copper ("Chalcolithic") predecessors. In early use, the natural impurity arsenic sometimes created a superior natural alloy called arsenical bronze.

The earliest bronzes made with tin date to the late fourth millennium B.C.E. in Susa (Iran), and some ancient sites in Luristan (Iran) and Mesopotamia (Iraq).[2]

Copper and its alloys have a huge variety of uses that reflect their versatile physical, mechanical, and chemical properties. Some common examples are the high electrical conductivity of pure copper, the excellent deep-drawing qualities of cartridge case brass, the low-friction properties of bearing bronze, the resonant qualities of bell bronze, and the resistance to corrosion by seawater of several bronze alloys.

In the twentieth century, silicon was introduced as the primary alloying element. It produced an alloy with wide applications in industry and the major form used in contemporary statuary. Aluminum is also used for the structural metal known as aluminum bronze.

Bronze is the most popular metal for top-quality bells and cymbals, and more recently, saxophones. It is also widely used for cast metal sculptures. Common bronze alloys often have the unusual and very desirable property of expanding slightly just before they set, thus filling in the finest details of a mold. Bronze parts are tough and typically used for bearings, clips, electrical connectors, and springs.

Bronze also has very little metal-on-metal friction, which made it invaluable for the building of cannons where iron cannonballs would otherwise stick in the barrel. It is still widely used today for springs, bearings, bushings, automobile transmission pilot bearings, and similar fittings, and is particularly common in the bearings of small electric motors. Phosphor bronze is particularly suited to precision-grade bearings and springs. Bronze is typically 60 percent copper and 40 percent tin. Alpha bronze consists of the alpha solid solution of tin in copper. Alpha bronze alloys of four to five percent tin are used to make coins, springs, turbines, and blades. [5]

Another useful property of bronze is that it is non-sparking (unlike steel). That is, when struck against a hard surface, it will not generate sparks. This is used to advantage to make hammers, mallets, wrenches, and other durable tools to be used in explosive atmospheres or in the presence of flammable vapours. [5]

1 http://www.historyworld.net/.

2 http://www.newworldencyclopedia.org/

Brass

Brass is usually the first-choice material for many of the components for equipment made in the general, electrical and precision engineering industries. Brass is specified because of the unique combination of properties, matched by no other material, that make it indispensable where a long, cost-effective service life is required.

The generic term 'brass' covers a wide range of copper-zinc alloys with differing combinations of properties, including:

- Strength
- Machinability
- Ductility
- Wear resistance
- Hardness
- Colour
- Conductivity
- Corrosion resistance


Figure 3. Brass bar

Brasses can easily be cast to shape or fabricated by extrusion, rolling, drawing, hot stamping and cold forming.

• The machinability of brass sets the standard by which other materials are judged.
• Brasses are ideal for a very wide range of applications.
• Brass is frequently the cheapest material to select.
• The correct choice of brass is important if manufacturing and operating requirements are to be met in the most cost-effective way.

To suit every need, there are over sixty Standard compositions for brass with copper contents ranging from 58% to 95%. Apart from the major alloying element, zinc, small additions (less than 5%) of other alloying elements are made to modify the properties so that the resulting material is fit for a given purpose.

Brass is the best material from which to manufacture many components because of its unique combinations of properties. Good strength and ductility are combined with excellent corrosion resistance and superb machinability. Brasses set the standard by which the machinability of other materials is judged and are also available in a very wide variety of product forms and sizes to allow minimum machining to finished dimensions. As rod or bar, brasses are readily available from manufacturers and stockists. For longer runs it is frequently worth considering the purchase of special sizes or extruded shapes designed to minimise subsequent production costs. Brass rod manufacturers are able to produce a very wide variety of shapes and sizes of product with minimum order quantities that are very low compared with many other materials. Die costs for special extrusions can be inexpensive when spread over a long production run and hollow extrusions can save excessive boring operations.

Brasses, having various combinations of strength and ductility, corrosion resistance, machinability, conductivity and many other attributes, are very widely used in the manufacture of components and finished goods. Alternative materials can be considered but it must be remembered that the main criteria to be assessed are those that affect the overall lifetime costeffectiveness rather than first cost or raw material cost.

The History of Brass

Brass has been made for almost as many centuries as copper but has only in the last millenium been appreciated as an engineering alloy used to make mass produced goods and as an alloy capable of being formed by working or casting, finished by embossing, engraving and piercing and joined by soldering and brazing into exquisite objects of the finest artistic calibre. Before the 18th century, zinc metal could not be made since it melts at 420°C and boils at about 950°C, below the temperature needed to reduce zinc oxide with charcoal. In the absence of native zinc, it was necessary to make brass by mixing ground smithsonite ore (calamine) with copper and heating the mixture in a crucible. The heat was sufficient to reduce the ore to metallic state but not melt the copper. The vapour from the zinc permeated the copper to form brass, which could then be melted to give a uniform alloy.

In Mediaeval times there was still no source of pure zinc. When Swansea, in South Wales, was effectively the centre of the world's copper industry, brass was made from calamine found in the Mendip hills in Somerset. Brass was popular for church monuments, thin plates being let in to stone floors and inscribed to commemorate the dead. These usually contained 23-29% zinc, frequently with small quantities of lead and tin as well. On occasions, some were recycled by being turned over and re-cut.

With the coming of the industrial revolution, the production of brass became even more important. In 1738, William Champion was able to take out a patent for the production of zinc by distillation from calamine and charcoal. This gave great impetus to brass production in Bristol.
Wire was initially produced by hand drawing and plate by stamp mills. Although the first rolling mill in Swansea was installed at Dockwra in 1697, it was not until the mid-19th century that powerful rolling mills were generally introduced. The Dockwra works specialised in the manufacture of brass pins, the starting stock being a plate weighing about 30kg. This was cut into strips, stretched on a water-powered rolling mill and given periodic interstage anneals until suitable for wiredrawing.

With the invention of 60/40 brass by Muntz in 1832 it became possible to make cheap, hot workable brass plates. These supplanted the use of copper for the sheathing of wooden ships to prevent biofouling and worm attack. An example of brass sheathing was the Cutty Sark launched in 1869. The Muntz metal was about two thirds the cost of copper and had identical properties to copper for this application. Muntz made his fortune.

Subsequent developments in production technology have kept pace with customers' demands for better, consistent quality in larger quantities. The brass now is cast to extrusion billet form in three-strand horizontal continuous casting machines, cut to length, reheated and extruded in modern presses designed to give high quality and minimum wastage. Subsequent straightening, drawing, annealing, cutting to length, pointing and inspection is carried out under approved quality management schemes that ensure material is supplied as ordered.

Today, brass is the best material from which to manufacture many components because of its unique combination of properties. Good strength and ductility are combined with excellent corrosion resistance, attractive colour and superb machinability.

The valuable properties of copper which were evident at the dawn of civilisation were an attractive colour, excellent ductility and malleability and were capable of being hardened by working. In modern times, further properties have been appreciated and exploited across a wide range of applications; high thermal and electrical conductivities, excellent corrosion and biofouling resistance and antimicrobial properties.

In the 21st century, copper and copper alloys make a significant contribution to the latest developments in renewable energy, information and communication technology, coinage, architecture, transport, etc.

Effects of alloying elements

Lead
The addition most commonly made to brasses to modify their properties is lead, up to 3% of which may be added to alpha-beta brasses to provide free-machining properties. The lead does not form a solid solution with the copper and zinc but is present as a dispersed discontinuous phase distributed throughout the alloy. It has no effect on corrosion resistance. Lead is not added to wrought alpha brasses since, in the absence of sufficient beta phase, it gives rise to cracking during hot working.

Tin
1% tin is included in the composition of Admiralty brass CW706R (CZ111) and Naval brass CZ112 (nearest CW712R). As their names indicate, these brasses were developed originally for seawater service, the tin being added to provide improved corrosion resistance.

Nowadays Aluminium brass CW702R (CZ110) has replaced Admiralty brass for marine service but Admiralty brass is used for fresh water. Naval brass retains some important applications in seawater service.

Silicon
Silicon increases the strength and wear resistance of brass and is also sometimes included in die casting brasses and in filler alloys for gas welding to reduce oxidation of the zinc and to assist fluidity. Its principal effect from the corrosion point of view is to increase the beta phase content.

Arsenic
Arsenic is often added in small amounts to alpha brass alloys to provide protection against dezincification corrosion

Nickel silvers
The range of copper-nickel-zinc alloys containing from 10 to 20% nickel and known as nickel silvers can be regarded as special brasses. They have a silvery appearance rather than the typical brassy colour. In most respects they show similar corrosion characteristics to alpha brasses but the higher nickel versions have superior tarnish resistance and resistance to stress corrosion cracking.
Lead-free machining brasses
Some concern has been expressed regarding the possibility that lead could be leached from water fittings in aggressive supply waters. Generally this does not cause a long-term problem, but some work has been done to investigate alternative additions able to produce the required insoluble globules of good lubricity. One of the additions suggested is bismuth but, as yet, no alternative materials have been standardised in Europe. The EU End of Life Vehicle (ELV) Directive, adopted in September 2000, includes provision for phasing out metals such as lead used in automotive components. However, copper alloys containing up to 4% lead are exempt from the Directive. Applications for these copper alloys include bearing shells and bushes (phosphor bronze), nozzles, connection parts, fixtures and locks (leaded brass).

Brasses for corrosion resistance

A market survey of users' attitudes revealed that the most important perceived property of brass is corrosion resistance. All brasses have excellent corrosion resistance in conditions of normal usage, the fact that it is the standard safe material for millions of electrical terminals being just one example. For use in aggressive working environments, consideration has to be given to the selection of brass for optimum lifetime. This section of the publication details the topics to be considered and the brasses to be selected to meet the most demanding conditions.

The basic price of brass may sometimes be higher than other alternatives, but that is only part of the overall cost picture. The availability of the brasses in precise preformed shapes such as extrusions, hot stampings and die castings, eliminates much of the machining costs required to produce finished components. This fact, combined with the considerable value of recycled offcuts and swarf, often results in items made from brass being cheaper than those in other apparently lower cost materials. Brasses also frequently offer better and longer service performance, avoiding consequential service and guarantee claims.

Cost-effectiveness

There are many factors, sometimes overlooked, that contribute to the low costs of brass components:
- Close tolerance manufacturing techniques can be employed so that finishing costs are minimal
- Tooling costs may be significantly lower than for other materials or processes.
- Ease of machining means that production costs can be minimised.
- The good corrosion resistance of the brasses means that the cost of protective finishing is lower than for many other materials.
- In addition to these benefits, the high value of any process scrap can be used to reduce production costs significantly.
- The long service life normally expected of well-designed brass components means that the costs of service failures are minimal

Choosing the right brass

There are over sixty brasses specified in EN Standards. The alloys cover a wide range of properties and attributes, so it is essential to select the appropriate alloy for the application and fabrication route required.

It is possible to classify all brasses into the following categories:
- High-speed machining brasses
- Brasses for hot working
- Hot stamping brasses
- Brasses for cold working
- Brasses for casting
- High tensile brasses
- Brasses for electrical applications
- Brasses for architectural applications
- Brasses for decorative applications
- Dezincification-resistant brass
- Brasses for service in seawater
- Brass tubes for fluid handling

Types of brass
Brasses are copper alloys in which the principal alloying constituent is zinc. Their properties depend primarily upon the proportion of zinc present but can be usefully modified by the introduction of additional elements to further improve specific characteristics such as strength, machinability or resistance to particular forms of corrosion.
The inclusion of certain third elements - particularly aluminium, silicon or tin - has the effect of increasing the beta phase content for any particular zinc content. The presence of the beta phase in the alpha-beta brasses gives reduced cold ductility but greatly increased amenability to hot working by extrusion or stamping and to die casting without hot cracking, even when lead is present.

The alpha-beta alloys are also stronger and, since they contain a higher proportion of zinc, cheaper than the alpha brasses. However, they do show higher susceptibility to dezincification corrosion and are therefore less suitable for service under conditions where this type of attack is likely to occur.

Alpha brasses
The range of alloys, termed ‘alpha brasses’, or ‘cold working brasses’, contain a minimum 63% of copper. They are characterised by their ductility at room temperature, and can be extensively deformed by rolling, drawing, bending, spinning, deep drawing, cold heading and thread rolling. The best known material in this group contains 30% zinc and is often known as ‘70/30’ or ‘cartridge’ brass, CuZn30 - due to the ease with which the alloy can be deep drawn for the manufacture of cartridge cases. The cases (up to 100mm diameter) start as flat discs blanked from strip or plate and are successively formed to the final shape by a series of operations, carried out at room temperature, which progressively elongate the sidewalls and reduce their thickness. CuZn30 possesses the optimum combination of properties of strength, ductility and minimal directionality which make it capable of being severely cold drawn. Its ductility allows cold manipulation and the alloy has better corrosion resistance than the brasses with a higher zinc content.

Alpha-beta brasses
The ‘alpha-beta brasses’, ‘duplex brasses’ or ‘hot working brasses’ usually contain between 38% and 42% zinc. In contrast to the alloys of the first group, their ability to be deformed at room temperature is more limited. They are, however, significantly more workable than the alpha brasses at elevated temperatures and can be extruded into bars of complex section, either solid or hollow, and hot forged in closed dies (hot stamped) to complex shapes. The ideal hot working temperature range is whilst the brass is cooling, between 750ºC and 650ºC, during which the alpha phase is being deposited (see Figure 4). The mechanical working process breaks down the alpha phase into small particles as it is deposited, resulting in good mechanical properties.

Note the need for careful control of annealing temperature and cooling rate if it is required to obtain a single-phase alpha structure in a brass of high zinc content such as common brass and dezincification-resistant brass. Current use of continuous annealing techniques for sheet, strip, wire and tube gives a much quicker cooling rate than previous batch annealing in controlled atmosphere bell furnaces.

The addition of lead to these alloys aids chip breakage during machining, producing short broken chips which are easily cleared from the cutting area to improve machinability. Since the cost of zinc is lower than that of copper, brasses of higher zinc content have a lower first cost. This may be significant in assessing manufacturing and total-lifetime costs.

Effect of alloying addtion

Alloying additions are made to the basic copper-zinc alloys for a variety of reasons:-
• to improve machinability
• to improve strength and wear resistance
• to improve corrosion resistance
• for other special reasons
The very wide variety of standard brass compositions that are available reflect the many ways in which an optimum combination of properties can be tailored to ensure fitness for the desired application.

Corrosion-resistant applications of brasses

In selecting materials for particular applications, engineers and designers take into consideration a wide range of properties and attributes. Strength, ductility, machinability, castability, appearance, price, availability in convenient form, corrosion resistance etc. are all of greater or less importance according to the purpose for which the material is to be used. Brasses score highly in most of these requirements, including corrosion resistance. Whereas, however, it is a straightforward task to tabulate mechanical properties, corrosion resistance is more difficult to define and to quantify - especially in view of the wide range of different brasses available and the even wider range of environments and conditions in which they are used. Hence the reason for this section, which provides guidance on the selection of appropriate brasses for different service conditions.

Dezincification-resistant brasses for hot working or diecasting have been given a sub-section of their own because they are alpha-beta brasses above about 550ºC but alpha brasses in the heat-treated condition in which they are used. The most important dezincification-resistant brass is CW602N (CZ132). It is most used in the form of hot stampings and items machined from rod or bar, for the production of water fittings for use in areas where the supply causes meringue dezincification of alpha-beta brass.

A stop tap typically employs hot stampings in CW602N (CZ132) for the body, bonnet and washer plate, the spindle being machined from CW602N (CZ132) rod. The gland nut does not come into contact with water and may therefore be of alpha-beta brass unless the tap is for underground use, in which case it must also be in CW602N (CZ132). The capstan head does not need to be dezincification-resistant and may be a hot stamping in CW617N (CZ122). Such fittings frequently have ends machined for capillary soldered connection to 15mm copper tube. CW602N (CZ132) is suitable for all conventional soft soldering procedures but, if it is heated above 550ºC, beta phase is formed and its dezincification-resistance lost. Capillary brazing is, therefore, not satisfactory. Silver soldering can be employed for the manufacture of mixer valve components etc. from CW602N (CZ132) parts, provided that the silver solder used is itself resistant to dezincification and the component is heat treated according to the requirements of EN 12164 for CW602N (CZ132), after fabrication.

Proprietary dezincification-resistant brasses, formulated on the same principle as CW602N (CZ132) but usually containing silicon and/or manganese for greater fluidity, are used as diecastings for valve and water meter bodies, etc. The need for heat-treatment after casting, to ensure an all-alpha structure, can sometimes be avoided by controlled slow cooling through the temperature range 550ºC to 450ºC.

Dezincification

Dezincification is an example of dealloying, in which one of the constituents of an alloy is preferentially removed by corrosion. Another example is graphitisation of cast iron. Cast iron has a structure consisting of ferrite together with graphite and iron carbide. Corrosion causes progressive dissolution of the ferrite (iron) constituent, leaving the graphite behind. The dezincification of brass is a little more complicated since the zinc and copper are not present as separate constituents but as alpha and beta solid solutions. The effect of dezincification corrosion is however similar to graphitisation in that one constituent of the alloy (zinc) is selectively removed leaving the other (copper) behind. The mechanism by which this occurs is probably different in that, instead of the zinc being selectively leached out from the brass, the zinc and copper both pass into solution together, but the copper is then almost immediately redeposited in virtually the same position that it occupied originally. The result therefore is to remove the zinc as corrosion products and leave a residue of copper. Dezincified brass, like graphitised cast iron, retains the original shape and dimensions of the metal component before corrosion but, in both cases, the residue is porous and has very little strength.

Dezincification was first recognised as a serious problem in 70/30 brass tubes used for ships' condensers c1920. It was stated that 'Condenseritis' (dezincification of condenser tubes) had more effect than the German navy in putting HM ships out of action in the First World War. Research on the problem established that dezincification could be prevented by the incorporation of about 0.03% arsenic in the 70/30 brass alloy and this addition is now standard in all alpha-brass tube specifications including Admiralty brass and Aluminium brass. Alpha-brass strip is not usually arsenical since it is mostly used in situations where dezincification does not occur or is not significant. Dezincification as a problem with alpha-beta brass water fittings in some districts was first recognised in the late 1950s. This was a type of dezincification, now termed 'meringue dezincification', in which the zinc passing into solution from the brass forms very bulky hollow mounds of corrosion product which block the fitting. It attacks the beta phase preferentially but spreads at a later stage into the adjoining alpha phase. Since the addition of arsenic to the alloy does not inhibit dezincification of the beta phase, arsenic additions are of no value in alpha-beta brasses.

Recognition

Dezincification may show itself as dull red spots developing on the surface of brass after long periods of exposure to urban or industrial atmospheres. These do not normally represent any significant loss of strength in the component concerned but, since they are more than simply superficial they cannot be removed by the cleaning and polishing procedures that would normally restore the brass to its original appearance. Dezincification in water fittings, valves etc. can show itself in a variety of ways depending on the water composition and service conditions. Blockage due to meringue dezincification has already been mentioned. Other possible manifestations are seepage of water through the walls of fittings after long periods of service or leakage at valve seatings due to dezincification coupled with erosion of the soft, dezincified residue.

The extreme case of damage by dezincification is actual breakage, with a dull coppery appearance to the fracture surface. Breakage is not common but can affect alpha-beta brass underground fittings (in which dezincification may be occurring from both the water side and the soil side), valve spindles, screws and 'bronze-welded' joints.

Conditions for dezincification

The particular form of dezincification giving rise to bulky corrosion products (meringue dezincification) is associated with waters having a high chloride to temporary hardness ratio, coupled with a high pH usually above 8.0 and often above 8.3.

Two factors that can increase the probability and rate of dezincification occurring in service are elevated temperature and coupling to a more noble metal. If brass bosses are used on copper hot water cylinders, the combined effects of the high water temperature and coupling to a large area of copper can give rise to significant dezincification, even in waters that normally give no trouble at all. Consequently, this is one point in a domestic plumbing system where brasses are not used.

Avoidance

Dezincification problems in service can be avoided by recognising in advance whether the service conditions are likely to produce dezincification and, if so, using appropriate dezincification-resistant brasses. For heat-exchanger or other tubing the question solves itself since all alpha brass tube specifications require the presence of arsenic in the alloy to inhibit dezincification. Alpha brass strip or sheet, other than Aluminium brass, is not usually arsenical since it is mostly used for purposes where no significant dezincification will occur. For more corrosive conditions Aluminium brass strip can be used, or one of the higher-copper brasses, with 15% or less of zinc, which are practically immune to dezincification. Nickel silvers also show high resistance to dezincification and can be an appropriate choice for some applications when this property is important.

If the manufacturing process involves hot stamping or requires free-machining rod or bar, alpha beta brasses are normally used but these are susceptible to dezincification in unfavourable environments. Research work solved this problem by producing brasses which, at the hot stamping or extrusion temperature, contain sufficient beta phase to be hot-worked satisfactorily but which can be converted by subsequent heat treatment to an all-alpha structure which is protected against dezincification by incorporating arsenic in the alloy. For protection from dezincification the arsenic % must be greater that the % (iron +manganese). It must be in solution and not combined with the impurities iron plus manganese. The problem is that the specification allows a maximum of 0.1% iron and manganese and arsenic is 0.02 to 0.15%. Such a forgeable, dezincification-resistant brass CW602N (CZ132), is included in EN rod and forging specifications. CW602N (CZ132) is a leaded brass and its machinability is comparable with the leaded duplex brass CW617N (CZ122), commonly used for production of water fittings. CW602N (CZ132) rods and bars for machining are heat treated by the materials supplier to put them into the dezincification-resistant condition. CW602N (CZ132) forging stock is supplied un heat treated since it must be heated after forging to 500-525ºC, held for at least two hours and slowly cooled, to ensure resistance to dezincification. This is done by the fittings manufacturer. To retain corrosion resistance, fittings should not be reheated above the heat treatment temperature, as happens in brazing. If accidentally overheated, corrosion resistance can be regained byrepeating the original treatment. To retain corrosion resistance, fittings should not be reheated above the heat treatment temperature, as happens in brazing. If accidentally overheated, corrosion resistance can be regained by repeating the original treatment.

Stress corrosion cracking (SCC)

Stress corrosion cracking, or 'season cracking', occurs only in the simultaneous presence of a sufficiently high tensile stress and a specific corrosive environment. For brasses the environment involved is usually one containing ammonia or closely related substances such as amines, but atmospheres containing between 0.05% and 0.5% of sulphur dioxide by volume can also cause stress corrosion cracking. The test methods for stress corrosion resistance of brass can either be according to ISO 6957 (using ammonia) or EN ISO 196 (using mercurous nitrate). Mercury stress corrosion cracking of brass components can also occur in service due to contamination from broken thermometers. Potential problems with mercury in offshore oil wells has been reported.

Recognition

Stress corrosion cracking in brass is usually localised and, if ammonia has been involved, may be accompanied by black staining of the surrounding surface. The fracture surface of the crack may be stained or bright, according to whether the crack propagated slowly or rapidly. The cracks run roughly perpendicular to the direction of the tensile stress involved. For example, drawn brass tube that has not been stress relief annealed has a built-in circumferential hoop-stress; consequently exposure to an ammoniacal environment is liable to cause longitudinal cracking. Stress corrosion cracking in pipes that have been cold bent without a subsequent stress relief anneal occurs typically along the neutral axis of the bend. Stress corrosion cracking due to operating stresses is transverse to the axis of the applied stress. Examination of metallographic sections through cracked areas will usually show a markedly intergranular crack pattern in simple alpha brasses. In Aluminium brass the cracking is transgranular and much branched and in Admiralty brass either or both forms of cracking may be observed. Stress corrosion cracks in alpha-beta brasses run transgranularly through the beta phase or, occasionally, along the alpha-beta interface. The cracks look discontinuous in metallographic sections, as they divert above or below the plane of the section to pass round the alpha phase.

Influence of zinc content and stress level

D H Thompson and A W Tracey made a detailed study of the effect of stress level and zinc content

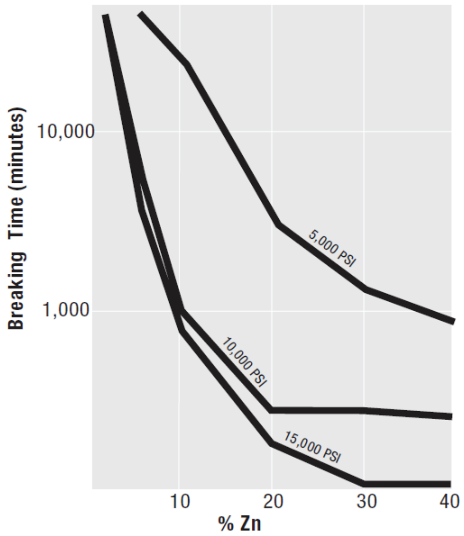


Figure 4: Effect of zinc content on stress corrosion susceptibility of brass

on the time for failure by stress corrosion cracking to take place in axially loaded specimens exposed to air containing 10% ammonia and 3.7% water vapour at 35ºC. This is an accelerated test giving failures in much shorter times than would be experienced under most service conditions; the results, presented in Figure 2, are therefore to be taken as indicative of trends, but should not be used to predict service life. It does show that the higher the copper content, the better the resistance to stress corrosion cracking. Accelerated tests in an ammoniacal atmosphere at three different stresses In another series of experiments, D H Thompson used loop specimens to study the effect of adding a third element on the stress corrosion behaviour of various brasses in a moist ammoniacal atmosphere. Their results showed marked beneficial effects of nickel - the 10% nickel, 25% zinc, nickel silver tested being superior to 15% zinc brass without additions. Addition of silicon to a 17% zinc brass was also beneficial. Similar results to these have been found by other researchers and are supported by practical experience. A further point of interest arising from Thompson and Tracey's loop tests is that Aluminium brass was shown to have betterstress corrosion resistance than Admiralty brass. This was confirmed in atmospheric stress corrosion tests of various copper alloys carried out by J M Popplewell and T C Gearing. U-bend specimens of Aluminium brass exposed to industrial atmospheres at Newhaven and Brooklyn failed in times ranging from 221 to 495 days, while Admiralty brass specimens failed between 41 and 95 days. Both materials were in the 40% cold rolled condition. It has occasionally been suggested that arsenic levels near the 0.06% maximum permitted by most national standards may increase the susceptibility of Aluminium brass to stress corrosion. A survey of relevant publications by H S Campbell concluded that, reducing the maximum arsenic content from 0.06 to 0.03%, would have only a marginal effect on stress corrosion susceptibility and would reduce the reliability of the arsenic addition as an inhibitor of dezincification. Consequently, no change in the standards was considered desirable. The test results and practical experience outlined above refer to alpha or alpha-beta brasses and principally to ammoniacal environments, though sulphur dioxide may have been the more important corrosive factor in the industrial atmospheric exposure tests. All-beta brass (the only important commercial example of which is the cast high tensile brass HTB3) is susceptible to stress corrosion cracking also in environments containing chlorides and is therefore much more restricted in use.

Avoidance

Provided that service and manufacturing process requirements permit, improved resistance to stress corrosion cracking can be achieved by selecting the less susceptible brasses - low zinc rather than high zinc alloys; nickel silver rather than simple brass; Aluminium brass rather than Admiralty; CC765S (HTB1) rather than CC762S (HTB3), for example. However, since all brasses are susceptible to stress corrosion cracking to some extent it is more important to control manufacturing, assembly and operating conditions to avoid the combination of high stress and unfavourable environment that may cause stress corrosion. Cold working operations such as pressing, spinning, drawing and bending leave internal stresses which, unless removed or substantially reduced by stress relief heat treatment, can lead to stress corrosion cracking. The optimum time and temperature for stress relief depends upon the alloy but will lie within the range 1⁄2 to 1 hour at 250-300ºC. A second, avoidable source of dangerously high stress levels that can induce stress corrosion cracking is careless fitting in assembly and installation. Poor alignment, gaps at joints and overtightening of bolts are obvious examples of bad practice in this respect. One that is not so often recognised is the practice of screwing taper-threaded connectors into parallel-threaded brass valves. When PTFE tape is used to seal the thread, it is all too easy to overtighten such joints to a point where a very high circumferential hoop stress is generated in the female member. There have been many examples of subsequent longitudinal stress corrosion cracking of the valve ends as a result of contact with quite low concentrations of ammonia in service.

The control of the environment in which brass is used may seem an impractical way of ensuring freedom from stress corrosion cracking in service, in view of the wide range of service conditions under which brass articles and components are in daily use, but it is possible to avoid unnecessary exposure to ammoniacal contamination. One source of such contamination that has caused brass fittings, overstressed in assembly, to crack in service is some varieties of foamed plastic insulating material in which amines or other ammonia-related chemicals are used as foaming or curing agents. Chilled water valves in air conditioning units are most likely to be affected since these are subjected to condensed moisture as well as the ammoniacal chemicals. More common, but usually less harmful, sources of ammonia are latex cements used to fix wall and floor tiles and certain household cleaners (which usually advertise their ammonia content as one of their great advantages). The best advice regarding these possible sources of trouble is to provide good ventilation after using latex cement, so that any stressed brass articles in the room have only a short period of exposure to ammonia, and to wash away ammoniacal household cleaner residues after use.

Brass versus Bronze

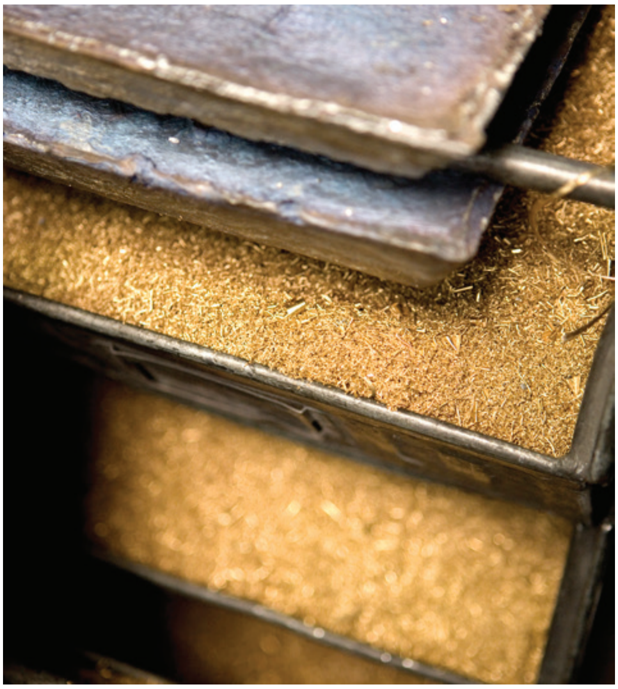
Taking into account the main factors and features of copper based materials (brass and bronze) it seems necessary to summarise them in one comparison table.

Brass	Bronze
By combining the different alloys of brass it is possible to reach perfect dezinfication resistance, excellent machinability, good cold workability.	Dezinfication resistance due to the absence of Zn in most cases. Limited machinability.
The price is basically lower than bronze, due to the absence of Tin in alloy, which is a relatively expensive material.	The price is basically higher than brass and is dependant on the level of tin.
Brass is easier to use in the tapping process because the liquid phase in the chamber keeps a constant physical state.	Upper layer of chamber is relatively fast being covered by solid state, which makes the tapping process more difficult.
It is possible to achieve good hot ductility by combining the alloys.	Due to the good hot ductiliy it is possible to create very complex forms in molds.
Brass has a yellow colour, somehow similar to gold. It is relatively resistant to tarnishing, and is often used as decoration.	Commercial bronze (otherwise known as brass) is 90% copper and 10% zinc, and contains no tin. It is stronger than copper and it has equivalent ductility. It is used for screws and wires.
There is a lead additon for better machinability. The quantity of lead in alloys is always controlled, and in the sanitary industry it is reduced to a negligible amount.	Due to the absence of lead, bronze fits better to the manufacturing of valves, fittings, circuit regulating valves, dynamic control fittings and thermostatic valves etc., but the production costs rise significantly.
Brass melts at lower temperature and therefore uses less energy to melt. It machines and polishes much easier than Bronze and therefore the price to make a fitting from it is lower. It also wears out quicker and therefore the customer will have to purchase replacement parts much sooner.	When steel is excluded from the discussion, bronze is superior to iron in nearly every application. While it develops a patina, it does not oxidize. It is considerably less brittle than iron and has a lower casting temperature. (Steel, of course, has properties with which bronze cannot compete.)

How we do ...

HERZ basically use 6 different types of the brass for different applications using the special features of every type:

- CW617N and CW614N - excellent machinability, limited cold working, best for hot stamping. Both are used for drinking water valves. Generally the preference is given to CW617N because of its higher standard grades.
- CW626N - is a dezinfication resistant brass, used in fitting and drinking vater valves production.
- CW602N - is a dezinfication resistant brass, has a good hot ductility. Heat treated to give DZR properties.
- CW511N - brass for general purposes, might serve as an alternative to CW626N
- CC752S - used only for balancing valves, not for radiator equipment.



References and acknowledgement

This report is based on two reports by **InTech company (www.intechopen.com) pages 2 and 3**, and **COPPER DEVELOPMENT ASSOCIATION Publication No. 117, 1996 by Vin Callcut Revised 2005 by Peter Webster, pages 5 - 12**. We want to express our gratitude to these companies for providing all necessary information for this report.

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HERZ Armaturen GmbH
Richard-Strauss-Str. 22, A-1230 Vienna
Tel.: +43 (0)1 616 26 31-0, Fax: +43 (0)1 616 26 31-227
E-Mail: office@herz.eu

www.herz.eu