Section 7 – 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.

CORROSION-RESISTANT APPLICATIONS OF BRASSES

This section presents briefly, for the most widely used brasses, some typical applications for which corrosion resistance is important. The examples chosen form only a small fraction of the range of purposes for which the brasses concerned are commonly used.

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. As is made clear in other CDA publications, 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.

ALPHA BRASSES

SHEET, STRIP, PLATE AND WIRE

Low-zinc brasses

The low-zinc brasses, or gilding metals, are used for architectural metalwork and costume jewellery because of their golden colour, but require a clear lacquer or other form of protection to preserve their appearance without tarnishing. The benzotriazole-inhibited lacquer **Incralac** is recommended for most applications (*see page 32*). For service involving heavy wear or rough handling this air-drying, acrylic ester lacquer is not really sufficiently hard and a shop-applied, benzotriazole-inhibited, polyurethane lacquer (such as BNF-CB) is preferable.

Brasses for cold working

As previously mentioned, CuZn30, CuZn33, CuZn36 and CuZn37 are used for a great variety of purposes involving cold working by forming, drawing, spinning etc, CuZn30, having the greatest ductility, is used when deep drawing operations are involved. Deep drawn or other heavily worked articles should be stress relief heat treated to avoid possible stress corrosion cracking in service but, for most purposes, no other corrosion protection is called for. CuZn37, with 63% Cu and 37% Zn, has a zinc content very close to the maximum for all-alpha brass. Modern methods of strip production entail rapid cooling after annealing and can result in small amounts of beta phase being retained - with consequent reduction of corrosion resistance. To avoid this, the 64/36 composition is now more commonly employed. Except in particularly aggressive environments CuZn30, CuZn33, CuZn36 and CuZn37 tarnish slowly to a uniform dull bronze colour with no pitting or localised attack. Their original appearance can be preserved, if required, by lacquering or regular polishing.

Since these brasses do not contain arsenic to inhibit dezincification, they are not recommended for service in contact with seawater. They are, however, the standard materials for core tubes and header tanks of motor car radiators and similar coolers operating on recirculating fresh water or inhibited antifreeze solutions, and are completely satisfactory for that purpose.

Aluminium brass, CW702R (CZ110), strip is used when corrosion resistance to seawater is essential - for example header tanks and tube plates of Aluminium brass tubed air-coolers operated on seawater. It is sometimes employed in plate-type heat exchangers but the extremely high local flow rates involved make it unreliable for this purpose with seawater as the coolant; titanium plates are usually preferred.

Rolled plate

An arsenic-inhibited version of 70/30 brass, CuZn30As, CW707R (CZ105), supplied in plate form, may be used for tube-and-shell heat exchanger tubeplates. Aluminium brass plate is also used for that purpose and for the production of welded, large diameter seawater pipe systems.

ALPHA-BETA BRASSES

Alpha-beta brasses have a wide range of use in a variety of forms including hot-rolled plate, extruded sections, machining stock, forgings, sand castings and diecastings - as well as for brazing or 'bronze welding' fillers. Some examples of their use, in which corrosion resistance is an important factor, are given.

60/40 brass (Muntz Metal)

CW509L (CZ109) is used for tube plates of condensers and heat exchangers with brass or copper-nickel tubes - especially in the USA; Naval brass is generally preferred in the UK. CuZn40 is subject to dezincification in seawater service, but the tube plates may be cathodically protected to prevent this. The uncoated cast iron water boxes often used for small heat exchangers will themselves provide sacrificial cathodic protection to brass tube plates but the water box will, as a result, suffer accelerated corrosion - especially near its interface with the tube plate. If the water box is coated for corrosion protection the tube plate can be protected with iron or zinc sacrificial anodes or by an impressed current cathodic protection system. However, since tube plates are very thick, a considerable amount of dezincification can usually be tolerated before replacement or repair need be considered.

Naval brass

The presence of 1% tin in Naval brass, CW712R (CZ112), gives it higher resistance to dezincification than CuZn40. This is particularly true if the copper content is near the top end of the range, since this reduces the amount of beta phase present. For large tube plates the practical limit to the copper content is governed by the increasing difficulty of hot rolling but, for small heat exchangers, some manufacturers use cast tube plates of high-copper Naval brass. In this material the beta phase is discontinuous and is largely enveloped by a delta phase of high tin content which protects it from dezincification in normal seawater service.

In the UK rolled Naval brass is the most usual choice for tube plates for condensers and other large heat exchangers - usually with Aluminium brass or copper-nickel tubes. 70/30 copper-nickel tubes produce some galvanic acceleration of attack on the tube plate but, as with 60/40 brass, the thickness of the tube plate is such that the dezincification is rarely sufficient to require any remedial action. As with 60/40 brass, cathodic protection with iron or zinc anodes or by impressed current is often provided.

In condensers with titanium tubes galvanic action causes seriously accelerated attack on Naval brass tube plates. Some success has been experienced with epoxy coatings to protect Naval brass tube plates in condensers originally tubed with brass or copper-nickel and subsequently retubed, wholly or in part, with titanium. This procedure does, however, rely heavily on the integrity of the coating and, for new construction, Naval brass tube plates are not considered suitable if titanium tubes are to be used. Nickel aluminium bronze, alloy CW304G (CA105), is then recommended.

EXTRUDED BRASSES

Sections for engineering components requiring extra corrosion resistance

The widespread application of extruded sections in engineering components is a result of the combination of close dimensional tolerances maintained in the wide variety of sections available, free-machining properties, good electrical conductivity and corrosion resistance. CW624N (CZ130) is the brass most widely employed in this form. The aluminium-free version is selected if the application involves soft soldering or plating; otherwise the version containing 0.5% aluminium is chosen for its brighter appearance and particularly good tarnish resistance. Typical uses for which no corrosion protection is normally required include machine parts, instruments, electrical appliances, switchgear, fusegear and hinges.

Sections for architectural use

CW624N (CZ130) with aluminium provides sections for shopfitting etc, which have a bright yellow appearance and good tarnish resistance. CW720R (CZ136) or a manganese brass containing 38% zinc with 2% manganese, 1% lead and 0.5% each of tin and iron is sometimes preferred since it is stronger, and superficial oxidation occurring during extrusion gives it a chocolate brown colour which obviously cannot tarnish. It does become dull and eventually starts to form a green patina on outdoor exposure, but can be preserved by rubbing over with very light oil at one- or two-monthly intervals or by lacquering. Wax polish is sometimes used - especially for indoor service involving handling. The same treatments can be applied to preserve the original appearance of CW624N (CZ130) sections.

Architectural brass sections are often used in conjunction with gilding metal panels, both being toned to the same 'brown bronze' colour with proprietary colouring compounds based, for example, on antimony sulphide. If used on outdoor items these patinated finishes should be preserved by oiling or lacquering. Wax polish is often used indoors.

Rod and bar for machining

The choice of zinc and lead contents of free-cutting brass is made according to the requirements for machinability and cold working ability. All have similar corrosion resistance, being subject to dezincification in dezincifying environments, but requiring no special protection for most purposes. Naval brass CW712R (CZ112) and the free-machining leaded versions of this alloy have slightly better resistance to dezincification but for use in seawater, acidic conditions or supply waters that cause meringue dezincification the dezincification-resistant brass, CW602N (CZ132), is required.

Higher strength, with susceptibility to dezincification similar to that of CW712R (CZ112), is provided by the high tensile brasses CW721R (CZ114) and CW705R (CZ116). These are used, for example, as bolting materials and for valve spindles in situations where significant dezincification is unlikely to occur. They should not be used in seawater unless cathodically protected. Because of the possibility of stress corrosion cracking occurring after prolonged service, high tensile brasses are not employed in situations where stress corrosion cracking could have serious consequences, for example as load-bearing masonry fixings.

FORGINGS (Hot stampings)

All the alpha-beta brasses are similar from the corrosion point of view, having excellent corrosion resistance without the need of protection under most conditions of service. They are subject to dezincification in seawater, in supply waters that cause meringue dezincification or if buried in corrosive soils. For these purposes the dezincification-resistant brass is employed.

One of the biggest uses for hot stampings in CW617N (CZ122) is for water fittings, gas fittings and other pipe connectors or valves. These are sometimes chromium plated or gold plated for decorative effect but will provide almost indefinite service without any need for corrosion protection. Watch cases are plated both for decorative purposes and to prevent tarnish and staining from contact with perspiration. Stampings used for machine parts or instrument parts normally neither receive nor require any corrosion protection.

Like CW617N (CZ122) the alpha-beta alloys are not suitable for service in environments conducive to rapid dezincification though their corrosion resistance is, in general, slightly superior. One particular purpose, for which the high tensile brass CW722R (CZ115) has been found inferior to the 'ordinary' leaded forging brass CW612N (CZ128), is for valves fitted to high pressure carbon dioxide cylinders. Following some failures of CW722R (CZ115) valves by stress corrosion cracking from the inside, laboratory stress corrosion tests in carbon dioxide plus water at high pressure produced similar cracking in valves of CW722R (CZ115) but not in CW612N (CZ128). The mode of cracking, both in service and in the laboratory tests, was transgranular and through the beta phase. Since it is evident that high tensile brass valves can sometimes fail by stress corrosion cracking in service with carbon dioxide, the standard material for carbon dioxide cylinder valves is now CW612N (CZ128).

DEZINCIFICATION-RESISTANT BRASSES

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. In the photograph of a stop tap, on ***page 59***, note the 'CR' mark indicating that fittings of the same type, supplied by the same manufacturer, have been tested for dezincification-resistance, as laid down in the EN Standard specifications for CW602N (CZ132), and are approved by the Water Regulations Advisory Scheme (WRAS).

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.

The photograph of a tee, on ***page 59***, shows a hot stamping in CW602N (CZ132) with Type A compression coupling ends (EN 1254: Part 2). The nuts on this type of fitting do not come into contact with the water and are usually of alpha beta brass. For fittings to be used underground, however, the nuts must be of CW602N (CZ132).

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. It is not easy, by this method, to achieve the degree of dezincification-resistance required to qualify for the 'CR' mark in the UK although the casting may meet the standard required for classification as dezincification-resistant brass in Scandinavia. Users requiring diecast fittings that are fully dezincification-resistant are advised to use only those bearing the 'CR' mark.

CASTINGS

The gravity diecasting brasses CC767S (DCB1) and CC754S (DCB3) are much used for tap bodies and similar objects required in large numbers but of too complicated a shape to be hot stamped. They are often plated for decorative effect but otherwise are used without special corrosion protection. Being alpha-beta brasses they are subject to dezincification in unsuitable environments, CC754S (DCB3) somewhat less than CC767S (DCB1) but it is worth repeating here, since one of the largest uses of brass gravity diecastings is for terminal taps, that terminal taps for service in meringue dezincification areas do not need to be dezincification-resistant, though stop taps do.

Pressure diecastings in PCB1 (no EN designation) are used when large numbers are required and it is desired to take advantage of the thinner wall sections achievable by this process. The copper content of PCB1 is slightly lower than that of CC767S (DCB1), and the thinner-walled pressure diecastings often cool more rapidly from the casting temperature. Both of these factors tend to give a higher beta content in the product, but any consequent difference in resistance to dezincification is marginal. Pressure diecastings in brass are, in any case, mostly used for purposes, such as instrument parts, where the environment will not cause dezincification. They are generally used unprotected but may be plated or painted for the sake of appearance.

High tensile brasses are used when the strength of the conventional cast 60/40 brasses may be inadequate. Of the conventional British alloys, the higher tin content and duplex structure of CC765S (HTB1) gives it much better corrosion resistance than the stronger CC762S (HTB3) 'beta' brass.

Bronze welding fillers

The filler alloys specified in BS 1724: 'Bronze welding by gas' are designated C2, C4, C5 and C6 in BS 1453: 'Filler metals for gas welding'. Each is an alpha-beta brass alloy containing approximately 40% zinc with between 0.2 and 0.5% silicon and an optional addition of up to 0.5% tin; C4 contains, in addition, small amounts of iron and manganese while C5 and C6 contain 10% nickel and 15% nickel to improve their mechanical properties.

As with other alpha-beta brasses, the possibility of dezincification has to be considered. C5 and C6 are used for joining ferrous materials, from which they will usually receive galvanic protection in a corrosive environment. C2 and C4 are used both for ferrous materials, which will provide galvanic protection, and for copper which will cause galvanic stimulation of corrosion. Consequently, while bronze welding is generally satisfactory for copper drainage lines and for copper plumbing systems handling water with little tendency to cause dezincification, it is not suitable for copper or copper alloy seawater or brackish water lines. For such service, and for plumbing systems generally, capillary brazed joints made with silver-brazing or copper-phosphorus brazing alloys are safer. The note of caution concerning plumbing systems generally is because the galvanic effect of a large area of copper acting upon a small area of joint filler can cause serious damage in waters that normally cause only an acceptable degree of dezincification in brass fittings. The larger the diameter of the copper pipe the greater this effect will be.

Nickel silvers

Nickel silver is available as sheet, strip, wire, stamping, extrusions, and hot stampings. It is the base metal on which silver is plated to give 'EPNS' for good quality tableware. It is also used for architectural purposes to give a warm, silvery-coloured facade, doorway or balustrade when required. Nickel silver sheet, extrusions in nickel brass (known as 'silver bronze') and nickel silver castings are used for these purposes - especially in prestige buildings. The Royal Institute of British Architects building in Portland Place, London, is perhaps the prime example, but many much more recent buildings also display nickel silver used to good effect. The combination of cold working, hot working and cast forms still offers exceptional scope for architectural craftsmanship.

Nickel silvers and nickel brasses show superior tarnish resistance and require no protection or special attention when used indoors, though uniform slight yellowing of the original silver-white colour will occur on the lower-nickel alloys. Outdoors, treatment with very light oil, wax polish or lacquer is required to prevent eventual development of a light powdery green patina. **Incralac** is recommended. One of the early uses made of this benzotriazole-inhibited lacquer was on the large wrought nickel silver gates of the Air Forces Memorial at Egham. Although situated facing south, on an exposed hilltop, in the flight path westward from Heathrow only 8km away, they were effectively protected by the **Incralac** for 10-12 years. Unfortunately, it was several more years before they were stripped and relacquered - using an uninhibited lacquer that has proved much less satisfactory.

An important specialised use of the 12% and 18% nickel silvers CW403J (NS104) and CW410J (NS107) is for relay contact springs in telecommunications and other equipment. For this purpose their spring properties, solderability and resistance to corrosion by the atmosphere, and by the acidic coronets liable to be generated from organic insulating materials in an enclosed space, are all important.

The leaded nickel silvers, CW404J (NS111), CW408J (NS112) and NS113 (no EN), are used where machinability, good appearance, corrosion resistance and wear resistance are required. Common examples are cylinder lock keys, screws, gears, pinions and other parts for clocks, cameras and musical instruments.

CORROSION RESISTANCE DATA

Introduction

The results of a survey of users' attitudes to brass showed that corrosion resistance was the most highly appreciated property. In average industrial, commercial and domestic environments, brass lasts well and is fit for purpose for many years, showing only a superficial darkening with age. In use in more aggressive environments, careful consideration has to be given to product design, material selection and finishing. This is true for all materials. The following section describes some of the corrosion mechanisms that can be encountered in industrial environments and techniques for controlling their effects.

TYPES OF CORROSION

GENERAL CORROSION AND TARNISHING

General corrosion and tarnishing are probably the manifestations of corrosion most readily recognised by the public. Typical examples are rusting of steel, the development of brown tarnish (and, under more severe exposure conditions, a layer of green corrosion product) on copper, and the widespread formation of small corrosion pits on unprotected aluminium - especially under semi-sheltered exposure conditions such as the underside of bus shelter roofs. Brasses show considerably greater tarnish resistance then copper with no tendency to severe general attack comparable to rusting or to significant pitting.

A domestic example which everyone takes for granted is the pins of electric plugs which remain free from corrosion, other than very slight tarnishing, almost indefinitely in indoor service. This safety-critical product remains reliable for many years.

In outdoor exposure conditions, especially where there is industrial pollution of the atmosphere or in situations very close to the sea, a heavier tarnish develops on most brasses. This eventually produces a thin deposit of brown-green copper compounds which, since it is adherent and spreads uniformly across the surface, helps to protect against further attack. Consequently, unless aesthetic considerations require the preservation of the original appearance of the brass, no protection is generally necessary. If it is desired to retain a bright appearance this may be achieved by regular cleaning or by lacquering.

Suitable lacquers for different conditions of service are discussed in ***Section 5***.

The information in this brief summary of some of the recommendations made for the uses made of brasses in contact with chemicals, building materials etc, is largely taken from E Rabald's Corrosion Guide.

Notes to Table 24

All copper alloys are rapidly attacked by ammonia in moist conditions, with the formation of a bright blue corrosion product, and contact should therefore obviously be avoided. Even in very low concentrations of ammonia, brass that is stressed by either residual or applied tension will spontaneously crack by 'stress corrosion', a phenomenon first observed many years ago and at that time called 'season cracking'. For failure to occur in this way, two conditions must apply: that the brass is under stress, and that ammonia is present (Mercury and moist chlorine may also cause similar failure). Internal tensile stresses caused by cold working, as in the cold drawing of tubes or cold bending of pipework, are sufficient to make brass susceptible to stress corrosion cracking. Under such circumstances a stress-relief heat treatment is advisable before such items are put to use in aggressive environments. Test methods to ensure that the heat treatment has been effective are detailed in relevant Standards.

Dry chlorine and very low concentrations of chlorine in solution, such as the dosing of seawater to prevent marine fouling, and biocidal additions made to swimming pool water, present no difficulties and no corrosion problems are encountered when brass components are used. Brass is completely unaffected by the full range of medical gases; likewise gaseous fuels, with the exception of acetylene, do not affect brass.

The duplex 60/40 alloys are satisfactorily used for the manufacture of acetylene control valves for welding and cutting equipment. However, the single phase alpha brasses containing over 64% of copper should not be used in contact with acetylene due to the likelihood of the formation of explosive copper acetylide.

Seawater can cause dezincification to occur in duplex brasses but, in heavy sections such as condenser and heat exchanger tube plates and propellers, the rate is low enough for them to give a good economic life. The single phase brasses, with an inhibiting arsenic addition, are widely used for tubing seawater cooled heat exchangers and condensers, and for the construction of seawater pipework for shipboard installations, in which applications they give excellent service. Dezincification-resistant brasses are also approved for through-hull yacht fittings.

The brasses are resistant to alkalis, organic acids, the full range of industrial solvents and refrigerants. However, brasses are not suitable for use in contact with ammonia or strong mineral acids such as nitric or hydrochloric. Foodstuffs do not corrode brasses significantly, but prolonged contact may cause a sufficient amount of copper pickup to occur to give the food an unpleasant, though non-toxic 'metallic' flavour. For this reason, it is normal practice to coat brass parts with either tin, nickel or chromium when they are to be used in contact with foodstuffs.

Lubricating oils, transformer oil, fuels and hydraulic fluids do not attack brass significantly. Copper pickup can accelerate the oxidation and consequent 'sludging' of some of these substances but normally commercial products contain anti-oxidants to prevent such problems arising. The biostatic nature of copper means that water-based lubricants do not become a health hazard due to the growth of micro-organisms.

Detergents and most cleaners in domestic use are quite compatible with brass and cause no problems. A few powerful domestic cleaners do, however, contain ammonia and while normal contact with these substances does not result in any noticeable attack, prolonged exposure, such as overnight soaking, should be avoided.

TABLE 24 – Applications of brasses in aggressive environments	
Chemical	**Remarks**
Acetic Acid	Admiralty brass used for centrifugal pumps handling 20%-100% acid at 20ºC.
Acetone	Valves.
Alcohol	Used for fittings in distillation equipment.
Amyl Acetate	Alpha brasses used for fittings in distillation plant.
Amyl Alcohol	Fittings in distillation plant.
Aniline	Used for condensers but risk of stress corrosion.
Barium Chloride	Fittings for neutral solutions to 100ºC.
Benzene	Used for valves and fittings even when sulphur content would cause marked corrosion on copper (0.34% quoted).
Boric Acid	Satisfactory for saturated solutions if air-free.
Butyl Acetate	Used for condensers and fittings.
Butyl Alcohol	Valves and fittings.
Calcium Chloride	More resistant than copper. 40% solution at 80ºC with air gives corrosion rate 15g/m^2 per day for brass. Used for valves, pipes.
Carbon Disulphide	Used for fittings, flanges, valves, etc. in extraction of crude sulphur with carbon disulphide.
Cement Mortar etc.	Portland cement and concrete produce no significant corrosion. Danger of stress corrosion from lightweight concrete foaming agents containing ammonia.
Chloroform	Cocks and valves handling dry Chloroform; wet Chloroform forms hydrochloric acid and causes corrosion.
Citric Acid	High copper brasses (15% Zn) as woven mesh baskets for centrifuges and for fittings.
Resin	Fittings, steam heated cocks and sieves in distillation of crude gum.
Coumarin	Fittings. Room temperature up to 100ºC.
Dextrose	Used for taps, valves and cocks handling solutions of dextrose and starch syrup up to 100ºC.
Dichlorodifluoromethane (Freon)	Used for valves and cocks.
Distillers Wash	Fittings and valves. Room temperature to 100ºC with pH greater than 3. Less liable than copper to blacken if hydrogen sulphide present.
Essential Oils	Fittings in distillation equipment. Avoid long contact since copper corrosion products spoil flavour and oxidation resistance.
Natural Fats	Insignificant corrosion of metal but minute traces of copper picked up catalyse oxidation and reduce quality and storage life.
Fatty Acids	Alpha brasses used for fittings and valves if air is excluded.
Formaldehyde	Alpha brasses - especially Admiralty brass - used for fittings, valves, pumps and piping.
Formic Acid	High copper brasses (15% Zn) for pumps and fittings up to 100ºC in absence of air.
Gelatine	Alpha brass used for heating coils - not for photographic gelatine.
Hydrogen Peroxide	Insignificant corrosion but traces of copper catalyse decomposition of peroxide.
Hydrogen Sulphide	Brasses - especially those containing tin - show much superior resistance to hydrogen sulphide and hydrogen sulphide contaminated gasoline than copper.
Methyl Alcohol	Fittings and valves.
Nitroglycerol	Brass brooms for sweeping up explosives.
Nitrotoluene	Paddle wheels for pumps.
Oak Bark Extracts	Vessels, piping etc. Superior to copper.
Oxalic Acid	Alpha-beta brasses unsatisfactory but brasses containing 80% or more copper give low corrosion rate if air is excluded.
Phenol	Fittings, valves, heat exchangers. Corrosion rate 0.01g/m^2 per day at room temperature. 1.0g/m^2 at boiling point.
Phosphoric Acid	Corrosion rates in mm/year for 70/30 brass: Acid Concn. 15ºC 50ºC 75ºC 20%H_3PO_4 0.27 0.14 0.27 40%H_3PO_4 0.11 - 0.09 60%H_3PO_4 0.02 - 0.04 Pipes of CuZn33Pb0.5 used for 10% H_3PO_4 at 60ºC - no corrosion after 22 months.
Plaster	Does not affect brass when dry but is corrosive while still wet. Walls should be allowed to dry out before brass switchplates are installed unless the plate bases are well protected.
Potassium Carbonate	Alpha brasses satisfactory up to boiling point at all concentrations. Alpha beta brasses attacked at high temperatures.
Potassium Hydroxide	Heat exchanger tubes of admiralty brass. Aeration and higher temperatures (greater than 100ºC) increase corrosion rate.
Pyridine	Sometimes used for condensers but some risk of stress corrosion cracking.
Sodium Carbonate	See Potassium Carbonate.
Sodium Hydroxide	Pumps and valves, room temperature to 60ºC at all concentrations up to 30%. Corrosion rates in presence of air at room temperature: CuZn29Sn1 4% NaOH 3.3 g/m^2/day CuZn15 4% NaOH 1.1 g/m^2/day CuZn40Pb3 33% NaOH 0.0 g/m^2/day
Sodium Hypochlorite	Room temperature solutions under 2%.
Sodium Silicate	Only high copper (15% zinc) brasses satisfactory.
Sodium Sulphate	Piping and valves. All concentrates up to BP.
Sodium Sulphite	Only alpha brasses satisfactory.
Drying Oils & Varnishes	Used for cocks and valves.
Sugar Refineries	CuZn30 for evaporator tubes. Occasional trouble from stress corrosion cracking by ammonia in beet sugar refineries.
Sulphurous Acid	Strong solutions attack but solutions of sugar containing some sulphur dioxide corrode only slowly. Used for valves in sugar and cellulose industries.
Turpentine Oil	Condensers, fittings, pipes and pumps.

The influence of zinc content

Because of their higher zinc content, alpha-beta brasses generally show better tarnish resistance than alpha brasses under mild or moderately severe exposure conditions but, under more severe conditions, may be affected by dezincification corrosion as described later.

The influence of alloying additions

The nickel silvers are more resistant to tarnishing than ordinary brasses, the least tendency to tarnishing being shown by those of highest nickel content. Under indoor exposure conditions the tarnishing results only in the development of a yellow tinge in place of the original silvery appearance, but long-term outdoor exposure can produce darker surface staining and, eventually, a deposit of light green corrosion products.

Aluminium also confers increased tarnish resistance. Aluminium brass consequently retains its original appearance much longer than other alpha brasses though, in common with other brasses containing arsenic, it eventually develops a blackish tarnish rather than the usual brown.

Staining during transport or storage

An occasional problem with brass semi-finished products, such as sheet, is the development of patchy brown areas of tarnish during transport or storage. This staining is sometimes due to sulphide but more often simply to rain or condensed water drawn in between the brass sheets in a pack, or between adjacent turns in a coil. The unusual conditions of water retention in the narrow gap give rise to staining which would not occur under normal fully exposed conditions. For many manufacturing purposes the presence of slight water or sulphide staining on brass sheet or strip stock is not important since it does not represent any significant damage except for its effect on appearance. It is, however, obviously sensible not to leave sheet or strip stock unnecessarily exposed to the weather. Manufacturers often take additional precautions to prevent staining in transit and storage by the use of the inhibitor benzotriazole (bta), either by direct application to the metal or by interleaving with bta-impregnated paper. Methods of using bta to inhibit tarnishing and staining of brass products are discussed in ***Section 5***.

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.

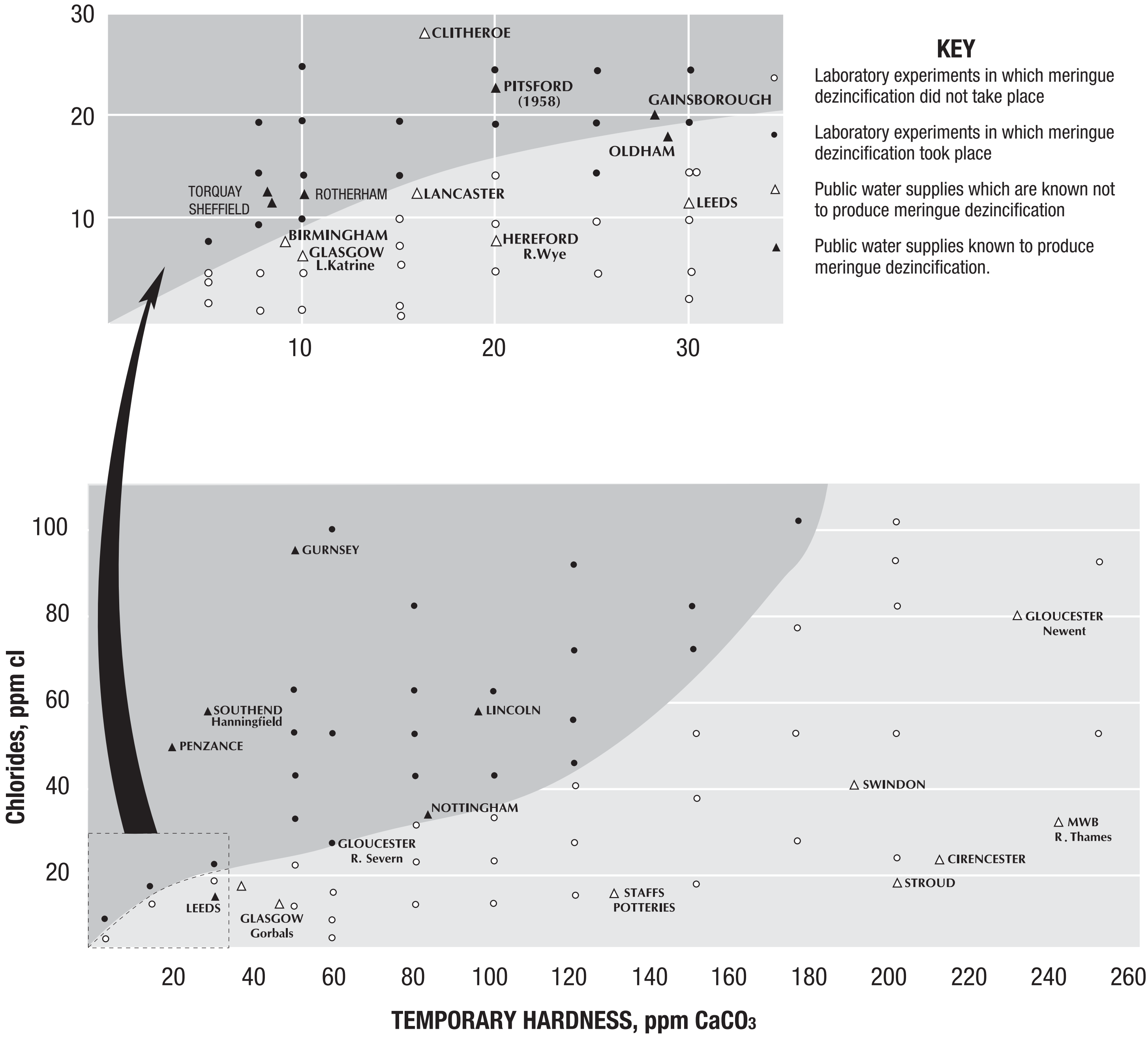
Conditions for dezincification

The possibility of spots of dezincification occurring as a result of long exposure to polluted atmospheres has already been mentioned. Service conditions that can give rise to more significant dezincification usually involve acidic or highly saline conditions. These include for example exposure to waters with a pH below 7. Such waters are not normally used for public supplies in the UK but some private supplies, mine waters and industrial rinse waters are sufficiently acidic to cause dezincification in susceptible brasses.

Service in seawater or brackish water is also likely to produce dezincification in susceptible brasses, as is burial in corrosive soils such as acid peat, salt marsh, waterlogged clay or made-up ground containing cinders.

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. Water compositions falling within the shaded area in ***Figure 13*** are liable to cause meringue dezincification of alpha-beta brass fittings. The boundary between the shaded and clear area is not precise and any water composition close to the boundary should be regarded as potentially liable to cause meringue dezincification. It should also be noted that waters with a composition just within the shaded zone can cause as rapid dezincification as waters with compositions well within it.

FIGURE 13 – Relationship between chloride to carbonate hardness ratio and dezincification aggressiveness of waters



The water supplies to most parts of the UK, including almost all the major centres of population, are of compositions that do not give rise to meringue dezincification. The waters that do give trouble are certain moorland-derived supplies (but by no means all such waters) and lowland river supplies that have been treated by the lime-softening process. Water authorities in areas where water liable to cause meringue dezincification is supplied usually advise the use of dezincification-resistant materials for water fittings. However, this advice does not generally apply to terminal taps since the flow conditions in these are such that the hollow shells of meringue corrosion product do not build up.

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; the British Standards covering the construction of copper water cylinders specifically require the bosses to be of dezincification-resistant materials.

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. 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 500-525°C, 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 by repeating the original treatment.

Tests for dezincification resistance

EN Standards specify a test for resistance of samples of CW602N (CZ132) brass to dezincification. This involves exposure to a 1% solution of cupric chloride at 75ºC for 24 hours followed by examination of sections to establish the maximum depth of any dezincification that has occurred. The sample passes the test if the maximum depth of dezincification in a forging does not exceed 100μm. A maximum depth of 200μm is permitted in the longitudinal direction of extruded material. The European Standard version of this test is referenced in EN ISO 6509 and the maximum permitted depths of dezincification are defined in product standards.

This test and these criteria for acceptance are also applied by the Water Regulations Advisory Scheme (WRAS) to fittings made from brasses other than CW602N (CZ132) which the manufacturers claim to be resistant to dezincification. Water fittings accepted by WRAS are listed in their publication ***'Water Regulations Guide'*** - details may be found on ***www.wras.co.uk***.

Fittings described therein as being of dezincification-resistant brass have been subjected to the cupric chloride test specified for CW602N (CZ132) and have performed satisfactorily. They are identified by the mark 'CR' embossed or engraved on the side of the fitting (***see page 59***).

It should be noted that there are some proprietary brasses that are described as 'dezincification-resistant' by the manufacturers, and would be accepted as such in Scandinavia where a maximum depth of dezincification of 400μm in the cupric chloride test is permitted, but which cannot meet the 100μm maximum depth of attack which would make them acceptable as dezincification-resistant fittings in the UK. Such fittings are not listed as dezincification-resistant by the WRAS and do not carry the 'CR' mark.

Historical background to the development of DZR brass

Two types of brass are in common use. The higher copper brasses generally contain over 63% copper and have a single-phase (alpha) structure. These are used particularly for their good cold forming properties as in deep drawing or in tube drawing. For optimum hot working properties, required for the manufacture of water fittings by hot stamping, brasses of a lower copper content with a duplex (alpha-beta) structure are used.

Dezincification was first recognised as a serious problem in the alpha brass used for ships condenser tubes, but alloying additions were developed which made the material immune. The same additions do not succeed with the duplex brasses because of the presence of beta phase as well as the alpha.

Dezincification first became a recognised problem with duplex brass water fittings in the late 1950s, when certain water authorities banned the use of duplex brass fittings after experiencing rapid blockage of hot water fittings as a result of dezincification. Research carried out by the British Non-Ferrous Metals Research Association (BNFMRA, later the BNF Metals Technology Centre) in collaboration with Copper Development Association and the British Waterworks Association established the relationship between the composition of supply waters and their liability to produce dezincification. The number of areas affected was not large and the problem was overcome by manufacturers developing ranges of fittings in copper or gunmetal which are immune to dezincification and could be specified for use in the areas concerned.

Later developments in the water supply industry, involving new large-scale schemes for water abstraction and treatment and facilities for interchange of water between different supply areas, revived concern about the risk of dezincification in water fittings. In 1969 the brass industry, together with the BNF, set up a further programme of research aimed at developing a brass suitable for the manufacture of water fittings by hot stamping but resistant to dezincification. Over the next five years this research established the range of alloying additions and the heat treatment that would provide a brass which, at the hot stamping temperature, would contain sufficient beta phase to forge satisfactorily but could by subsequent heat treatment, be converted to an all-alpha structure protected against dezincification. The laboratory work was followed by practical evaluation of the material in a wide range of waters and is described in a paper by J E Bowers and colleagues. Their work culminated in 1980 in the publication of amendments to BS 2872 and 2874 defining the composition, mechanical properties, heat treatment and dezincification testing criteria for forgings and extruded bar in CW602N (CZ132).

The results of standard tests of the acceptability of these fittings show them to be completely safe for handling potable water.

Although CW602N (CZ132) was developed primarily for resistance to meringue dezincification in domestic plumbing systems, its use is not restricted to fresh water service. Following a one-year test of a submerged seawater filter, in which suspension lugs machined from CW602N (CZ132) bar showed no dezincification, while a Naval brass plate containing less than 10% beta was dezincified to a depth of 150µm, CW602N (CZ132) has been accepted by Lloyd's Register of Shipping, Yacht and Small Craft Department for through-hull fittings in seawater service.

Central heating systems

Water in these closed-circuit systems is de-aerated during heating. This suppresses dezincification, even if the water used to fill the system initially is one known to cause dezincification in aerated plumbing systems. Consequently radiator valves, pipe fittings etc. for central heating systems do not have to be of dezincification-resistant brass.

EROSION CORROSION

After dezincification had been eliminated by the introduction of arsenic-inhibited alloys, the next problem to arise in brass condenser tubes for steam turbines was inlet-end impingement attack associated with higher water speeds. Brasses, like all metals and alloys other than gold, platinum and a few other very expensive 'noble' metals, owe their long-term corrosion resistance to the protective effect of thin, adherent films of corrosion products which form during the early life of the component and form a barrier between the metal surface and its corrosive environment. Water flow conditions which produce high water velocities at the protected metal surface can generate shear forces sufficient to cause local removal of the protective corrosion product film, exposing bare metal to corrosion, and to sweep away the fresh corrosion products resulting from this exposure before they can form a new protective layer. Such conditions are obviously associated with high average water velocities, but arise particularly where excessively turbulent flow – as often occurs at the inlet ends of heat-exchanger tubes – gives rise to local water velocity much higher than the average flow rate. The severe local attack that results is commonly termed impingement attack or, more accurately, since it is the result of corrosion of the metal combined with erosion of the corrosion product film, erosion corrosion.

Recognition

Metal that has suffered erosion corrosion exhibits a smooth water-swept surface usually without corrosion products. Localised attack, often associated with local turbulence immediately downstream of an obstruction, forms individual water-swept pits, undercut on the upstream side and often horseshoe-shaped with the open end of the horseshoe pointing downstream. More widespread attack produces a broad smooth surface in which small horseshoe-shaped features are often visible.

Apart from its characteristic form, erosion corrosion can often be recognised by its occurrence in regions where local turbulence might be expected. Common situations, apart from the inlet ends of condenser and other heat exchanger tubes, are immediately downstream of elbows, tee pieces and valves – particularly partly-closed valves.

Avoidance

Choice of alloy

The problem of inlet end impingement in seawater cooled condenser tubes was largely cured by the invention of Aluminium brass. This alloy, first used for condenser tubes in 1928, remains one of the preferred alloys for this purpose, though in competition with 90/10 and 70/30 copper-nickel and more recently with titanium. *Table 25 on page 54* indicates the relative resistance of Admiralty brass, Aluminium brass, 90/10 copper-nickel and 70/30 copper-nickel to erosion corrosion in seawater in terms of recommended maximum design water velocities for tube-and-shell condensers or heat exchangers of conventional design.

TABLE 25 – Resistance of copper alloy heat exchanger tubes to erosion corrosion in seawater	
Alloy	**Max water speed - (m/s)**
Admiralty brass CW706R (CZ111)	3.0
Aluminium brass CW702R (CZ110)	4.0
90/10 copper-nickel CW352H (CN102)	3.5
70/30 copper-nickel CW354H (CN107)	4.5

Slightly different figures are to be found in the literature, with 90/10 copper-nickel sometimes shown as marginally superior to Aluminium brass. The two alloys are certainly very similar in resistance to erosion corrosion in seawater - small differences in pollution or operating conditions tending to favour one or the other. In polluted conditions (i.e. when the seawater contains sulphide) experience of the relative performance of these two alloys in service is still variable - some users finding Aluminium brass superior and others favouring 90/10 copper-nickel. It is often stated that for such conditions 70/30 copper-nickel CW354H (CN107) is superior to either, but experience in Japanese coastal power stations shows Aluminium brass to be the best of the three alloys under the conditions obtained there, though still not recommended for badly polluted waters. The data in ***Table 25*** indicates that, while the erosion corrosion resistance of Admiralty brass in seawater is inferior to that of Aluminium brass, the substantially higher water speed required to produce erosion corrosion in fresh water results in Admiralty brass being perfectly suitable for fresh water cooled condensers and heat exchangers. It is therefore the alloy most commonly used for fresh water heat exchange service and is to be preferred to Aluminium brass for this purpose since Aluminium brass is liable to pitting corrosion in some fresh waters.

Design features

Having selected the correct alloy for service in conditions where there is a possibility of erosion corrosion occurring, it is important also to eliminate design features likely to induce excessive turbulence in the water flow. To this end sharp changes of direction should be avoided by using swept bends rather than elbows, and swept tees or Y-pieces rather than right-angled tees.

Partially open valves not only induce turbulence in the water flow downstream but may, because of the pressure drop across the valve, cause air bubbles to come out of solution; these can cause erosion corrosion to occur at water velocities below those at which it would occur in their absence. Flow control valves should therefore be sited where there will be least danger of erosion corrosion occurring as a result of air release and downstream turbulence. They should always be on the outlet side of heat exchangers rather than the inlet side and should, if possible, be followed by a straight length of pipe in which the water flow can become smooth again before the next flow-disturbing feature is reached.

Other protective measures

When Aluminium brass was first introduced as a condenser tube alloy, it was recognised that it formed the best protective film only if iron compounds were present in the cooling water. However, since water boxes and cooling water mains were at that time of unprotected or poorly protected cast iron, there was no shortage of iron corrosion products. Later, with the adoption of coated water boxes and pipes, occasional unexpected failures of Aluminium brass condenser tubes by erosion commenced. It was then found that by providing iron in a suitable form - principally by injection of **ferrous sulphate** into the cooling water - the optimum performance of the Aluminium brass could be ensured.

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

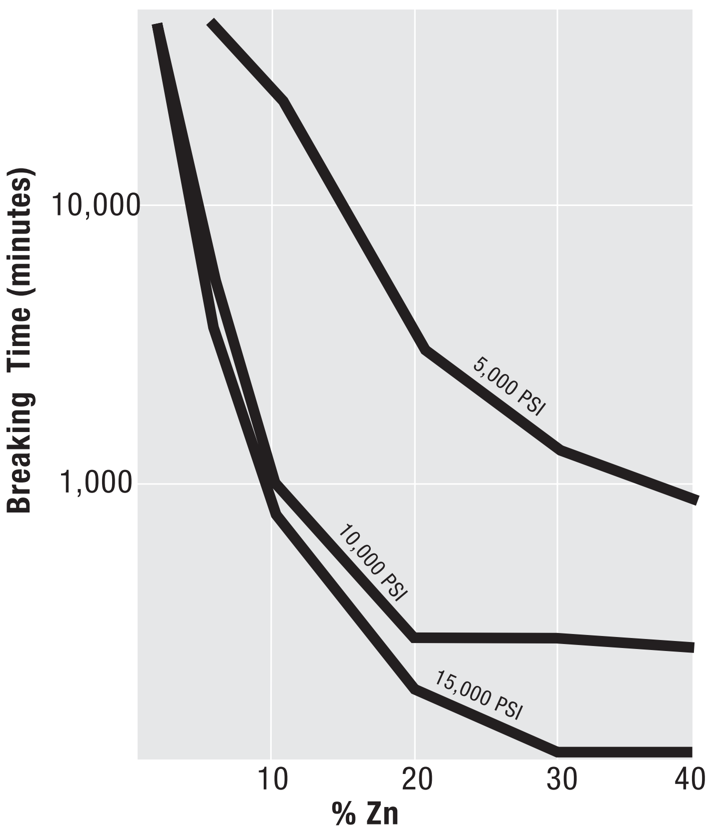
D H Thompson and A W Tracey made a detailed study of the effect of stress level and zinc content on the time for failure by stress corrosion cracking to take place in axially loaded specimens exposed to air containing 10% ammonia and 3.7% water vapour at 35ºC. This is an accelerated test giving failures in much shorter times than would be experienced under most service conditions; the results, presented in ***Figure 14***, 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 better stress 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.

FIGURE 14 – Effect of zinc content on stress corrosion susceptibility of brass



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 ½ 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.

INTERGRANULAR CORROSION

Intergranular corrosion is a form of attack in which corrosion proceeds preferentially along grain boundaries, with the result that relatively little total corrosion can cause serious loss of strength. As a possible problem with brasses in service it is restricted to Aluminium brass of abnormally high phosphorus content in service in sulphide-polluted water. Provided that the phosphorus impurity level is below 0.015% no trouble is experienced. No maximum for phosphorus is given in standards for Aluminium brass but commercial material is normally well below the 0.015% level.

PITTING CORROSION

Pitting corrosion, which some years ago was a rather common cause of failure of copper water pipes in some districts, is not a serious problem with brasses. Alpha brasses inhibited against dezincification can, however, suffer pitting under some circumstances. As in copper, the pitting produces very localised attack, often in approximately hemispherical form beneath a small adherent mound of green corrosion product. If this mound is carefully removed, crystals of red cuprous oxide can usually be seen in the cavity. Service in slow-flowing sulphide-polluted seawater is most likely to produce pitting in Aluminium brass but this alloy sometimes develops pitting corrosion in fresh water service. The number of examples of this that have been reported are too few to establish the range of water composition and service conditions that are necessary to cause it and it is therefore advisable to use Admiralty brass instead of Aluminium brass for all fresh waters.

GALVANIC CORROSION

When different metals or alloys are in contact with one another in an electrolyte (seawater, fresh water, rain, dew, condensation) they affect one another's resistance to corrosion. Usually one - the more 'noble' - will cause some degree of accelerated attack (galvanic corrosion) on the other and will itself receive a corresponding degree of protection. ***Figure 15*** lists a number of common metals and alloys in their order of nobility in seawater and may be used to give some indication of the possible galvanic corrosion effects of coupling brasses to other metals. In general, the further the other metal is from the brasses in the electrochemical series, the greater the corrosive effect will be.

The relative positions of metals and alloys in seawater are indicated in ***Figure 15***. these may change in a different environment or even under prolonged stagnant conditions in seawater, where the passive films on stainless steels could break down and sulphide films could form on the copper alloys. The series shown can, however, be taken as representing the majority of service conditions.

Among the brasses themselves there are small differences of electro-chemical potential, those of highest copper content being more noble. In particular, the alpha brasses are somewhat more noble than the beta brasses; this shows itself in the tendency for the beta phase in alpha-beta brasses to suffer preferential attack but the difference between the two is not great.

Relative area effects

The extent to which additional (galvanic) corrosion takes place on brass coupled to a more noble metal depends, not only upon the difference between them in the galvanic series, but also upon their relative areas, exposed to the seawater or other electrolyte, sufficiently close to one another for significant corrosion currents to flow through the electrolyte between them. If the effective area of more noble (cathodic) metal greatly exceeds that of the brass, galvanic attack on the brass may be severe but, if the area of cathodic metal is smaller than that of the brass, the effect will be negligible. For example, stainless steel or Monel trim in a brass valve is quite acceptable, but brass bolts on a stainless steel structure would certainly not be.

In a water system with brass valves and fittings and copper or stainless steel pipes, the total area of the cathodic metal greatly exceeds that of the brass but, because of the limiting influence of the electrical resistance of the water, significant corrosion currents flow only between the brass and the copper or stainless steel very close to it. Consequently the effective areas of brass and copper or stainless steel are not very different and the extent of any galvanic action between them is small. A brass fitting in a copper or stainless steel tank, on the other hand, would come under the influence of a much larger area of cathodic metal and severe galvanic attack would be expected.

Similarly, naval brass tubeplates can be used with copper-nickel tubes in seawater cooled condensers because the effective cathodic area of the tubes does not extend more than a few tube diameters from the tube plate surface. If, however, the copper-nickel tubes are replaced by titanium, which is much further from the brasses in the galvanic series, deep attack on the tubeplate will occur.

FIGURE 15 – Galvanic series for common metals and alloys in seawater

Corrosion susceptibility of metals

Most susceptible to corrosive attack (less noble)

Magnesium and its alloys
Zinc and its alloys
Aluminium and its alloys
Cadmium
Mild steel
Cast iron
Stainless steel, 13% Cr, type 410 (active)
Lead-tin solder, 50/50
Stainless steel, 18/18 type 304 (active)
Stainless steel, 18/18/3 Mo, type 316 (active)
Lead
Tin
BRASSES
Gunmetals
Aluminium bronzes
Copper
Copper-nickel alloys
Monel
Titanium and its alloys
Stainless steel, 18/8, type 304 (passive)
Stainless steel, 18/8/3 Mo, type 316 (passive)
Silver
Gold
Platinum

Least susceptible to corrosive attack (more noble)

It can be seen from this general table that brasses are more noble than other commonly used engineering materials. The listing represents the galvanic behaviour of metals in seawater. Where dissimilar metals are in bimetallic contact, the one higher in the table will corrode preferentially. Actual performance depends on the surface films formed under conditions of service. On exposed surfaces the free oxygen in the water ensures a passive film on many metals. In crevices at fastenings, or under attached biofouling, oxygen may be depleted and passive films not formed. This explains the occasionally anomalous behaviour of stainless steels. Similar considerations apply in other media such as acids which may be oxidising or reducing in nature.

(Ref: 'Guide to Engineered Materials', ASM, Ohio, 1986)

Beneficial effects of galvanic corrosion

Just as coupling to a metal above it in the galvanic series will generally cause additional corrosion of brass, coupling to a metal below it can reduce attack. The prime example of this is the use of galvanic anodes for cathodic protection. A less obvious example is the successful use of high tensile brass spindles in cast iron valves. In gunmetal valves the galvanic action between an HTB spindle and the valve body causes accelerated dezincification of the spindle, but in a cast iron valve the galvanic action reduces the corrosion of the spindle and this combination is generally satisfactory in service.

Prevention by insulating or coating

It is possible, but often wrongly assumed to be easy, to prevent galvanic corrosion by electrically insulating the more noble and less noble metals from one another. The difficulty arises because the metallic connection (more accurately, the electronically-conducting connection) between the two members of the galvanic couple does not have to be by direct contact between them. The possibility of galvanically accelerated dezincification of an alpha-beta brass valve bolted to a flange on a large copper vessel is not eliminated, or even reduced, simply by fitting an insulating gasket between the two, since they will remain connected through the bolts. It is necessary also to fit insulating washers under the bolt heads and insulating bushes in the holes drilled in the flange of the valve. Even then there remains the possibility of the valve and vessel being in electronically-conducting connection with one another though the pipework and supporting steel work.

Whenever steps are taken to insulate the two members of a potential galvanic couple from one another it is important to check, before they are brought in contact with the water or other electrolyte for which they are to be used, that the desired absence of electrical continuity between them has been achieved.

As an alternative to insulating the two members of a couple from one another, one or both of them can be isolated from the electrolyte by coating or painting. In some cases the anodic member needs to be painted or coated to protect it from corrosion that would take place even in the absence of the galvanic effect - for example ferrous water boxes of condensers with brass tubes and tubeplates. In principle, however, galvanic corrosion is more safely prevented by painting or coating the cathodic member. This follows from the relative area effect. If a coating applied to the anodic member is only 90% complete, the total amount of galvanic corrosion will remain the same but it will all be concentrated on the exposed 10%, i.e. the situation will actually have been made worse. If, on the other hand, a coating applied to the cathodic member is 90% complete the total amount of galvanic corrosion will be reduced by 90%.

BRASSES								
Property	Units	90/10	80/20	Aluminium Brass	70/30	60/40	60/40 + Lead	High Tensile Brasses
Density (room temperature)	g/cm^3	8.8	8.6	8.3	8.5	8.4	8.5	8.1 - 8.4
Coefficient of linear expansion (20ºC - 200ºC)	x10^{-6} per ºC	18	19	20	20	21	21	19 - 22
Specific heat (thermal capacity) at room temperature	J/gºC	0.38	0.38	0.3	0.38	0.3	0.38	0.38
Thermal conductivity at 20ºC at 200ºC	 W/mºC W/mºC	 190 225	 140 168	 101 127	 120 147	 125 142	 120 –	–
Electrical conductivity (volume) at 20ºC (annealed) at 200ºC (annealed) at 20ºC (cold worked)	 %IACS %IACS %IACS	 44 33 40	 32 25 27	 23 18 –	 28 22 22	 28 21 –	 28 – –	6 - 19
Electrical resistivity (volume) at 20ºC (annealed) at 200ºC (annealed) at 20ºC (cold worked)	 μΩm μΩm μΩm	 0.039 0.053 0.043	 0.054 0.070 0.064	 0.075 0.096 –	 0.062 0.079 0.078	 0.062 0.082 –	 0.062 – –	0.055 - 0.096
Modulus of elasticity (tension) at 20ºC (annealed) at 20ºC (cold worked)	 x10^3 N/mm^2 x10^3 N/mm^2	 127 120 - 127	 121 106 - 121	 110 –	 117 99 - 117	 104 95 - 104	 98 –	93 - 100
Modulus of rigidity (torsion) at 20ºC (annealed) at 20ºC (cold worked)	 x10^3 N/mm^2 x10^3 N/mm^2	 46.5 44.0 - 46.5	 44.0 41.5 - 44.0	 40.0 –	 41.5 37.0 - 41.5	 39.0 35.0 - 39.0	 30.0 –	–

NB: The range in modulus values for cold worked material corresponds to the range of cold worked tempers.

TABLE 26 – Physical properties of brasses

Hot Stampings – examples

Selection of components made by hot stamping

This selection shows the complexity and variety of shapes and wall thicknesses that can be achieved by hot stamping to near-net-shape.

(Copper Development Association (Pty) Ltd, South Africa)

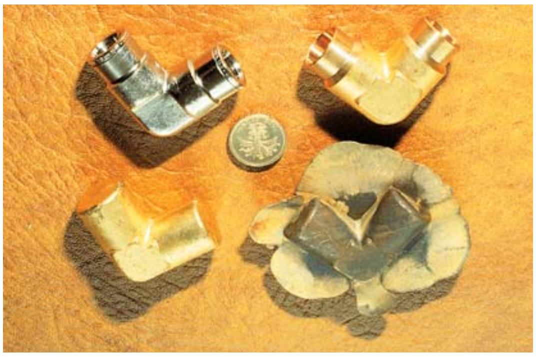
Union nut

These fittings could easily be produced from solid rod, hollow rod or from hot stampings. For reasonably long production runs hot stampings are the most cost-effective choice. Machining is only required to thread the finished nuts.

(Delta EMS Ltd)

Pneumatic power fitting

This shows the succession of stages in this low cost production method. After hot stamping, the flash is cleaned off, the component bores are drilled through and the important exterior dimensions are machined. Finally, it is finished by plating and will give many years of reliable service in a variety of environments.



(Norgren Martonair Ltd)

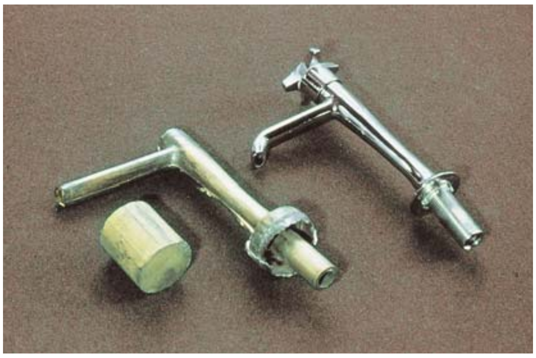
Dezincification-resistant brass – stop tap and tee

Where local water is known to be aggressive it is recommended that water supply fittings should be made from dezincification-resistant brass, designated in wrought form as CW602N (CZ132). Only if the product is assured to pass the stringent EN ISO 6509 test, is the special ‘CR’ mark used.

(IMI Yorkshire Fittings)

Water taps

Depending on size and design, taps may be made by gravity die casting or from hot stampings. Complex coring is possible in the castings. Hot stampings can be cored to some extent and have the advantage of having a wrought structure that allows thin-walled, strong, elegant designs. The illustration shows a slug cut from extruded bar ready for re-heating, the intermediate hot stamping and a finished, plated tap.



(Armitage Shanks)

Strip and Wire – examples

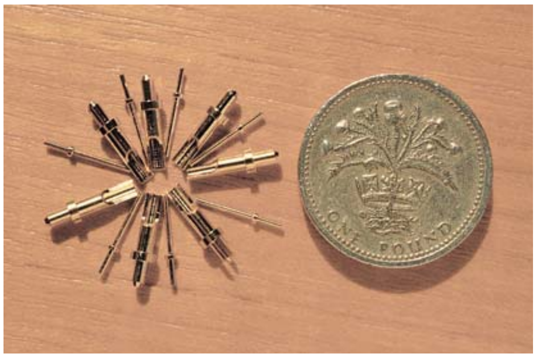
Selection of fasteners made from drawn wire stock

The production process would involve shaping, heading, thread rolling, forming and cutting to length. This gives a range of strong, cheap, corrosion-resistant components.

(Delta Extruded Metals Co Ltd)

Precision terminals

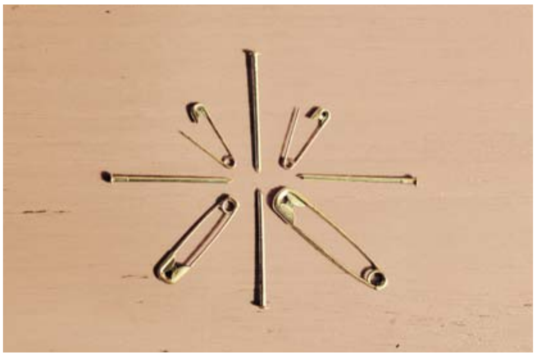
These miniature electronic terminals are made cheaply but to a high standard of precision and reliability by the million to meet the needs of manufacturers of quality electronic equipment.



(Greenpar Jubilee Ltd)

Pins and safety pins

Selection of components made from brass wire showing good use of strength, ductility, formability and surface finish.



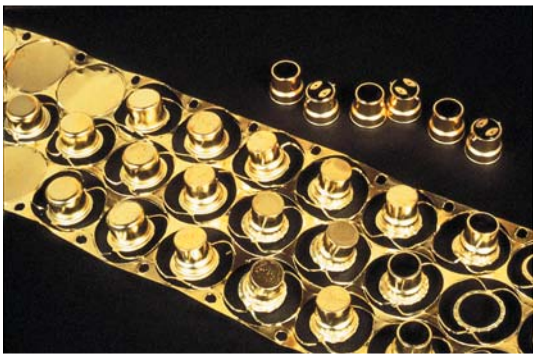
(United Wire Ltd)

13 amp plug

For economic production of these critical safety items, brass is used to make the pins to ensure a long, trouble free life. Brass does not corrode in service, has good strength, conductivity and resistance to wear as well as being easy to manufacture. Some makers machine pins from long coils of rectangular rod, others cut pins from an extruded profile that requires less machining.

Light bulbs

Good quality light bulbs have brass caps that will last the life of the bulb without corroding or sticking in the holder. They are made by repetition stamping from brass sheet by a rapid succession of operations that index the strip, preform, finish and detach the caps. The webbing scrap is, of course, recycled.



(Lamp Caps Ltd)