Section 5 – HOW TO MAKE IT IN BRASS

FABRICATION AND JOINING

Because of their excellent ductility, machinability and ability to be joined by riveting, welding, soldering and brazing, the manufacture of assemblies from most brasses is very economical. The technology involved is briefly covered in this section with more detail on brazing and welding included in CDA Publication 98.

FORMING BRASS

Bending

The minimum bend radius for forming parts cut from sheet or strip depends on the alloy, the temper, and the direction of the bend in relation to the rolling direction. Minimum bend test requirements are specified in EN 1654.

Riveting and cold forming

The single phase alloys can be readily riveted-over or used to manufacture rivets and cold formed parts. When components are being stamped from strip it is useful to have good liaison between the designer of the tooling and the materials manufacturer to facilitate the expected long runs of components with clean edges, reliable bends and good depth of draw.

Rivets, pins, screws and similar items are mass produced from wire by cold heading, up to 30,000 items an hour being possible. CW508L (CZ108) is normally chosen for its good strength and relatively low cost but, for greater ductility, CW505L (CZ106) can be used. '**Heading limit**' is the ratio of the maximum head diameter to the original wire, this value peaking at 17% zinc (see *Figure 11, page 41*). '**Upset ratio**' is the ratio of the length of wire that can be upset to the original wire diameter. For brass the maximum value is normally up to 2.3 for a single blow machine or 4.5 for a two-blow header.

The duplex alloys, in particular those containing lead, have limited cold ductility. For items which are required to be machined from bar, and also subsequently cold formed therefore, the higher copper, lower lead content alloys, for example CW606N (CZ119 or CZ131), should be used. Small screws may be produced by cold heading wire blanks followed by thread rolling. Wire may also be used for the production of circlips and zip fasteners.

Deep drawing and spinning

The single phase alloys, in particular CW505L (CZ106, 70/30), can be readily shaped by either of these processes, with appropriate interstage annealing operations if the total deformation is severe. For the manufacture of many items the purchaser should specify 'Deep Drawing Quality (DDQ)' brass which has a closely controlled hardness, grain size, surface finish and limited directionality of properties e.g. hardness less than 80HV, average grain size less than 0.03mm. Manufacturers of eyelets and ferrules from CW507L strip of 0.025mm and less prefer a combination of grain size 0.020mm with a hardness of 90HV maximum. For the relationship between hardness and grain size see ***Figure 12, page 42*.**

The 'Limiting drawing ratio' (Blank diameter/cup diameter) for CW505L is normally up to 2.2 for a single draw.

Coining

As a closed die squeezing operation carried out cold, all surfaces of the blank are confined or restrained in a coining operation. This results in a good impression of the die on the item. Zip fastener teeth can be produced at 100,000 per hour in alpha brasses from CW508L (CZ108) to CW502L (CZ102) using this technique.

An 80/20 brass containing nickel is used for the manufacture of British pound coins.

Spring winding

Having good electrical conductivity and being non-magnetic, brasses are ideal for the manufacture of springs. For wire spring design calculations, the modulus of rigidity (torsion) 'G' for copper alloys can be taken as 40% of the value of Young's Modulus (E). Torsional elastic limits are normally about 45% of the tensile strength. Further information on spring design is included in CDA TN12.

Impact extrusion

The 70/30 brass and gilding metals may be formed into thin-walled cans and tubes by this process, starting with fully annealed material. Companies specialising in this type of work should be consulted for the potential of the process as applied to brass.

Hot rolling

Plate is made by hot rolling cast slabs of brass in order to break up the coarse cast structure and give good strength and ductility. Due to the finishing temperature being variable and dependent on the final thickness, plate is normally sold in the 'as manufactured' condition. Hot rolled plate is also used as the starting stock for cold rolling to sheet and strip.

Extrusion

Billets are cut from logs cast fully- or semi-continuously or statically and reheated for extrusion through dies that may be round or shaped to give rod, square, hexagon or special profiles as required. The use of a mandrel allows hollow extrusions to be produced. Normally, the brasses extruded are the duplex materials which have good ductility at hot working temperatures.

Hot Stamping

Using relatively cheap shaped dies, hot stamping is a very economical process for repetition production of brass components from 20g up to around 3kg each. This process gives a near-net-shape needing very little further finishing. Dies can be made as simple opposed shapes or fitted with further cores to suit the need for hollows.
For further information see CDA Publication 103.

HEAT TREATMENT

As for all production techniques, with all heat treatment operations care should be taken to ensure good control of the process. The recommendations given are approximate and need to be refined with experience. Temperatures and times of treatment vary with batch size, metal composition, extent of cold work, furnace characteristics and temperature measurement techniques.

Annealing

When cold worked brass is progressively heated, the first effect, at about 250ºC, is for the internal stresses to be relieved. This prevents stress corrosion cracking subsequently occurring and also minimises the amount of distortion which may occur during machining. This low temperature heat treatment, which should be applied for ½ to 1 hour, is known as 'stress-relief annealing' and has little, if any, measurable effect on the mechanical properties of the material. The improved strength due to the cold working is therefore retained.

As the temperature is increased further, a rather more fundamental change occurs at about 400ºC and above and the material starts to 'anneal' or soften with time at temperature. The strengthening effect of the cold working is progressively lost, until at about 500ºC the alloy is in the fully annealed condition. Restoration of the cold worked properties can then only be achieved by further cold work. Due to the volatility of the zinc at the surface of the brass, it is not easy to anneal in a batch furnace with a 'bright' finish solely by the use of a controlled furnace atmosphere, although strip is now commonly continuously annealed during production. When designing components which will be exposed to temperatures of 400ºC or above during manufacture (e.g. pipework with brazed or welded flanges), strength calculations must be based on the properties of the material in the annealed condition. Although cold worked material may be specified initially, it will be locally annealed during fabrication or joining operations that involve heating.

Annealing (full)

In order to fully soften most brasses, heat to 500-550ºC for ½ to 1 hour at temperature, then either air cool or, especially for alpha alloys, ensure that excessive grain growth is prevented by a quench or rapid furnace cool. 'Flash' annealing can be carried out at higher temperatures for considerably shorter times, but care is needed to avoid excessive grain growth.

The use of a protective atmosphere reduces oxidation. Normally this can be prepared from cracked or partly burnt ammonia to give an atmosphere high in nitrogen and water vapour. Since zinc is volatile, care needs to be taken to avoid overheating.

Stress relieving

In order to relieve internal stresses without loss of properties a low-temperature anneal such as ½ to 1 hour at 250-300ºC should be used, dependent on section size.

Checking effectiveness of stress relief

For many years, the mercurous nitrate test, now defined in EN ISO 196, has been used to check for residual stresses likely to cause stress corrosion in service. This has meant that reliable products could be guaranteed as a result of experience and testing. This test is included in the EN standards. The usual care should, of course, be taken to avoid ingestion of mercury. Alternative test methods, defined in ISO 6957, using ammonia as a vapour or liquid are available; see the EN standards. Results of tests using ammonia should not be compared directly with mercurous nitrate test results, since the latter checks stress levels by the different mechanism of liquid metal penetration.

Temper annealing

Many brasses cold worked to hard temper can be partially softened to produce intermediate tempers by carefully controlled heat treatment. Time and temperatures need to be established by experiment, starting from, say, ½ hour at 400ºC and altering time and/or temperature to achieve the desired temper. Results are monitored by measuring hardness, grain size, directionality or other relevant properties.

JOINING BRASSES

Details of all joining processes are contained in CDA Publication 98 'Joining of Copper and Copper Alloys'.

Soldering

Soldering is easily carried out using any of the lead/tin or lead-free solders to EN 29453, and either an active or non-active flux. Sudden heating of stressed parts in contact with molten solder can result in cracking of the material due to intergranular solder penetration. In such cases parts should be stress relieved before soldering. After soldering it is good practice to remove any flux residues in order to reduce the tendency for these to cause staining or corrosion.

The lead-free tin-based solders are chosen for use where the presence of lead may be undesirable.

Brazing

All the brasses are readily joined by brazing alloys covered by EN 1044. When a flux is used it is likely to cause corrosion if allowed to remain in place on the component. It should be washed off as soon as practicable. This is easy if the component is still warm after brazing but the brass should not be quenched directly from the brazing temperature or quench-cracks may be caused.

CuproBraze®

When efficient removal of heat is required brass is an excellent choice due to its high thermal conductivity. In the CuproBraze® process for making motor vehicle radiators (which started in 1999) brazing at 630-660ºC (environmentally friendly since flux and lead free) produces a much stronger structure than previously soldered radiators. CuproBraze® radiators are much better in terms of cooling performance than those constructed from aluminium due to:

- *superior strength (4-5 times stronger at 250ºC)*
- *superior thermal conductivity (x2)*
- *lower thermal expansion (less distortion)*
- *lower specific heat (less energy required for heating)*

Plants all over the world are adopting the CuproBraze® process for producing heat exchangers including radiators, oil coolers and charge air coolers for diesel engines. More information on the CuproBraze® process may be obtained from:

www.outokumpu.com
www.copper.org
www.cuprobraze.com

Bronze welding

The high copper brasses can, with care, be joined by this process.

Fusion welding

The major problem when attempting to weld brasses is the evolution of zinc oxide fumes due to zinc boiling off in the weld pool. With the correct choice of filler alloy, however, this problem can be minimised and satisfactory welds achieved.

Electron beam welding

This is not normally recommended due to contamination of the vacuum pumping equipment by volatilised zinc.

Friction welding

Satisfactory joints between components can be made by this process. Advice should be sought from machinery manufacturers.

MACHINING

For recommendations see *Section 2*.

Electroforming

Processes such as electro-discharge ('spark') machining and electro-chemical machining can be used as appropriate to produce components. Advice should be sought from machinery manufacturers.

Contour milling

Profiled strip is a useful starting stock for stampings such as edge connector terminals.

Etch forming

Many components can be economically produced to high precision from strip in relatively small batches by modern techniques of etching carried out to close tolerances on size and surface relief.

EXTRA SURFACE PROTECTION

As mentioned in preceding sections, brasses usually do not require special measures to protect them against corrosion. There are, however, some applications where inhibitors, lacquers, plating or cathodic protection are chosen to reinforce their natural corrosion resistance or to protect a decorative surface. Some of these are reviewed below.

Surface cleaning techniques

Before any finish can be applied, it is normal to clean the surface thoroughly in order to ensure good results.

Chemical pre-treatment in alkaline solutions

For the cleaning of copper and copper-alloy material, solutions are based on compounds such as trisodium phosphate, sodium metasilicate, sodium hydroxide and sodium carbonate, together with a blend of surfactants, wetting agents and emulsifiers. Generally the cleaning solution contains 2-5% of the salts. An efficient alkaline cleaner must also protect the surface from etching and staining, and must not cause any colour change of the surface. Cleaners containing complexants may allow simultaneous removal of the surface grease contamination and surface oxidation from copper and brass.

Degreasing in organic solvents

Many organic solvents dissolve oils and fats from metallic surfaces, but they do not always remove the tightly adherent dirt particles nor inorganic products such as polishing compound residues. For this purpose the cleaning process can be accelerated by the use of ultrasonic agitation.

All organic solvents must, of course, be used only in cleaning plant which prevents the release of the solvent or its vapour into the workplace or the surrounding air space. This requirement has led to the development of water-based cleaners and degreasers, which can be used without elaborate precautions or in fully automated plants.

Electrolytic degreasing in alkaline solutions

Alkaline solutions employed for chemical cleaning can be used for degreasing with an electric potential applied to accelerate the process. The components are subjected to alternating voltages to give a combined anodic/cathodic cycle, the final polarity being cathodic.

Patination

If exposed to a damp atmosphere, most brasses gradually develop an attractive green patina. This colour and many other artificial tones can be produced by a variety of chemical treatments.

Polishing

Conventional polishing procedures, using the appropriate compounds and equipment available from polishing and plating supply houses, can be used to produce a high surface finish on components ready for either lacquering or plating.

Plating

When a more wear resistant or decorative finish is required such as chromium plating, then brass provides the ideal substrate. Most plated coatings are porous to a certain extent and the inherently good corrosion resistance of brass under the plating prevents the early onset of cracks, blisters or eruptions of rust through plating that can occur when the substrate is steel.

All the brasses can be readily electroplated with all the normal metals applied in this way. For certain highly specialised applications the lead particles in the leaded free-machining alloys result in an unacceptable coating, and in these instances an undercoat of copper is applied before the final plating. The cost of chromium plating is relatively low and, since the substrate has an inherently good corrosion resistance, the finish is very satisfactory and durable.

Pickling

Oxides formed during heat treatment of most brasses can be removed by immersing the products in a 10% sulphuric acid mixture, followed by water rinsing.

Bright dipping

To produce a shiny, clean, pink surface, bright dipping is used. The component which would typically have a blackened surface after hot working (e.g. stamping) is immersed for 15-20 seconds in an aqueous solution of nitric, sulphuric and hydrochloric acids. The acids dissolve the surface oxides and contaminants such as baked-on grease, leaving a clean surface which will be preserved if the component is hot rinsed and flash dried. After bright dipping a component may be polished or chromated.

Chromate conversion coatings

To preserve the bright dipped finish on brass, chromate passivation is commonly used. A solution containing sodium dichromate is applied to the brass components, e.g. hot stampings. The surface of the brass is converted chemically to copper chromate and is rendered passive. This prevents atmospheric oxidation and maintains the clean, shiny surface. This is particularly useful for components such as plumbers' ware which may be stored for long periods before use.

It is essential that Health and Safety guidlines are followed when dealing with any of the substances mentioned in the above section on surface treatments.

Enamelling

The brasses are ideal for vitreous enamelling and a large range of attractively coloured frits is available. Brass is almost exclusively used for the manufacture of enamelled badges and jewellery, and a large range of enamelled decorative ware including domestic water taps.

'Bronzing' tones, ranging from a rich brown to ebony black, can be readily produced by a variety of processes using compounds available from supply houses specialising in surface finishing.

Inhibitors

Inhibitors are commonly added to heating systems, cooling systems, boiler feed systems etc. to protect the ferrous components which form the greater part of the installation. The inhibitors used are generally mildly beneficial or without significant effect upon brass components, but some amines used in boiler water treatment can cause stress corrosion cracking of brasses in condensers or condensate lines where oxygen is also present.

The inhibitor formulations used for treating the water in the heating systems of large buildings often include sodium nitrite, which can undergo microbiological reduction to produce ammonia. Some cases have occurred where, as a result of this, overstressed brass components have failed by stress corrosion. These have almost always been valves into which taper-threaded connectors have been screwed too far, producing high hoop stresses. If proper practices have been followed in making the installation there will be no problems of this sort but if not, and failures begin to occur, it is easier to change the inhibitor formulation to one that cannot produce ammonia than to replace every valve etc. that might have been overstressed in fitting and is consequently at risk.

The inhibitor most used for the protection of brasses is **benzotriazole (bta)** which is extremely effective in preventing tarnishing. It can be conveniently applied by dipping in a 0.2% aqueous solution at 60°C for 2 minutes or by swabbing. It is often added to the rinse water tanks at the end of acid pickling lines and has been much used to prevent tarnishing and staining of bright rolled brass sheets in storage or in transit - especially by interleaving with impregnated paper containing about 2% by weight bta. It has been shown that, for exports of copper and brass sheet, crossing the Atlantic and passing through the Panama Canal, a severe staining hazard was virtually eliminated by use of bta-treated tissue for interleaving. The bta tissue may also be used as a lining for large boxes containing ferrules, screws and nuts, whilst smaller boxes containing brass cartridges and electrical components have been made from bta impregnated card.

When used in the form of impregnated packaging material bta acts as a vapour phase inhibitor, forming a protective complex film on all the brass or copper articles within the package - not just on those that are in direct contact with the impregnated paper or card - and this protective effect persists after they have been unpacked. Note, however, that the vapour phase inhibitors, based on cyclohexylamine, that are used to protect ferrous articles in storage and transit cause accelerated attack on many non-ferrous metals including brass.

While bta will protect brass against most types of corrosion in most situations - including stress corrosion cracking in the presence of sulphur dioxide - it is not effective in ammoniacal environments. Laboratory tests have shown that phenylthiourea, applied in a clear lacquer, will inhibit ammoniacal stress corrosion of brass as well as preventing staining.

Dimethyldithiocarbamate has an important use as an inhibitor for brass. The Royal Navy has adopted a procedure requiring all heat exchangers in ships under construction to be filled for at least 24 hours with a dimethyldithiocarbamate solution to produce an inhibitive film; for Aluminium brass an inhibitor concentration of 200mg/l is employed. The fitting-out period for naval vessels often lasts for up to a year, during which time the installed plant is operated from time to time on polluted seawater from the basin in which the ship lies. This can result in sulphide attack on the tubes, followed by rapid erosion corrosion failures when the ship goes into service. The dimethyldithiocarbamate treatment has been found to eliminate this problem.

A discussion of inhibitors for brasses would not be complete without mention of the use of **ferrous sulphate** dosing to suppress corrosion erosion in Aluminium brass condenser tubes.

Lacquers

Lacquers and stoving finishes for application by brushing, spraying or dipping are readily available commercially. They should be selected from those specially recommended for copper, brass and other copper alloys since inferior lacquers may often cause tarnishing to occur on the metal underneath the coating. Adequate indoor protection can be given by air-drying lacquers; for heavy duty or outdoor protection a stoving lacquer or a stoving clear powder may be required. To ensure satisfactory service life, correct surface preparation and lacquer application, following the instructions is essential for a good finish.

The cheap, nitro-cellulose clear lacquers often used to preserve the bright appearance of small domestic decorative items afford adequate protection for the purpose but underfilm tarnishing usually becomes apparent after a year or so of indoor exposure. Superior performance is obtained from lacquers based on cellulose acetate or acrylic resins without inhibitive additions but these also fail, after perhaps a couple of years, by tarnishing spreading beneath the lacquer film from pinholes or scratches. This problem can be overcome by the incorporation of benzotriazole in the lacquer. **Incralac** (so named after the International Copper Research Association, which sponsored the research in the UK and USA that produced the inhibited lacquer formulation) is an air-drying acrylic ester lacquer containing benzotriazole, together with ultraviolet absorbing agents and anti-oxidants to extend its life in outdoor service.

Incralac is manufactured under licence in most countries and has been used commercially throughout the world for the past 20 years. It can be relied upon to provide protection to copper, gilding metal, bronze, brass and nickel silver for 3-8 years outdoors and for much longer periods indoors. The usual precautions concerning cleaning of the metal surface before lacquering must of course be observed and a minimum dry film thickness of 25μm (0.001”) is recommended. This normally requires the application of two coats since a single coat will provide about 13μm. Since, even after long periods of service, the bta still prevents any extensive tarnishing of the metal, it is easy to remove the lacquer with solvent and respray after a minimum of re-preparation when its general appearance is no longer considered satisfactory.

[The word ‘lacquer’ has an Indian origin (in Sanskrit ‘laksha’ means hundred thousands, derived from the thousands of cochineal insects used to make shellac.) It also conveys the implication of the multiple possibilities that lacquer in itself holds. Because of their moisture resistance lacquers were formerly applied by Egyptians and the Incas to embalm the dead and were connected with the notion of indestructibility.]

Plating

Plating on brass is usually less a matter of providing corrosion protection to the brass than of providing a high quality substrate for the plating. Brasses provide an excellent basis for decorative plating since they offer good corrosion resistance and can readily be polished mechanically or electrochemically to give a good finish.

Nickel-chromium

The familiar chromium plating consists of a very thin deposit of chromium on a very much thicker deposit of nickel. EN 12540 'Electro-plated coatings of nickel and chromium' specifies the minimum thickness of nickel required, according to the service conditions for which the plated article is intended and the types of nickel and chromium deposits employed. In all cases the thickness of nickel specified for a brass substrate is substantially less than for a ferrous substrate. For example, on articles for exposure outdoors in normal conditions the Standard requires a nickel thickness of 30μm for steel or iron but only 20μm for copper or copper alloys.

TABLE 21 – Polymers used for clear coatings (see CDA TN41)

Polymer	Film Properties	Typical Application
Acrylic	Available in air-drying or thermosetting compositions, acrylics are relatively high cost materials. The air drying modifications are popular for exterior applications. The thermosetting types are useful for applications requiring high resistance to heat and abrasion. The addition of a chelating agent such as benzotriazole gives good protection against tarnishing occurring under the lacquer.	Since the thermosetting coatings are not easily stripped off for re-coating, they are not normally suitable for major architectural applications. The copper roof of the Sports Palace in Mexico City is covered with Incralac, an inhibited air-drying acrylic lacquer formulated also with an ultra-violet absorber.
Modified acrylic	Acrylic resins can be modified with polyisocyanate, polyurethane, amino and other resins to produce cross-linked systems with good mechanical strength, abrasion resistance, flexibility and adhesion.	These lacquers are durable and have good resistance to chemicals.
Epoxy	Epoxy coatings have excellent resistance to wear and chemicals. They are relatively expensive and are available in thermosetting or two-part compositions, the latter having a relatively short pot life. They are good for severe indoor applications, but they darken in a few months of exterior service.	Outstanding adhesion and protection for copper surfaces used indoors.
Modified epoxy	The most important combination partners are phenolic or amino resins for improving elasticity, impact resistance, hardness and abrasion resistance.	Ideal for severe service such as bathroom taps.
Nitrocellulose	These are less expensive and the most common air drying coatings for interior service. They are modified with alkyd, acrylic, polyurethane and other resins. They do not have high resistance to chemicals, but they are fast drying and easy to use.	Mainly used for interior applications. They can be used outdoors, but they are usually stripped and replaced at intervals of less than one year.
Cellulose acetate butyrate and propionate	These coatings have a cost comparable with acrylics. They can be used alone or to modify acrylics or alkyds.	Could be used for interior or exterior applications.
Polyurethane	Tough and flexible films with good adhesion. They have good abrasion resistance and are resistant to chemicals. Available in both single and two component formulations. Some forms are prone to yellow with time. They darken on exposure to elevated temperatures.	Good for all interior applications.
Vinyl	Vinyl films are flexible and resistant with good adhesion. Stabilisation is required.	Very good protection for interior applications. Good for exterior applications provided they are well stabilised.
Silicone	Silicones provide the best potential for coatings which must operate at elevated temperatures. They have excellent resistance up to 250ºC. Thin films of these high cost coatings are sometimes used with protection by a second coat of a more durable, abrasion resistant lacquer. They require extended curing at high temperatures, and this may cause discolouration of the brass surface.	High temperature applications.
Alkyd	Slow drying or baking is required when applying the alkyd coatings. They can be modified with melamine or urea resins. They have a low cost and are sufficiently durable for exterior applications, although yellowing may occur. Resistance to chemicals is usually good.	Domestic applications where high wear resistance is required.
Soluble fluoro polymer	Will cure to full hardness at ambient temperature or can be stoved to accelerate hardening. Resistant to weathering and ultra-violet light.	Excellent protection with 20 years life expectancy for exterior applications. Suitable for coil coating or on-site application.

Silver
Electroplated nickel silver (EPNS), which has a long history of use for high quality domestic and hotel tableware, is covered by BS 4290 'Electroplated coatings of silver for cutlery, flatware and hollow-ware'. Specified thicknesses range from 50μm for best quality hotel ware intended to give 20 years regular service to 10-15μm for ornamental or domestic tableware intended for occasional use. Not much EPNS is now manufactured but silver-plated brass goblets and similar items are popular. These usually have a very thin silver coating over a bright nickel undercoat and consist of a cup and base, pressed from brass sheet, silver soldered to a cast brass stem. The plating thickness inside the cup, and especially right at the bottom, is considerably less than on the outside (a characteristic of electroplated coatings generally) and, as a result of normal use, brass may soon become exposed at that point. Superficial local dezincification producing a pink colouration in the bottom of the cup then occurs but, unless the goblet is frequently left with the dregs of an acidic wine in it, this slight corrosion is generally accepted and, indeed, often unnoticed.

Gold
Gold, like silver, is often applied to brass objects purely for decorative purposes. For example, on cheap jewellery a gold deposit of less than 0.5μm is often applied over a bright nickel undercoat. Such thin coatings are always porous and will therefore tend to increase corrosion of the substrate rather than protect it; they are therefore generally lacquered.

Thicker gold coatings, suitable for use without lacquering, are covered by BS 4292 'Electroplated coatings of gold and gold alloys'. An important application in relation to brasses is for taps and other bathroom fittings. For these it is usual to employ a cobalt or nickel hardened acid gold plating solution. These deposit a 99.5% gold alloy which is harder and more wear resistant than pure gold. 2μm of gold with a bright nickel undercoat is commonly applied.

Gold plated brass finds wide application for pins and connectors in computers and microelectronic devices generally. Here one function of the plating is corrosion protection since slight tarnishing, which would have no effect on the performance of brass plugs etc. for mains electricity or even low voltage battery connections, becomes important when minute currents are concerned. Gold combines freedom from tarnishing with low contact resistance and excellent solderability. Hard gold alloys, rather than pure gold, are used on electronic connectors, as on bathroom fittings, to provide wear resistance. A nickel undercoat permits the use of thinner gold deposits than would otherwise be satisfactory and provides a diffusion barrier which prevents inter-diffusion between the brass and the gold at elevated temperatures.

Electroless nickel
Electroless nickel plating differs from electrodeposited coatings in that its rate of deposition on different parts of the item to be plated is uniform - even down inside holes where it is practically impossible to lay down electroplating. It has therefore been used to provide corrosion protection to components of mixer valves etc., machined from leaded alpha-beta brasses, which are to be used in contact with waters that cause dezincification. The type of electroless nickel plating usually employed in the UK - commonly known as 'Kanigen' nickel - lays down an alloy of nickel and phosphorus. This has been used successfully to prevent dezincification and consequent blockage of narrow waterways in gas water heater control valves in service in a water supply notorious for causing meringue dezincification. Numerous other successful applications of this type of electroless nickel for the prevention of dezincification are known but tests with an alternative type of electroless nickel, which contains boron instead of phosphorus, were not satisfactory as the rate of corrosion of the nickel-boron coating itself was excessive.

Cathodic protection
Where galvanic corrosion is made possible when dissimilar metals are coupled in a corrosive environment, the extent of corrosion on one metal is reduced by coupling to one that is below it in the galvanic series. This principle is taken to its logical conclusion in cathodic protection using galvanic anodes. The system is most widely used for protecting iron and steel pipelines or other structures immersed in water (especially seawater) or buried in the ground, but is applied also to some brass components - principally to the tubeplates and tube ends of condensers. When a metal is connected to one that is below it in the galvanic series its electrochemical potential is depressed towards that of the less noble - the anodic member of the couple. Any such change in potential will reduce the corrosion rate but, for each combination of metal and environment, there is a 'protection potential' below which corrosion is completely suppressed. The objective in cathodic protection is to depress the potential of the metal concerned below its protection potential. For iron and steel this is achieved by connecting to sacrificial anodes of zinc, aluminium or magnesium. Alloys rather than commercially pure metals are used to ensure that the anodes remain 'active' in service. Zinc and aluminium are also used to protect brass but iron anodes are also satisfactory since the protection potentials for brasses are sufficiently far above that of corroding iron.

Instead of relying on coupling to a less noble metal to depress the potential into the 'protected' range a current can be passed from an external source between the metal to be protected and an anode of highly corrosion resistant material such as platinum. The metal to be protected (the cathode) is connected to the negative side and the anode to the positive side of a DC source - usually a low voltage transformer and rectifier operating on the AC mains supply - and the applied voltage or current adjusted to depress the potential of the cathode to the desired level. This method of protection is termed impressed current cathodic protection.