The Brasses

properties & applications

excellent MACHINABILITY

cost-EFFECTIVE

100% RECYCLABLE

corrosion RESISTANT

anti-MICROBIAL

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cost-EFFECTIVE

good DUCTILITY

good STRENGTH

corrosion RESISTANT

wear RESISTANT

Copper Development Association

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The Brasses
properties & applications

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Section 1 – INTRODUCTION

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

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

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

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

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

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

Brass Designations

Brasses are described by a number of systems of common terminology. As an example, in the old British Standards BS 2870 to 2875, the designation CZ106 is referred to as ‘70/30 Brass’ or ‘Cartridge Brass’ or sometimes ‘Deep Drawing Brass’.

In EN Standards the composition symbol for 70/30 Brass is CuZn30 and the material designation number is CW505L. In this publication the notation used in the text gives the EN number first, followed by the old BS number in brackets. Hence, for the above brass the designation is CW505L (CZ106).

TABLE 1 – Brasses - typical engineering applications

Form	Cold Working	Free-Machining	High Tensile	High Corrosion Resistance
Rods	Rivets Pinions Motion sensors	Unions Terminals Spindles Screws Jets Injectors Cable glands	Valve spindles Shafts	Marine fittings Plumbing fittings Gas fittings Pneumatic fittings
Sections	Bathroom hardware	Terminals Tracks Valve bodies Balance weights	Valves Spark resistant mining components	Shower parts
Hollows	Automotive components	Nuts Cable connectors	Bearings	Nuts
Hot Stampings	n/a	Tube fittings Electrical components Plumbing hardware	Syncromesh gearings Cavity wall ties Mining equipment	Plumbing fittings
Plate	n/a	n/a	n/a	Condenser tubeplates
Sheet	Holloware Lamp caps Reflectors	Clock plates Instrument frames	n/a	Instrument cases Cartridge cases
Strip	Springs Terminals Fuse caps Bellows Precision etchings	n/a	Wear plates and strips	Heat exchangers
Wire	Springs Pins Rivets Zip fasteners Jewellery	Screws Terminals	n/a	Scouring pads Papermaking screens Brake pad carrier wire
Tube	Heat exchanger tubes	(See hollows)	n/a	Heat exchanger tubes for corrosive environments
Castings	n/a	Taps Water fittings	Bearings	Valve bodies

Section 2 – WHY MAKE IT IN BRASS ?

Brass is the best material from which to manufacture many components because of its unique combinations of properties. Good strength and ductility are combined with excellent corrosion resistance and superb machinability. Brasses set the standard by which the machinability of other materials is judged and are also available in a very wide variety of product forms and sizes to allow minimum machining to finished dimensions.

As rod or bar, brasses are readily available from manufacturers and stockists. For longer runs it is frequently worth considering the purchase of special sizes or extruded shapes designed to minimise subsequent production costs. Brass rod manufacturers are able to produce a very wide variety of shapes and sizes of product with minimum order quantities that are very low compared with many other materials.

Die costs for special extrusions can be inexpensive when spread over a long production run and hollow extrusions can save excessive boring operations.

The die costs for hot stampings are much less than for the die casting or injection moulding techniques used for some alternative materials. For special shapes, hot stampings can provide very economical feedstock. Manufacturers welcome discussions regarding optimum alloy, sizes and tolerances at an early stage in the design of components.

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

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

LIFETIME COSTING

For any product, the first cost is of importance but not necessarily paramount when fitness for purpose must be assured. Lifetime costing can be used within parameters set up in an organisation to monitor cost-effectiveness.

The costing of component production depends on many factors. Some to be considered are:

First Cost

Material plus production costs.

Cheapest material costs may involve higher production costs. It is frequently possible to reduce total costs by buying free-machining material or components made near-net-shape before finish machining and assembly.

A simple example of comparison of first costs for heavy duty valve chests is shown in ***Table 2***.

Lifetime Cost

First costs plus servicing costs and costs of failure during component life.

Well designed and specified components can be cheaper if they last their full expected life than if designed only for lowest first cost.

Material Cost

Cost of metal mixture plus casting and fabrication costs, less the value of reclaimed process scrap.

COST-EFFECTIVENESS

There are many factors, sometimes overlooked, that contribute to the low costs of brass components:

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

This is only a part of the production cost of components. Careful consideration of material costs can reduce total costs. Rather than buy stock material, it is frequently worth paying more for special preforms that give more significant savings on production costs.

Economic Order Size

For wrought material stock, large orders can be placed with material manufacturers who are pleased to supply directly, and frequently make material that is specially designed to suit non-standard requirements agreed with the customer. Minimum order quantities depend on production considerations including optimum batch sizes and the programming requirements needed to meet any special orders.

Small quantities of materials are bought from stockists rather than materials manufacturers. This is because it is economical for manufacturers to make material in long runs of large quantities and distribute these to a variety of stockists in different areas. Stockists themselves have different specialities, many being able to offer cutting to size or other services as required.

The properties which lead to lifetime cost-effectiveness are:-

Availability in a wide range of forms

The hot and cold ductility of the brasses make them amenable to all the normal metalforming processes. They are also easily cast. From the range of compositions, standardised alloys can be selected for:

- *Extruded rods and sections (solid and hollow)*
- *Hot stampings and forgings*
- *Rolled plate, sheet, strip and cut circles*
- *Drawn tubes - round and shaped*
- *Drawn wire - round and shaped*
- *Castings - sand, shell, investment, gravity and pressure-die*

Strength

In the softened or annealed condition, the brasses are ductile and strong but, when hardened by cold working techniques such as rolling or drawing, their strength increases markedly. Strong, stiff structures can be assembled from sections which have been extruded and drawn. Bars, rolled sheet and plate can be fabricated into containers and other items of plant which operate under pressure.

The strength of brasses is substantially retained at temperatures up to around 200ºC and reduces by only about 30% at 300ºC, which compares favourably with many alternative materials.

The brasses are very suitable for use at cryogenic temperatures, since the mechanical properties are retained or slightly improved under these operating conditions. ***(see Figure 1).***

FIGURE 1 – Effect of temperature on properties of free-machining brass CW614N (CZ121)

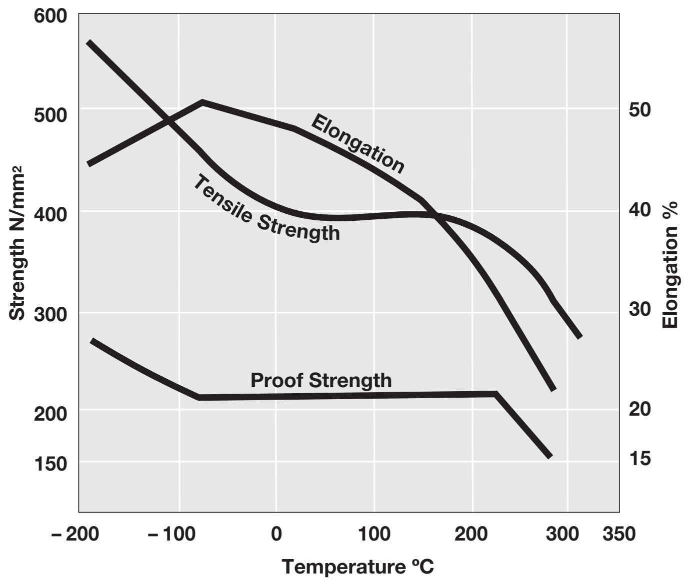


TABLE 2 – Comparison of first costs for heavy duty valve chests *(courtesy Meco International)*			
	High Tensile Brass	**Steel**	*The requirement is to produce a reliable, robust and safe valve chest for the operation of mine roof support hydraulic jacks.* *When made from steel the amount of pre-machining from bar stock is extensive, the finish machining time extended and there is also a need to send out the components for protective plating.* *High tensile brass is supplied to the required shape, is relatively easy to machine and requires no plating in order to be safe for this application.* ***(See page 14)***
Design requirements sought			
Working pressure (bar)	350	350	
Non sparking for mining application	Yes	No	
Cost per component (£)			
Raw material	6.22	2.35	
Pre-machining	–	3.50	
Milling	–	2.50	
Finish machining	7.90	11.70	
Plating	–	1.41	
Total cost per component	**14.12**	**21.46**	

For applications demanding higher strengths the high tensile brasses are available. These contain additional alloying elements which further improve the properties.

Ductility and formability

Brasses with a copper content greater than 63% can be extensively deformed at room temperature, and are widely used for the manufacture of complex components by pressing, deep drawing, spinning and other cold forming processes. If the copper content is below 63% and no other alloying elements are present, the room temperature ductility is reduced, but such alloys can be extensively hot worked by rolling, extrusion, forging and stamping.

Machinability – the standard by which others are judged

Whilst all brasses are intrinsically easy to machine, the addition of small amounts of lead to brasses further improves this property and the well-known 'free-machining brass' is universally accepted as setting the standard by which other materials are judged when machinability is being assessed. Higher machining speeds and lower rates of tool wear mean that overall production costs are minimised, tolerances are held during long production runs and surface finish is excellent.

Corrosion resistance

Brasses have excellent resistance to corrosion that makes them a natural, economic first choice for many applications.

Atmospheric exposure of the brasses results in the development of a superficial tarnish film. Outdoor exposure will ultimately result in the formation of a thin protective green 'patina' which is frequently seen as a visually attractive feature in buildings, but the brass will remain essentially unaffected for an unlimited period of time, i.e. it will not rust away like iron and steel. Seawater can be handled successfully providing the correct alloy is chosen, and there is a long history of the use of brass tube and tube fittings, valves, etc. in domestic plumbing, central heating, seawater lines, steam condensers and desalination plant. High tensile brasses containing manganese have excellent resistance to atmospheric corrosion, continual exposure resulting in a gradual darkening of the bronze colour.

Conductivity

Brasses have good electrical and thermal conductivities and are markedly superior in this respect to ferrous alloys, nickel-based alloys and titanium. Their relatively high conductivity, combined with corrosion resistance, makes them an ideal choice for the manufacture of electrical equipment, both domestic and industrial. Condenser and heat exchanger tubing also require the good thermal conductivity of copper and its alloys *(see Table 26 on page 58)*.

Wear resistance

The presence of lead in brass has a lubricating effect that gives good low friction and low wear properties utilised in the plates, pinions and gears used in instruments and clocks. Special brasses are available with additions of manganese and silicon that make the material ideal for use in heavy duty bearings. The wear resistance arises due to the presence of manganese silicide particles.

Spark resistance

Brasses do not spark when struck and are approved for use in hazardous environments.

Attractive colour

Copper and gold are the only two metals with any distinctive colour. In brasses, the red of copper is toned to a range of attractive yellow hues by the addition of varying amounts of zinc, ranging from the gold-like colours of the 95/5, 90/10, 85/15 and 80/20 alloys (appropriately called 'gilding metals') through the more subtle variations in the 70/30, 2/1 and 64/36 series of brasses to the stronger yellow colour of the 60/40 alloy, formerly known as 'yellow metal'. In consequence, brasses are extensively used for durable decorative applications and for the manufacture of functional items where aesthetic appeal is a requirement in addition to a long service life. Aluminium brasses have a distinctive silvery sheen and the addition of manganese to certain brasses gives them an attractive bronze colour when extruded. High tensile brasses, some of which are otherwise known as 'manganese brasses', or previously 'manganese bronzes', are particularly suitable for architectural applications since they can also be patinated to a range of durable brown and bronze finishes.

Decorative or protective finishing is easily applied

Brasses may be polished to a high surface finish which can then be either easily repolished when required or lacquered to preserve the natural colour, enamelled or plated with chromium, nickel, tin, silver, gold, etc. as required. Alternatively, the surface can be toned to a range of colours, from 'bronze' through various shades of brown, to blue-black and black, using commercially available toning chemicals. These coloured finishes are frequently used for decorative and architectural metalwork.

All types of common plating processes may be used. For many other metals it is usual to use a copper plate underlayer. This is not required on brass because it is easily polished and does not need the expense of an initial copper strike. Cadmium plating of steel was traditionally used to give it corrosion protection when used against brass but, since cadmium is toxic, this has now been replaced by zinc.

Ease of joining

Brasses may readily be joined to other copper alloys or to other metals by most of the commercial joining processes such as riveting, soft soldering, silver brazing and friction welding. Modern adhesive joining practice can also be used.

Hygiene - control of MRSA contamination

Copper is well-known for its anti-bacterial properties and the copper content of the brasses has the beneficial effect of restricting the growth of micro-organisms. Tests at Southampton University have shown the superiority of copper alloys such as brasses compared to stainless steels in controlling harmful micro-organisms. These tests strongly indicate that the use of copper alloys in applications, including door knobs, push plates, fittings, fixtures and work surfaces, would considerably mitigate MRSA in hospitals and reduce the risk of cross-contamination between staff and patients in critical care areas. It has also been shown that copper alloys are effective in controlling *E.Coli* OH 157 and *Listeria monocytogenes*, both of which cause serious food poisoning.

LOW COST MANUFACTURING

Machining operations

To take greatest advantage of the excellent machinability of brasses, production techniques are optimised to give lowest component costs. There are some useful machining parameters such as tool geometry, speed, feed and depth of cut that give good guidance ***(see Figure 2)***. These can be modified in the light of experience with equipment.

A good introduction to the principal recommendations for the machining of coppers and copper based alloys, including the brasses, is given in CDA TN44. Materials are divided into groups depending on ease of machinability. Group 1 includes the traditional free-machining brasses, whilst Group 2 mainly covers the lead-free alloys. None of the brasses considered falls into Group 3, which includes other copper alloys not so easily machined as brass.

The ease with which free-machining brass swarf clears from the tools means that a 0º back rake is used on turning tools and form tools. Tool wear is minimal for these materials and, when regrinding is eventually needed, the absence of back rake means that one less operation is required, giving a reduction of 20% in tooling costs.

The cutting speeds used for the improved free-machining brass may be up to double those established at present, that is up to 200 surface metres per minute (650ft/min). With older equipment it may not be possible to take advantage of this, but the benefits of improvement in tool life and reduction in failures are achieved.

The good corrosion resistance of brass allows the use of water-soluble cutting oils. The neat oils required for many alternative materials are not necessary. This can result in a saving of up to 70% in lubricant costs, giving improved cooling of both the bar stock and cutting tools, and also avoiding the problem of the noxious fumes from overheated mineral oils.

Free-machining brass gives a swarf consisting of small chips which clear from the tool very easily ***(see page 14)***. This means that continual attention to swarf removal is not required and machine manning levels can be reduced, often by a factor of four. The fine swarf is also easy to collect and recycle.

Brass prices

The price of zinc is normally about half that of copper, although the relationship varies. Therefore the alloys containing the most zinc have the lowest basic metal cost. The higher zinc brasses also lend themselves to relatively cheap production routes compared with the higher copper alloys. As a result the 60/40 hot working brasses are the most frequently ordered for general purposes, while the 70/30 and 64/36 brasses tend to dominate the brass sheet, strip, tube and wire markets. The higher copper materials tend to be used only if there is a particular advantage.

♲ Swarf value - recyclability

Careful consideration of design and feedstock can reduce swarf production but it is sometimes inevitable that large quantities of swarf are produced, up to 70% of the original weight on occasions. The brass industry is well organised and equipped to recycle this. Because of the ease with which clean swarf and offcuts can be recycled, it retains a high proportion of its initial value. It is possible for large users to be offered a firm buy-back price for swarf and other process scrap at the time stock is ordered, so facilitating accurate economical budgeting for lowest possible production costs.

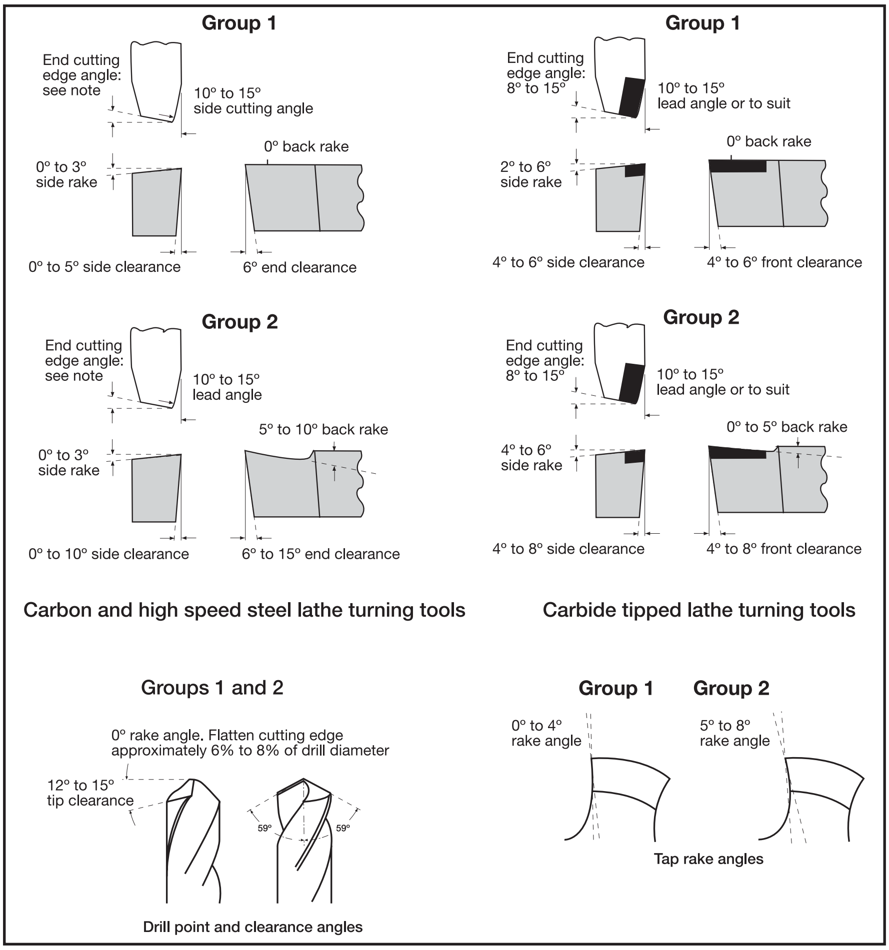
Use of profiles and hollow extrusions

As well as round rod, special shapes can be extruded to give a two-dimensional near-net-shape feedstock needing little further machining. Design of these profiles can be improved if there is good liaison between customer and fabricator regarding the most suitable geometry to suit both the end use requirement and the extrusion process. Hollow sections may also be specified in order to reduce the mass of metal to be removed in the manufacture of hollow components. Since the manufacture of hollow sections is more complicated than for solid material, there is an extra cost involved to be offset against the savings in machining costs.

Brass may be extruded over a mandrel to produce a hollow section. This is possible because of the lower friction of brass when compared with other materials which gall and wear the mandrel very quickly. For many other materials, hollows are produced by extrusion over a bridge die which splits the metal and then rewelds it at the die exit. By examination of the etched cross-section of extruded hollows it is normally possible to detect the joins in bridge-die extruded metal and this type of process is not recommended in specifications for materials requiring good integrity.

Although hollow extrusions cost more per unit weight than solid sections, this is frequently offset by the saving in drilling and reduction of swarf. Very small hollows may be uneconomic to produce and it must also be borne in mind that large, thin-walled hollows can be easily damaged. Broadly speaking, however, for the majority of sizes the advantages can be considerable. Using modern production techniques the eccentricity of hollows is minimal.

FIGURE 2 – Tool geometry for the machining of brasses in machinability groups 1 & 2



(Group 1 includes all the free-machining brasses, the others are in Group 2. For further details of recommended machining practice see CDA TN 44 'Machining of copper and its alloys').

Use of stampings

Where it is required to produce irregular shapes such as elbows, tees or more complex items, then the use of stampings (also known as hot forgings) as feedstock is an obvious economy in reducing both machining time and metal wastage. Stampings have the advantage of a strong, uniform wrought structure, similar in properties to extrusions.

The use of stampings is also economical for uniaxial products where it is possible to show cost savings over machining from solid. As a general rule, if the largest outside diameter is more than 25% greater than the smallest internal diameter the economics of using hollow stampings are likely to be favourable. Close liaison with the manufacturers of hot stampings can ensure that the blank design is suitable for both ease of forging and subsequent machining. Forging techniques, as with most other production methods, are improving with time and die costs are not as high as for many other processes.

Castings

Near-net-shape preforms can also be made by casting processes including sand, shell moulding, diecasting, continuous casting or precision casting depending on size of component, number required and accuracy requirements.

High-speed machining – the facts

Until recently there was no way in which the machinability of metals could be accurately compared. A standard ASTM test gives results for a given combination of typical machining operations. Tests carried out give the values in ***Table 3*** relative to high-speed machining brass having a nominal 100% machinability, whilst ***Table 5*** gives typical mechanical properties of a number of brasses and low alloy and stainless steels.

CORROSION RESISTANCE

One of the many virtues of the brasses is their general resistance to corrosion, required in combination with other properties for many applications. For terminations of all sorts, from electric cables to hydraulic pipelines, brass fittings are ideal because of their good performance in air and also in many working and process fluids. For aggressive environments, especially marine, there are special brasses listed in ***Tables 19 and 20*** such as the naval brasses, high tensile brasses and dezincification-resistant brass. For general purposes, however, the standard free-machining alloys are excellent.

In common with the other copper based alloys, the brasses have excellent resistance to normal atmospheric corrosion and this is one of the key properties vital in materials selection decisions. For this reason brass is the first choice material to give many years of satisfactory service for many common but critical applications such as electrical components, scientific and other accurate instruments, clocks, hose and pipe fittings, etc.

Protective oxide films

When exposed to a dry atmosphere, brasses gradually darken over a period of time, due to the slow formation of a tarnish film on their exposed surfaces. This film is mainly oxide, but in locations where sulphur pollution is present, a proportion will be sulphide.

This film eventually becomes stable and protective and no further oxidation occurs. It is very thin and smooth and does not normally interfere with the operation of moving parts, as does for instance rust on ferrous parts. For electrical applications it is also useful that the oxide film formed does not have the disadvantages of the non-conducting refractory oxide formed on aluminium.

If the atmosphere is damp, or if exposed to the weather, the familiar green patina consisting of basic oxides, hydroxides and carbonates will eventually form. Again, this is thin and protective, but is rougher and more powdery than the tarnish film formed in dry atmospheres. In a marine environment, a green patina of similar appearance develops but, in this case, also contains basic chlorides.

In contact with most potable waters, a protective oxide film develops, in which is normally incorporated some of the constituents of the water such as salts of calcium, magnesium and iron.

MACHINABILITY

TABLE 3 – Relative machinability ratings of various metals

Material Description	Designation		US Designation	Hardness	Machinability Rating
	Old BS	EN		HB	%
Free-cutting mild steel	En1A	220M07	B1112	160	33
Plain low carbon steel	En3	070M26	C1025	143	22
Plain medium carbon steel	En8	080A40	C1040	205	20
High strength low alloy steel 1.5% NiCrMo	En24	817M40	A4340	210	17
High strength low alloy steel 2.5% NiCrMo	En25	826M31	6407	180	17
1% carbon, 1% Cr ballbearing steel	En31	535A99	E52100	206	10
Low carbon case hardening steel	En32	080M15	C1015	131	20
18/8 stainless steel	En58J	316	316	195	12
K-Monel	–	–	K500	240	12
Titanium alloy	–	–	A-70	188	10
Titanium alloy	–	–	C-130	255	6
Aluminium alloy	–	AA2017	2017-T	95	50
Free-cutting aluminium alloy	–	AA2011	2011	95	66
Aluminium bronze	CA104	CW307G	C63000	200	20
Aluminium silicon bronze	CA107	CW301G	C64400	180	60
Copper-chromium	CC101	CW105C	C18200	140	20
Copper-nickel	CN102	CW352H	C70600	90	20
Copper	C101	CW004A	C11000	50	20
Free-machining copper	C109 C111	CW118C CW114C	C14500 C14700	50 50	80 80
Forging brass	CZ122	CW617N	C37710	70	90
Free-cutting brass	CZ121	CW614N	C38500	70	100

Note: Machinability ratings (after Carboloy Systems Div) with high-speed machining brass rated at 100%. The higher the rating, the better the machinability.

A major machine shop with a wide experience of many materials has compiled a tabulation of actual metal removal rates under production conditions. Comparison is made with two aluminium alloys, one with a reasonable corrosion resistance (a), the other with better machinability (b), but with corrosion resistance inadequate for many applications ***(see Table 4).***

Following a series of in-depth comparisons of production techniques, a series of case histories has been established showing conclusively that, for the components considered, the finished cost is significantly less when they are made of brass than when machined from steel, even though the initial cost of the steel stock is lower than that of brass (***see pages 27 and 28).***

Figure 3 shows typical retail costs for brass and low alloy steel screwed rod (studding) for sizes from 6mm down to 2mm diameter. For the larger sizes, where the predominant cost is that of the material, then the steel is cheaper. Below 3mm diameter the low cost of machining brass to good tolerances and surface finish means that it gives a cheaper product, as well as having other advantages.

Stainless steel is more difficult to machine and can result in components being two to five times the cost of similar items made in brass.

TABLE 4 – Practical metal removal rates
(courtesy Hawke Cable Glands Ltd)

Alloy	Metal Removal Rate cm³/min
Brass CW609N (CZ121 Pb4)	133
Aluminium (a)	44
Aluminium (b)	80
Mild steel	36
Stainless steel (304)	6

FIGURE 3 – Comparison of costs of low alloy steel and brass studding

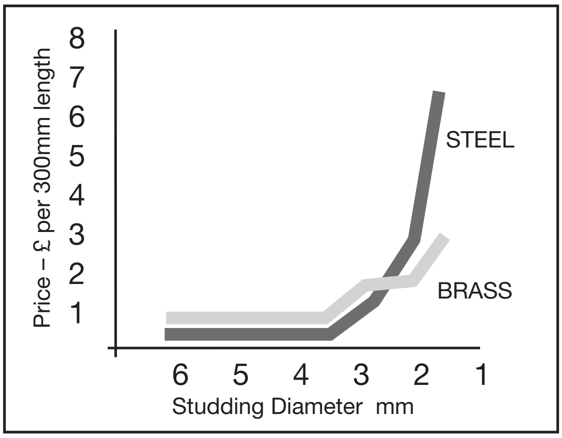
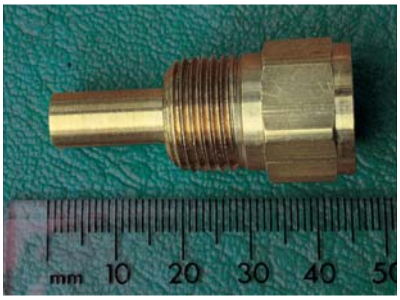


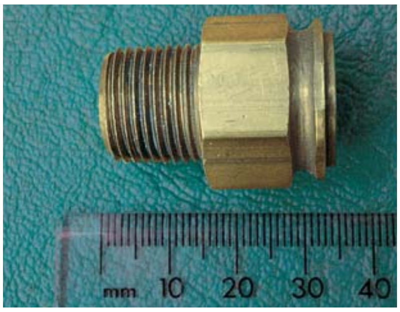
TABLE 5 – Comparison of typical mechanical properties of brasses, free-cutting mild steels and stainless steels					
Material	**Tensile Strength (N/mm²)**	**Yield Strength or 0.2% Proof Strength (N/mm²)**	**Elongation (%)**	**Hardness**	**Machinability Index %**
EN 12164 (BS 2874)					
CW614N (CZ121Pb3)	380-520	150-400	30-10	90-150 HV	100
CW617N (CZ122)	380-520	150-400	30-15	90-150 HV	90
CW603N (CZ124)	340-500	130-350	40-15	85-140 HV	97
CW608N (CZ128)	350-510	150-380	40-15	85-140 HV	80
BS 970					
220M07(EN 1A) Low Carbon, Unleaded, Free-Cutting					
Hot Rolled	360 Min	215 Min	22	–	–
Cold Drawn	355-465	355-465	10-7	–	33
230M07 Low Carbon, Unleaded, Free-Cutting					
Hot Rolled	360 Min	215 Min	22	103 HB	35
Cold Drawn	570-680	420-530	10-6	–	–
BS 4360 (Structural Steels)					
Grade 43C	430-580	275	22	–	–
BS 970 Austenitic Stainless Steels (Softened)					
304S11	480 Min	180 Min	40	183 HB Max	–
304S15	480 Min	195 Min	40	183 HB Max	–
204S31	490 Min	195 Min	40	183 HB Max	–
316S11	490 Min	190 Min	40	183 HB Max	12
316S13	490 Min	190 Min	40	183 HB Max	12
316S31	510 Min	205 Min	40	183 HB Max	12
316S33	510 Min	205 Min	40	183 HB Max	12
321S31	510 Min	200 Min	40	183 HB Max	–
303S31 (Free-machining grade)	510 Min	190 Min	40	183 HB Max	16
BS 970 Stainless Steels					
All Grades Cold Drawn (up to 45mm section)					
	650-865	310-695	18-12	–	–



1

Brass is cheaper than steel

(see examples 1 – 5 below)



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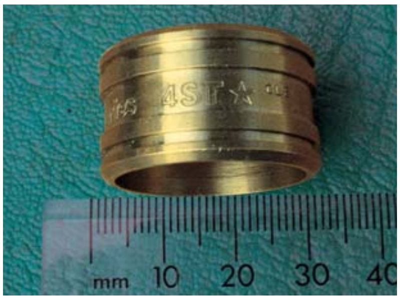

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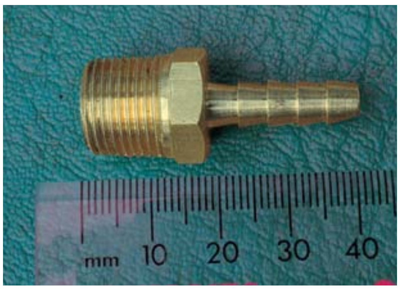

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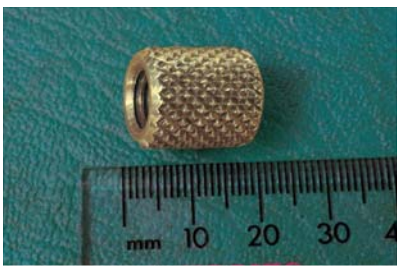


5

Component	Fitting body	Manifold adapter	Air brake hose fitting	Actuating sleeve	Pneumatic hose fitting	Knob insert (knurled)
Photograph	No 1	Not shown	No 2	No 3	No 4	No 5
Application	Underwater pump assembly	Automotive	Automotive	Pneumatic power	Aircraft	Garden equipment
Special features	Teflon coated	Better quality, cheaper	Safety-related	Deep hole	Productivity savings	
Part weight (g)	49	33	41	36	26	5.4
Brass premium (a)	23	30	36	17	42	32
Cycle time - brass (sec)	4.5	3.2	5.6	4.75	3.7	3.75
Cycle time - steel (sec)	8.0	5.9	9.1	8.4	8.3	5.5
Productivity gain using brass (%)	102	110	86	102	157	68
Cost saving gain using brass (£/1,000)	**3.92**	**0.58**	**33.98** (b)	**40.60** (c)	**25.08** (d)	**2.62**

Notes: Comparisons are between CW603N (CZ124) free-machining brass and leaded free-machining steel 12L14 and are based on multi-spindle auto production.

(a) Brass material cost premium includes scrap allowance.

(b) Brass v plated steel. For bare steel the saving is £26.26 per 1,000 parts.

(c) Brass v plated steel. For bare steel the saving is £33.58 per 1,000 parts.

(d) Brass v plated steel. For bare steel the saving is £20.09 per 1,000 parts.

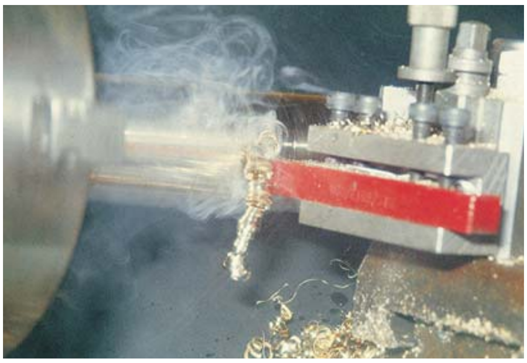
Free-machining brass
This gives fine chips of swarf which minimise tool wear and the need for lubrication.

Cable glands for offshore platforms
These close-tolerance cable glands made from brass are 33% cheaper than those made from aluminium.

Brass is easier to machine, has a higher metal removal rate and causes less tool wear than the aluminium alloy needed to give adequate corrosion resistance for this application. One operator can supervise the machining of brass on six lathes at a time whereas aluminium gives a constant build up of swarf when machining and needs the supervision of one operator per machine.

Valve chests for mining equipment
Valve chests made from brass are 34% cheaper than those made from steel.

Good strength, ductility, corrosion resistance and spark-resistant properties, combined with ease of manufacture, make brass the ideal choice for use as the material for heavy duty valve chests used for controlling complex hydraulic roof-supporting equipment. The chests are made from a large, near-net-shape extrusion in high tensile brass which is relatively easy to machine and requires no protective plating. Previously, chests were made from steel which required extensive pre-machining from bar stock as well as plating for protection. The costings are shown on ***page 7***.



The swarf from non free-machining metals
Swarf is slow to clear from the tool, giving higher tool wear, long tangles of swarf and needing expensive lubricants.

Section 3 – CHOOSING THE RIGHT BRASS

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

For convenience this section will also include some discussion of the nickel silvers which are a group of copper-zinc alloys containing significant amounts of nickel. They are noted for their corrosion resistance, white colour and excellent elastic properties.

The compositions and properties of all the standard brasses and nickel silvers are listed in ***Tables 19 and 20***.

Further information on the Standards documents is given in ***Section 4*** under 'Ordering Information'.

BRASSES FOR SPECIFIC MANUFACTURING PROCESSES

High-speed machining brasses

Lead is added to brass to improve its machinability. It also has the effect of reducing the cold ductility of the metal so the amount of lead used depends on the exact combination of properties required. The lead exists as discrete particles in the matrix and causes the swarf from the machining operation to be broken into fine chips rather than long curls, allowing it to clear from the work piece. The lead also has some lubricant action. Further information on these materials is given in ***Section 6***.

The most commonly available alloys are summarised in ***Table 6.***

The casting and extrusion of these brasses must be carefully controlled to ensure that the lead particles are finely dispersed and that any iron or silicon impurities are retained in solution. Lack of care in manufacture can result in these impurities precipitating out as hard particles which accentuate tool wear. For highest machining rates and minimum tool wear it is therefore desirable to purchase stock from reputable suppliers.

For applications where some cold forming operations are required after machining, a brass with a higher copper content and less lead must be used. For example the alloy CW601N (CZ131) is widely used where cold heading is to be carried out.

Brasses for hot working

In order to select an appropriate brass, a little knowledge of the basic metallurgy of the brasses is useful. This is discussed in more detail in ***Section 6***, but can briefly be summarised here.

When the alloy contains less than about 35% Zn, the zinc stays in solid solution in the copper. Such brasses are known as single phase, or alpha brasses. They have good ductility at ambient temperatures and are ideal for cold working. When more zinc is added, a second phase, beta, is formed, and at room temperature the alloy is a mixture of the two phases. These brasses are known as two-phase, alpha/beta, or duplex brasses.

Because the beta phase has very good hot ductility, the most appropriate alloys for hot working are the duplex brasses. The choice of alloy will then depend on other factors.

Hot stamping brasses

The most popular alloys for hot stamping are summarised in ***Table 7***, with a complete list being given in ***Table 13***. They combine maximum ductility at the stamping temperature (650° – 750°C) to allow complex shapes to be formed, with strength and reasonable ductility at room temperature. The optimum compositions are in the region of 60% Cu and 40% Zn. These are predominantly in the plastic, beta phase at the stamping temperature and have a mixture of alpha and beta phases at room temperature. The precise choice of alloy will depend on the service requirements and other fabrication processes. Other alloys which can be hot stamped are listed in ***Section 4***.

TABLE 6 – Free-machining brasses

Compositional Designation EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties
CuZn39Pb3 CW614N	CZ121 Pb3	The most commonly used alloy for high-speed machining. Has limited cold ductility but can be knurled.
CuZn36Pb3 CW603N	CZ124	Has better cold ductility coupled with excellent machinability.
CuZn36Pb2As CW602N	CZ132	Dezincification-resistant brass.
CuZn37Pb2 CW606N	CZ131	Good machinability with improved cold ductility. Suitable for cold heading and riveting.
CuZn39Pb2 CW612N	CZ128	Good machinability and sufficient ductility for some cold work.
CuZn40Pb2 CW617N	CZ122	Good machinability but limited cold ductility. Generally used for hot stamping.

TABLE 7 – The most popular brasses for hot stamping

Compositional Designation EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties
CuZn40Pb2 CW617N	CZ122	This is the alloy most frequently used for hot stamping. Complex shapes can be formed and it has good machinability.
CuZn40 CW509L	CZ109	This lead-free alloy has superior cold ductility as well as excellent hot working properties. It is not so easily machined.
CuZn39Pb3 CW614N	CZ121 Pb3	Has excellent machinability.
CuZn39Pb2 CW612N	CZ128	This alloy has better cold ductility than CuZn40Pb2.
CuZn36Pb2As CW602N	CZ132	Dezincification-resistant brass. Used for plumbing fittings.

Brasses for cold working (*Table 8*)

The alloys with maximum cold ductility are single phase alpha alloys. The most ductile, with the highest copper content is CW505L (CZ106, 70/30), also called Cartridge Brass, is widely used for deep drawing. For less demanding applications requiring simple forming, the lower copper, cheaper alloys CW507L (CZ107, 64/36) or CW508L (CZ108, 63/37) may be used.

Cold working brasses are typically used to make semi-finished products such as sheet, strip, foil, wire and tube.

The gilding metals, CW501L (CZ101), CW502L (CZ102) and CW503L (CZ103) have excellent ductility, strength and corrosion resistance and are frequently chosen for colour and durability for decorative architectural applications and costume jewellery. For special purposes, where even better corrosion resistance is required, aluminium or arsenical brasses are available. A typical application would be for condenser tubes for use with brackish or seawater.

Brasses for casting (*Table 9*)

Specific alloys have been developed for each of the different casting processes. The most commonly used are listed in ***Table 9***. Some of the alloys have an addition of lead for machinability, others have tin to improve corrosion resistance and strength. All have a good combination of fluidity while pouring, and hot strength to avoid hot tearing while solidifying. Manganese is a useful deoxidant, as little as 0.02% present giving stronger, sound castings. For diecasting the 60/40 type alloys are normally used. The higher zinc content lowers the casting temperature and gives essential hot ductility. Small additions of silicon or tin improve fluidity; tin also improves corrosion resistance. Aluminium is added to form a protective oxide film to keep the molten metal clean and reduce the attack on the die materials. This type of alloy with a suitably controlled composition may also be used for castings required to be resistant to dezincification.

For applications requiring higher strength, high tensile brasses can be used. These can be sand cast and CC7655 (HTB1) is also used for gravity diecasting.

The casting process is ideal for the production of complex shapes. End uses range from pipeline valves and electrical switchgear components which require high soundness and strength, a long operating life and, in the case of components for mines and the petrochemical industry, spark-resistant characteristics, to non critical ornamental applications where the requirement is for a good surface finish as well as a long service life.

BRASSES FOR SPECIAL APPLICATIONS

High tensile brasses

The high tensile brasses are copper-zinc alloys with additions to increase the tensile strength over that of the simple binary copper-zinc brasses. They have been in use for many years and were commonly but incorrectly called 'Manganese Bronzes'. Development work over many years has provided for industry a family of alloys with tensile strengths in excess of 700N/mm^2 and also with enhanced properties of wear resistance and corrosion resistance.

They are suitable for a wide range of applications and service conditions, ranging from decorative architectural use to wear-resistant automobile transmission components and the high strength, high integrity equipment used in mines. The alloys containing aluminium have an attractive, naturally lustrous surface; the self-healing film confers extra corrosion resistance. The silicon-containing alloy has excellent wear resistance.

The readily available high tensile brasses included in EN Standards are shown in ***Table 10.*** Further details of these materials can be found in ***Section 6.***

TABLE 8 – Brasses for Cold Working

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties
CuZn30 CW505L	CZ106	Excellent cold ductility. In sheet form can be used for deep drawing. As wire, suitable for the most severe cold deformation.
CuZn37 CW508L	CZ108	Known as 'Common Brass', this is a good general purpose alloy suitable for simple forming.
CuZn10 CW501L	CZ101	Gilding metal with highest copper content. Very good corrosion resistance. Can be brazed and enamelled.
CuZn15 CW502L	CZ102	Similar to CW501L with slightly superior mechanical properties.
CuZn20 CW503L	CZ103	Further improvement in mechanical properties. Corrosion resistance not quite so good as CW501L. Good for deep drawing.
CuZn20Al2As CW703R	CZ110	Aluminium brass, common in tube form. Has excellent corrosion resistance. Used particularly for applications in clean seawater.

TABLE 9 – Brasses for Casting

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties
CuZn33Pb2-C CC750S	SCB3	General purpose sand castings. Moderate strength and good corrosion resistance.
CuZn39Pb1Al-C CC754S	DCB3	This is the most commonly supplied die casting brass. A fine grained version is available.
CuZn35Pb2Al-C CC752S	DZR1	This and CC751S (DZR2) have properties similar to CC754S (DCB3) but can be heat-treated to give resistance to dezincification.
CuZn33Pb2Si-C CC751S	DZR2	See remarks for CC752S (DZR1).
CuZn35Mn2Al1Fe1-C CC765S	HTB1	Alloy has good strength and toughness and good corrosion resistance. Sand casting is employed for most purposes, but die castings can also be produced and these will have superior mechanical properties.
CuZn25Al5Mn4Fe3-C CC762S	HTB3	This alloy is the nearest equivalent to the British Standard CC762S (HTB3) but there are many differences. Neither alloy should be used for marine conditions. They have higher strength than CC765S (HTB1).

Brasses for electrical applications

Brass is widely used for contacts and terminals in electrical applications. Its electrical conductivity is good and it has the great advantage that the thin oxide film which forms on exposure to the air is electrically conductive so that contact resistance does not increase. The precise choice of alloy will depend on the service conditions. The electrical properties of some readily available alloys are listed in ***Table 11***.

Brasses for architectural applications

Brasses containing aluminium or manganese are frequently used for architectural applications because of the self-healing, attractive surface films which they exhibit. Manganese brass CW720R (CZ136) has a chocolate coloured film when oxidised and the aluminium-containing brasses which are included in EN 12167 as CW623N (CZ130) have a bright yellow colour with a silvery sheen. Both types of alloy have excellent hot workability which allows the complex section shapes required in many architectural applications to be produced. Other attractive colours are available with the use of the gilding metals, CW501L (CZ101), CW502L (CZ102) and CW503L (CZ103) available as extruded sections, rolled sheet and strip and as tube.

For information on surface finishes, see ***Section 5.***

TABLE 10 – High tensile brasses included in EN Standards

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties	
		Typical Applications	Tensile Strength N/mm²
CuZn40Mn1Pb1AlFeSn CW721R	CZ114	Gas valves, lift track sections, switchgear. Door lock parts for railway carriages. Spinners for classic cars. Yacht fittings - rope guides.	450-580
CuZn40Mn1Pb1FeSn CW722R	CZ115	Low aluminium content makes this suitable for use when components are to be assembled by soldering or brazing. Very suitable for finish plating.	450-580
CuZn25Al5Fe2Mn2Pb CW705R	CZ116	High strength and corrosion resistance. Suitable for valve spindles, etc.	600-750
CuZn37Mn3Al2PbSi CW713R	CZ135	Silicon addition gives extra wear and galling resistance to suit applications such as gearbox components.	540-700
CuZn40Mn1Pb1 CW720R	CZ136	Manganese brass for architectural sections.	350-600
CuZn35Mn2Al1Fe1-C CC765S	HTB1	Casting brass of good strength and corrosion resistance.	450 (sand cast)
CuZn25Al5Mn4Fe3-C CC762S	HTB3	Casting brass with higher strength but reduced corrosion resistance.	750 (sand cast)

Brasses for decorative applications

For costume jewellery, decorative trims and other similar applications the low-zinc brasses or gilding metals mentioned above are recommended. They have an attractive golden colour which varies with copper content, and good tarnish resistance. For applications where lustre must be retained indefinitely they should be lacquered (***see Section 5***).

Nickel silvers are also widely used for decorative purposes. They require no protection or special attention when used indoors, although it should be noted that there will be a slight yellowing of the original silvery-white colour 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.

Dezincification-resistant brass

In certain circumstances where water supplies are unusually aggressive, conventional duplex brass water fittings can suffer a form of corrosion known as dezincification. This involves selective leaching of the zinc which can cause fracture of the fitting. Dezincification-resistant brass, CW602N (CZ132), should then be specified. This is made as fittings, stopcocks and valves with a carefully controlled composition by extrusion or hot stamping, followed by heat treatment to ensure that the material will satisfy the requirements of the standard dezincification-resistance test. Versions of the alloy suitable for diecasting are also available. Further details of the alloy are given in ***Section 7***.

TABLE 11 – Electrical conductivity and elastic modulus of some brasses

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties		
		Typical Applications	Modulus of elasticity N/mm²x10³	Electrical Conductivity %IACS
CuZn10 CW501L	CZ101	Springs	124	44
CuZn30 CW505L	CZ106	Lamp caps. In strip and wire form for springs and contacts	117	28
CuZn37 CW508L	CZ108	Lamp caps and switch components. In strip and wire form for springs and contacts	111	26
CuNi12Zn24 CW403J	NS104	Used in strip form for relay and contact springs. Resistance wire and strip for moderately elevated temperatures, contacts, connectors, connector pins and terminals.	130	8
CuNi18Zn20 CW409J	NS106	As above	135	6
CuNi18Zn27 CW410J	NS107	As above	140	5.5
CuZn40Pb2 CW617N	CZ122	Hot stamped components such as terminals	96	27
CuZn39Pb3 CW614N	CZ121 Pb3	Machined components such as plug pins, switch terminals	96	28
CuZn33Pb2-C CC750S	SCB3	Cast components	-	20
CuZn39Pb1Al-C CC754S	DCB3	Cast components	-	18
CuZn35Mn2Al1Fe1-C CC765S	HTB1	Heavy duty components requiring strength and moderate electrical conductivity	-	22

Brasses for service in seawater

The small additions of tin in Naval brass and Admiralty brass improve the corrosion resistance in seawater. Naval brass, old BS specification CZ112, contains 60% Cu, 39% Zn and 1% Sn. It is a duplex brass and is therefore harder and stronger, but less ductile than Admiralty brass, CW706R (CZ111), which contains 71% Cu, 28% Zn with 1% Sn and is an alpha brass. The nearest equivalent to Naval brass is a leaded alloy, CW712R. Nowadays Aluminium brass CW702R (CZ110) has replaced Admiralty brass for tubes for marine service, but Admiralty brass continues to be used for fresh water. It should be noted that the alumina film which forms on Aluminium brass will prevent wetting by solder so aluminium-free alloys must be chosen if soldering is required.

Dezincification-resistant brass and some high tensile brasses can also be used for marine applications.

Brass tubes for fluid handling

If brass tubes are used in the hard drawn condition, or if they have been severely cold worked by bending or swaging in assembly, they should generally be stress relief heat treated to ensure freedom from stress corrosion cracking, unless the conditions of service are such that exposure to ammonia in any form is unlikely. Fuel lines, oil pipes etc, made up using annealed tube and with reasonably gentle bends, do not require treatment unless their service environment is unusual.

Arsenical 70/30 brass tube for heat exchangers CW707R (CZ126) is widely used in fresh water service and is the preferred brass for applications such as automotive radiators and oil coolers. Its arsenic content (0.02 - 0.06%) helps to combat dezincification and improves corrosion resistance. Admiralty brass CW706R (CZ111), containing 1% tin, offers slightly increased general resistance to erosion corrosion and substantially increased resistance to both pitting and erosion corrosion in the presence of sulphide pollution. It is the preferred brass for condenser and heat exchanger tubes handling fresh waters with less than 2,000ppm dissolved solids, but is not recommended for seawater service at water speeds in excess of 2.5-3.0 m/s. At the low water speeds commonly associated with oil coolers, for example, Admiralty brass should not suffer erosion corrosion and, if the cooling water is polluted with sulphide, or long periods of stagnation leading to decay of marine organisms and activity of sulphate-reducing bacteria within the tubes are experienced, the sulphide-resistance imparted by its tin content makes it preferable to Aluminium brass.

Aluminium brass CW702R (CZ110) is easily best for seawater service - both as condenser and heat exchanger tubing and as seawater piping. It has been very widely used for the condensers of fossil-fuelled and nuclear power stations throughout the world and also for the heat-recovery sections of desalination plants. For optimum performance the cooling water is treated with **ferrous sulphate**, which ensures the formation of a surface film which is highly protective and does not interfere seriously with heat transfer.

Tungum Tube

The aluminium-nickel-silicon brass CW700R (CZ127) Tungum was originally developed for the hydraulic lines in the control systems of aircraft. It combines excellent fatigue properties with high strength to weight ratio and good corrosion resistance particularly in seawater (***see case study on page 27***).

Like all brasses, Tungum maintains good mechanical properties at cryogenic temperatures with values for strength and ductility at –196ºC being slightly higher than at room temperature.

It has very good resistance to stress corrosion cracking but is not immune, so care should be taken not to leave highly stressed pipes in ammonical or mercurous environments.

Tungum Tube is used in:

- *Hydraulic systems in aviation, offshore and marine applications*
- *High pressure gas transportation, e.g. by BOC and Air Products for carrying high pressure oxygen where non-sparking requirements are mandatory.*

Cleanliness of tube - carbon films

Tube specified for use in fresh water or marine conditions should be purchased in accordance with EN 12449 (General) or EN 12451 (Heat exchangers). These standards specifically refer to Surface Quality (Clause 6.4) and particular consideration may need to be given to the actual or potential contamination of the surface with carbon films, even though carbon is not specifically mentioned in the standards.

Such films occur during the thermal decomposition of drawing lubricants during final annealing or they may occur during fitting if lubricant residue is left in the bores. (Most modern lubricants and manufacturing techniques are designed to avoid this problem and evidence of carbon may be a sign of questionable manufacturing practice).

Carbon films have been shown to increase the risk of pitting corrosion in copper water tube and pitting and erosion in brass condenser and heat exchanger tube. For this reason the purchaser may wish to consider invoking additional testing (***see EN 1057 annex B***).

Section 4 – WHICH FORMS OF BRASS?

EXTRUSIONS

Extruded rods, bars and profiles are one of the most readily available forms of the duplex brasses. They are made by forcing hot metal through a shaped die. Round or polygonal shaped sections are held in stock and specially shaped profiles can be produced to order. Material may be supplied either as extruded or may be further worked by cold drawing to improve properties, tolerances and surface finish. The material is sound and has a uniform, fine grain structure. The most readily available alloys are listed in ***Table 12***.

Hollow profiles are also available and may be the most cost-effective starting stock for the manufacture of many components.

HOT STAMPINGS

A hot stamping is manufactured by forming a hot, solid billet of material between two halves of a die. The die is so designed as to produce a component which is as close in size to the finished desired product as possible with a minimum of machining and surface finishing necessary. The metal structure is sound and uniformly fine grained. The duplex brasses are available in this form. Those listed in the Standards are shown in ***Table 13***, the most popular and readily available are covered in ***Table 7***.

Where needed, it is possible to use inserts in the dies to produce hollow recesses in hot stampings to reduce the need for subsequent drilling. The hot stamping process is ideal for medium to long runs of components such as bosses, elbows, tees, valves, other plumbing accessories and general engineering parts needing strength, machinability and corrosion resistance at a modest cost.

FORGINGS

Open forging is used to produce relatively short runs of large components. Preheated billets are repeatedly struck between head and anvil while the material is moved to obtain the required round, rectangular or complex shape. Formers and punches are used to help produce shapes near-net-size. Leaded alloys must be forged with more care than is needed for hot stamping. Single phase alloys can be forged relatively easily provided that impurity contents likely to produce hot shortness are kept low.

TABLE 12 – Brasses available as extruded rod and section

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Typical Applications
CuZn39Pb3 CW614N	CZ121 Pb3	High speed free-machining brass.
CuZn36Pb2As CW602N	CZ132	Dezincification resistant brass. Good corrosion resistance.
CuZn37Pb2 CW606N	CZ131	This alloy is suitable for riveting and also has good machinability.
CuZn39Pb2 CW612N	CZ128	Machining and semi-riveting brass.
CuZn40Pb2 CW617N	CZ122	General purpose brass.
CuZn43Pb2 CW623N	CZ130	Suitable for complex sections.
CuZn43Pb2Al CW624N	CZ130	Complex section brass with aluminium.
CuZn36Sn1Pb CW712R	CZ112	Corrosion resistant naval brass.
CuZn40Mn1Pb1AlFeSn CW721R	CZ114	High tensile brass.

TABLE 13 – Brasses for hot stamping

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Relevant Properties	Approximate Tensile Strength N/mm^2
CuZn40Pb2 CW617N	CZ122	This is the alloy most frequently used for hot stamping. Complex shapes can be formed and it has good machinability.	360
CuZn40 CW509L	CZ109	This lead-free alloy has superior cold ductility, as well as excellent hot working properties. It is not so easily machined.	340
CuZn39Pb3 CW614N	CZ121 Pb3	Has excellent machinability.	360
CuZn39Pb2 CW612N	CZ128	This alloy has better cold ductility than CuZn40Pb2.	350
CuZn36Pb2As CW602N	CZ132	Dezincification resistant brass. Used for plumbing fittings.	280
CuZn37Mn3 Al2PbSi CW713R	CZ135	High tensile brass. Silicon addition imparts excellent wear resistance.	510
CuZn40Mn1Pb1Al1FeSn CW721R	CZ114	High tensile brass with lead to improve machinability.	440
CuZn40Mn1Pb1FeSn CW722R	CZ115	High tensile brass with no aluminium. Can be soldered.	390
CuZn40Mn1Pb1 CW720R	CZ136	High tensile brass with excellent resistance to seizure. Also used for architectural fittings.	To be agreed between purchaser and supplier

Flanges, large bosses, bearing blocks and similar components are produced by this process, especially when the mechanical properties required are to be better and more uniform than available with castings.

WIRE

Wire is made by drawing cold from rod through a succession of dies that reduce the diameter to give a degree of work hardening not so easily achievable by any other process apart from strip rolling. This means that wire can be made with strength, hardness and springiness far higher than for most other materials. Depending on composition, tensile strengths in the range of 300–850N/mm^2, and hardness values up to 200HV can be produced. Due to the ductility of many brasses, reductions in sectional area of over 90% can be made between anneals.

Some of the brasses in wire form, covered in EN 12166, are shown in ***Table 14***.

The most usual shape of wire is round. In this form wire is available in sizes ranging from 0.10mm up to 8.00mm and beyond. There is little standardisation, however, since dimensional requirements are usually dictated by the individual customer's requirements. Improvements in die materials in recent years have meant that tolerances on size have been tightened to meet customer requirements and those listed in ***Table 15*** are now available as standard. Square, rectangular and custom shaped wires are also freely available in sizes from about 0.25mm to 8.0mm across flats. Wire is used for the manufacture of pins, springs, clips, zips, electrical applications and a wide variety of other uses including rail for model railways.

Irrespective of shape, wire is provided either as coils or on reels. Maximum package weights vary from about 1,000kg for larger sizes to 3kg for very fine wires.

SHEET AND STRIP

Brasses which are available in coil, flat lengths or circles, covered in EN 1652 are shown in ***Table 16***.

Strip widths up to 330mm are common with minimum thickness typically being 0.15mm. Specialist suppliers can provide strip with lengths joined by welding or brazing and layer wound on to wide steel drums containing up to 500kg of strip in one continuous length. Strip is used frequently as the feedstock for transfer presses and other continuously running machines to produce small parts punched, bent, formed and deep drawn to shape including locks, hinges, finger plates, reflectors, electrical components, terminals, contacts, springs, cartridge cases and good quality light bulb bases and holders.

Brass strip is widely produced from semi-continuous slabs or strip (***see Figure 7, page 39***). Slabs (150mm thick) are hot rolled, and strip (13 - 20mm) is cold rolled and annealed (625ºC) to break down the initial coarse as cast structure and soften the material to allow further cold rolling to produce strip in the desired temper.

Sheet is a product wider than 300mm and less than 10mm thick supplied flat. The alloys commonly available are as for strip but low-leaded Clock brasses and Aluminium brasses with extra corrosion resistance are also supplied.

The surface finish on sheet and strip is often an important consideration. For deep drawing operations it is useful to have some roughness in order to retain lubricant during deformation whereas for applications requiring subsequent polishing and plating at least one side should be 'plating quality'.

Besides surface finish, fitness for purpose is obtained by specifying hardness and/or grain size in order to be able to optimise the quality of edge shearing, bending, cupping or deep drawing without cracking or failure (***see Figure 12, page 42***).

TABLE 14 – Brass wire (EN 12166)

Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Typical Applications
CuZn10 CW501L	CZ101	Gilding Metal or Commercial Bronze. Zip fasteners and decorative items.
CuZn15 CW502L	CZ102	Jewellery Bronze - springs, contacts, wire shapes, jewellery.
CuZn30 CW505L	CZ106	Electrical applications include fluorescent tube studs, alkaline battery anodes, vacuum cleaner electrical systems. Decorative meshes and embossed shaped wire for use on dishes, salvers and trophies. Picture frame wire. Model making. Ferrules.
CuZn36 CW507L	CZ107	Widely used for cold headed fasteners, springs and screws with rolled threads. Picture frame wire. Knitted wire washers. Connector pins.
CuZn35Pb2 CW601N	CZ119 / CZ131	Screws and machined parts.
CuZn40Si	CZ6	Brazing wire - ideal for joining mild steel.
CuNi10Zn27	NS103	Nickel silver - white colour. Good corrosion resistance. Uses - toothbrush anchor wire, pins, jewellery, model making.

TABLE 15 – Standard tolerances on diameter of round wire

Specified Diameter		Tolerance (Class A)
Over (mm)	Up to & including (mm)	± (mm)
-	0.25	0.005
0.25	0.50	0.008
0.50	1.0	0.012
1.0	2.0	0.020
2.0	4.0	0.030
4.0	6.0	0.040
6.0	10.0	0.060
10.0	18.0	0.080

TABLE 16 – Brasses in sheet or strip (EN 1652)

Compositional Designation and EN number		Description	Nearest Equivalent Old British Standard Alloy
CW507L	CuZn36	Common Brass	CZ107
CW505L	CuZn30	70/30 Brass	CZ106
CW501L	CuZn10	90/10 Gilding Metal	CZ101
CW502L	CuZn15	85/15 Gilding Metal	CZ102
CW503L	CuZn20	80/20 Gilding Metal	CZ103
CW409J	CuNi18Zn20	Nickel Silver - polishes white	NS106

TUBE

Welded tube is manufactured from strip and has the benefit of this relatively cheaper cold working process but the disadvantage of needing high volume applications. Precision rolled strip can be made to thin gauge and subsequent roll-forming and welding operations automated. Welded tube is widely used for high volume decorative purposes where strength and proven integrity is less of an issue.

Seamless tubes (EN 12449, General Purpose Tubes) are normally made by drawing to size from hollow tube shells produced by extrusion. They are then cold drawn to size by a succession of passes with interstage anneals as required and supplied in either straight lengths or coil. Some of the tubes covered in EN 12449 are shown in ***Table 17***.

The advantages of using seamless tube in design is that the cold working results in a thin walled, close tolerance, high strength to weight product which may give weight advantages over corresponding cast and machined tubes.

Normally brass tubes are thought of as being circular, with tolerances on inside and outside diameters that make them easy to join with standard fittings. However, tubes can in fact be made by many different techniques to bespoke shapes and sizes. They can be square, circular or hexagonal. They can be made twisted or indented. They can be fluted, decoratively patterned or grooved. The inside shapes can be different from the outside and can have specified wall thicknesses, uniform or uneven. For example, a round hole inside a square tube is often needed to ensure correct flow of coolant. Another frequent need is for an oblong tube with the corners either square or typically, radiused to half the wall thickness. Often, one side must be significantly thicker than the other. In tubular heat exchangers, such as oil coolers, there are concentric tubes and the flow of coolant can be made turbulent by helical grooves or raised ridges.

Brass is frequently specified for the tubes of heat exchangers (EN 12451:– Aluminium, Admiralty, Arsenical) because it is relatively cheap, strong, corrosion resistant and easily soldered. Precision brass tube is used for the concentric thin walled tubes to make collapsible aerials and pointers.

PLATE

Plate is used to make the tubeplates of many heat exchangers, even when the tubes themselves may not be of brass. It is generally supplied 'as manufactured' in the hot rolled condition. If required it can be pickled clean before delivery or milled flat. It is usually supplied with sheared, sawn or machined edges. Thicknesses are generally greater than 10mm. Both single phase and duplex brasses in leaded and lead-free versions are available.

CASTINGS

Pouring of liquid metal into a shaped mould to solidify as a shape that needs minimal finishing is one of the oldest production methods. With modern technology the techniques available now produce products that are of good, reproducible quality and made to close tolerances on size and properties. Many techniques are available and described below. Further information is included in CDA TN42.

Sand and shell mould castings

Most castings are made by pouring metal into sand moulds. Depending on the casting required, the sand may be bonded with clay or silicates or various organic mixes. Shell moulding involves the use of a thermosetting resin bond. For hollow castings, cores are used. Moulding techniques range from simple hand moulding to fully mechanised repetition moulding for very long runs.

Permanent mould processes

For long production runs it is frequently economical to make permanent metallic moulds from which many castings can be made with good reproducibility. The rapid rate of cooling given by chill casting gives good properties. Metal may either be poured by gravity into simple open moulds or injected into a closed mould under pressure.

Low pressure die castings

Gravity diecasting is used to make taps and other plumbing fittings simply and cheaply. Fairly complex shapes can be made with a good surface finish. Because of solidification shrinkage and other considerations, not all brasses can be cast this way but the alloys available include conventional 60/40 leaded brasses and some high tensile brasses, sufficient for most applications.

High pressure die castings

For relatively long runs, this process gives excellent products with good properties, accurate reproduction and thin walls. If the mould costs can be amortised cost-effectively, it is an excellent process.

Investment casting

Investment casting by the 'lost wax' method has been used for centuries to make useful and decorative, high precision components in weights from grammes to tonnes.

TABLE 17 – Brass tubes – general purpose (EN 12449)

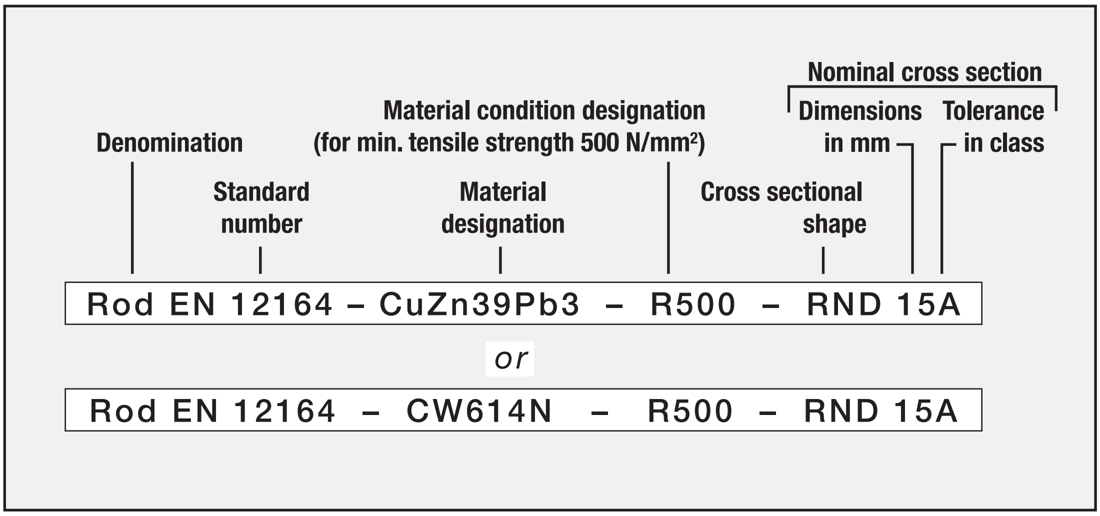
Compositional Designation and EN number	Nearest Equivalent Old British Standard Alloy	Comments
CuZn10 CW501L	CZ101	Widely used - driving bands for projectiles. Architectural applications - handrails. Communication systems - wave guides. Bellows for fluid and steam systems.
CuZn15 CW502L	CZ102	Used for condensers and cooling units, gauges and instrument tubes. Decorative uses. Musical instruments.
CuZn20 CW503L	CZ103	Architectural applications.
CuZn30 CW505L	CZ106	Easy to work - most ductile of all brasses (α structure).
CuZn37 CW508L	CZ108	Common brass. More difficult to work than CW505L ($\alpha + \beta$ structure).
CuZn35Pb1 CW600N	CZ118	Machinability good due to lead but limited cold working possible.
CuZn36Pb3 CW603N	CZ124	Machinability excellent due to increased lead but cold working should be avoided.
CuNi12Zn24 CW403J	NS104	Nickel Silver - white colour. Spring and decorative applications.
CuNi18Zn20 CW409J	NS106	Whitest of Nickel Silvers - good corrosion resistance - decorative applications.

ORDERING INFORMATION
European Standard Specifications

The EN Standards urge the use of a 'Product Designation' as a means of providing a description to 'convey mutual comprehension at international level'. This designation will comprise, in sequence :

Denomination	e.g. rod, wire, strip, etc.
Standard number	(EN xxxxx)
Material designation	Alloy symbol or number, e.g. CuZn30 or CW505L
Material condition designation	Mechanical property requirements, e.g. R380 for minimum tensile strength of 380N/mm²
Cross-sectional shape	e.g. RND - round or SQR - square
Nominal cross-sectional dimension	e.g. 15 for 15mm
Tolerance class	e.g. for wire: A, B, C, D or E
Corner type	Where appropriate, e.g. SH - sharp or RD - rounded

For example, free-machining brass rod can be ordered to the appropriate EN 12164 as:



The product designation provides a summary of primary ordering information when joined with quantity and length/pieceweight tolerance. Additional ordering information may include method of testing, packing details and type of quality assurance certification.

Table 18 shows a few of the titles of the EN standards for copper and copper alloys.

TABLE 18 – European standards for copper and copper alloys covering brasses		
Title	**EN Number**	**Superseded BS Number**
Plate, sheet, strip and circles for general purposes	1652	2870, 2875
Plate, sheet and circles for boilers, pressure vessels and hot water storage units	1653	2870, 2875
Strip for springs and connectors	1654	2870
Seamless round tubes for general purposes	12449	2871
Seamless round tubes for heat exchangers	12451	2871 Pt3
Rolled, finned seamless tubes for heat exchangers	12452	-
Rod for general purposes	12163	2874
Rod for free-machining purposes	12164	2874
Wrought and unwrought forging stock	12165	2872
Wire for general purposes	12166	2873
Profiles and rectangular bar for general purposes	12167	2874
Hollow rod for free-machining purposes	12168	-
Rod and wire for brazing and braze welding	1044	1845
Forgings	12420	2872
Plumbing fittings Parts 1-2	1254-1/2	864
Ingots and castings	1982	1400
Master alloys	1981	-
European numbering system	1412	-
Material condition or temper designation	1173	-
Scrap	12861	-

Tables 19 and 20, for wrought and cast material respectively, show the brasses and nickel silvers most common in Europe.

Quality assurance EN ISO 9001:2000

This standard for quality assurance has replaced BS 5750 Pt 2 as the document covering the requirements for quality management systems for the production of the materials covered in this publication. Conformance is assured by assessment of quality management systems by accredited organisations. Products manufactured in accordance with this standard are assured of conforming to order requirements. Although manufactured in accordance with an approved quality management system by the manufacturer, it is the customer's duty to check that the order is sufficiently explicit to ensure that material is fit for the purpose intended.

Certification

Certificates of conformity can be a valuable assurance of the compliance of the goods supplied with written order requirements. If self-certified by the manufacturer, the customer should ensure that full responsibility is accepted. If the goods are manufactured in accordance with an approved scheme such as EN ISO 9001, customers can be more certain that manufacturers' quality-monitoring equipment has been calibrated according to National Standards.

Kitemark

A product guaranteed to conform to standard and produced under a quality control system approved under the BSI 'Kitemark' scheme can bear the appropriate marking.

CE Mark

Products that are subject to EEC directives covering safety may be required to carry a 'CE' mark of conformity to specification. Frequently this mark is applied by manufacturers after self-certification.

Weight calculation

(Courtesy Outokumpu Copper MKM Ltd)

Calculation of the weight of brasses, assuming a density of 8450 kg/m^3

To use D in inches, apply the formulae and multiply the answer by 645.2

Shape	kg/m	kg/ft
Round	$D^2 \times 0.00663$	$D^2 \times 0.00203$
Hexagon	$D^2 \times 0.00732$	$D^2 \times 0.00223$
Square	$D^2 \times 0.00845$	$D^2 \times 0.00257$
Rectangle	Width x Thickness x 0.00845	Width x Thickness x 0.00257

TABLE 19 – BS and European designations - summary of compositions for wrought products

Alloy Designation			Common British Description	Remarks	Availability						
EN Compositional Designation and Number		Nearest Old BS Equivalent			Tube	Rod	Profiles	Wire	Forgings	Plate & Sheet	Strip
BINARY COPPER-ZINC ALLOYS											
CuZn0.5	CW119C			Used for radiator fin strip and for building purposes.							x
CuZn5	CW500L	CZ125	Cap copper	Industrial use practically confined to caps for ammunition.	x	x				x	x
CuZn10	CW501L	CZ101	Gilding Metal	Good corrosion resistance. Used for architectural metalwork and costume jewellery. Can be brazed and enamelled.	x	x		x		x	x
CuZn15	CW502L	CZ102	Gilding Metal, Jewellery bronze	Used for condenser units, gauges, instrument tubes, springs, contacts and jewellery	x	x		x		x	x
CuZn20	CW503L	CZ103	Ductile brass	As above. This alloy has good deep drawing properties.	x	x		x		x	x
CuZn28	CW504L			Suitable for cold deformation.		x					
CuZn30	CW505L	CZ106	70/30 brass (Cartridge brass)	In sheet form known as deep drawing brass. As wire, suitable for severe cold deformation.	x	x		x		x	x
CuZn33	CW506L			A good cold working brass.		x				x	x
CuZn36	CW507L	CZ107		General purpose alloy suitable for simple forming.	x	x	x	x		x	x
CuZn37	CW508L	CZ108	Common brass	As above	x	x	x	x	x	x	x
CuZn40	CW509L	CZ109	60/40 brass	Good for hot working. Limited ductility at room temperature.	x	x	x		x	x	x
COPPER-ZINC-LEAD ALLOYS											
CuZn35Pb1	CW600N			Machinable and has good workability.	x	x	x	x		x	x
CuZn35Pb2	CW601N			Machinable and has good workability. Used for riveting.	x	x	x	x			
CuZn36Pb2As	CW602N	CZ132	Dezincification-resistant brass	Good hot ductility. Heat treated to give dezincification resistance.	x	x	x		x		
CuZn36Pb3	CW603N	CZ124	Free-cutting brass	Excellent machinability but very limited cold workability.	x	x	x	x			
CuZn37Pb0.5	CW604N			Machinable and has some cold workability.	x					x	x
CuZn37Pb1	CW605N			Machinable and has good to very good cold workability.	x	x					
CuZn37Pb2	CW606N	CZ119/131	Free-cutting brass with improved ductility	Good machinability, some cold workability. Used for cold heading and riveting.		x	x	x		x	x
CuZn38Pb1	CW607N	CZ129		Machinable and has good to very good cold workability	x	x	x				
CuZn38Pb2	CW608N	CZ128	Free-cutting brass	Good machinability, sufficient ductility for some cold work.	x	x	x	x	x	x	x
CuZn39Pb0.5	CW610N	CZ137		Machinable and has some workability.		x	x	x	x	x	x
CuZn39Pb1	CW611N	CZ129	Free-cutting brass with improved ductility	Commonly used for hot stamping. Machinable and good workability.		x	x		x		
CuZn39Pb2	CW612N	CZ120/128	Free-cutting brass with improved ductility	Good machinability, some cold workability but lower than that of CZ131.		x	x	x	x	x	x
CuZn39Pb2Sn	CW613N			Similar to CZ128 but with higher permitted impurity level. Unsuitable for machining at highest speeds.		x	x		x		
CuZn39Pb3	CW614N	CZ121Pb3	High speed machining brass	Excellent machinability, very limited cold workability. Also used for hot stamping.	x	x	x	x	x		
CuZn39Pb3Sn	CW615N			Similar to CZ121Pb3 but with higher permitted impurity level. Unsuitable for machining at highest speeds.					x		
CuZn40Pb1Al	CW616N			Forging brass. The aluminium gives an attractive colour and eases extraction from the dies.					x		
CuZn40Pb2	CW617N	CZ122	Free-cutting brass	Most popular alloy for hot stamping. Excellent machinability but very limited cold ductility compared with alloys also containing 2% Pb but with higher copper content	x	x	x	x	x		
CuZn40Pb2Al	CW618N		Brass for architectural sections	Good bright yellow colour for architectural profiles. The higher the zinc content the more complex the profiles achievable.			x				

TABLE 19 – continued

Alloy Designation			Common British Description	Remarks	Availability						
EN Compositional Designation and Number		Nearest Old BS Equivalent			Tube	Rod	Profiles	Wire	Forgings	Plate & Sheet	Strip
CuZn40Pb2Sn	CW619N			Similar to CZ122 but with higher permitted impurity level. Unsuitable for machining at highest speeds.		x	x		x		
CuZn41Pb1Al	CW620N			Production of complex profiles by hot extrusion.			x				
CuZn42PbAl	CW621N			As above			x				
CuZn43Pb1Al	CW622N			As above			x				
CuZn43Pb2	CW623N	CZ130		Production of complex profiles by hot extrusion. Aluminium free.			x				
CuZn43Pb2Al	CW624N	CZ130		Good bright yellow colour for architectural profiles. The higher the zinc content the more complex the profiles achievable.			x				
COMPLEX COPPER-ZINC ALLOYS											
CuZn13Al1Ni1Si1	CW700R	CZ127	Tungum	Hydraulic tubes.	x						
CuZn20Al2As	CW702R	CZ110	Aluminium brass	Excellent corrosion resistance in clean seawater and is a favoured alloy for condenser tubes.	x					x	x
CuZn23Al3Co	CW703R			Used for springs and connectors.							x
CuZn23Al6Mn4Fe3Pb	CW704R					x			x		
CuZn25Al5Fe2Mn2Pb	CW705R	CZ116	High tensile brass	High strength and good corrosion resistance.		x			x		
CuZn31Si1	CW708R			General purpose alloy produced as rod and tube.		x					
CuZn32Pb2AsFeSi	CW709R			Dezincification-resistant brass of Swedish origin.	x	x					
CuZn35Ni3Mn2AlPb	CW710R				x	x	x		x		
CuZn36Pb2Sn1	CW711R	CZ134	Leaded naval brass	Tin addition improves corrosion resistance, especially in sea water. Lead improves machinability.		x					
CuZn38Sn1Pb	CW712R	CZ112	Leaded naval brass	As above		x	x	x	x		
CuZn37Mn3Al2PbSi	CW713R	CZ135	High tensile brass with silicon	Silicon addition gives extra wear and galling resistance to suit applications such as gear box components.	x	x	x		x		
CuZn37Pb1Sn1	CW714R					x	x	x	x		
CuZn38AlFeNiPbSn	CW715R									x	
CuZn38Mn1Al	CW716R					x					
CuZn39Mn1AlPbSi	CW718R			Silicon and manganese additions give good wear resistance for gear box components and bearings.	x	x	x		x		
CuZn39Sn1	CW719R	CZ133	Naval brass	Tin addition improves corrosion resistance especially in sea water.		x	x		x	x	
CuZn40Mn1Pb1	CW720R	CZ136	Manganese brass	Excellent resistance to seizure. Used in contact with cast iron. Used for architectural profiles. Attractive chocolate brown oxide.		x	x	x	x		
CuZn40Mn1Pb1AlFeSn	CW721R	CZ114	High tensile brass	General purpose high strength alloy.		x	x		x		
CuZn40Mn1Pb1FeSn	CW722R	CZ115	High tensile brass	Aluminium free, used where components are to be joined by soldering or brazing.		x	x		x		
CuZn40Mn2Fe1	CW723R			General purpose high strength alloy.	x	x	x		x		
COPPER-NICKEL-ZINC ALLOYS											
CuNi7Zn39Pb3Mn2	CW400J						x	x	x		
CuNi10Zn27	CW401J	NS103	10% nickel silver					x		x	x
CuNi10Zn42Pb2	CW402J	NS101	Leaded 10% nickel brass				x	x	x		
CuNi12Zn24	CW403J	NS104	12% nickel silver	Good spring properties.	x	x	x	x		x	x
CuNi12Zn25Pb1	CW404J	NS111		Lead addition improves machinability.						x	x
CuNi12Zn29	CW405J			Contains no lead and is only available as strip.							x
CuNi12Zn30Pb1	CW406J			Used for extrusions.			x	x			
CuNi12Zn38Mn5Pb2	CW407J						x				
CuNi18Zn19Pb1	CW408J	NS113					x	x			
CuNi18Zn20	CW409J	NS106	18% nickel silver	The whitest of the nickel silvers with optimum corrosion resistance.	x	x	x	x		x	x
CuNi18Zn27	CW410J	NS107		Contains no lead and is only available as strip.						x	x

TABLE 20 – EN and old BS designations for cast products		
Alloy designation		Remarks
EN Compositional Designation and Number	Nearest Old BS Equivalent	
CuZn33Pb2-C CC750S	SCB3	General purpose castings for less onerous duties, gas and water fittings. Good machinability.
CuZn33Pb2Si-C CC751S	DZR2	Die casting brass with dezincification resistance. Mainly for water fittings.
CuZn35Pb2Al-C CC752S	DZR1	Die casting brass with dezincification resistance. Mainly for water fittings.
CuZn37Pb2Ni1AlFe-C CC753S	–	Die casting brass, fine grained and freely machinable.
CuZn39Pb1Al-C CC754S	DCB3	Die casting brass. Used extensively for plumbing fittings.
CuZn39Pb2AlB-C CC755S	DCB3a (fine grained)	Die casting brass used where superior strength and thinner sections with finer finishes are required.
CuZn15As-C CC760S	Arsenical brass	Used for sand castings. Has good corrosion resistance, suitable for brazing.
CuZn16Si4-C CC761S	Silicon brass	General purpose castings, both sand and die. Used particularly for valves and water fittings. Low lead content.
CuZn25Al5Mn4Fe3-C CC762S	HTB3	Suitable for all casting methods. Good resistance to wear under high load at low speeds such as rolling mill slipper pads, screwdown nuts, etc. Unsuitable for marine conditions.
CuZn32Al2Mn2Fe1-C CC763S	HTB1(Pb)	Lead containing version of HTB1 used mainly where friction and wear occurs, e.g. valve spindles.
CuZn34Mn3Al2Fe1-C CC764S	–	General high tensile brass. Sand and die castings.
CuZn35Mn2Al1Fe1-C CC765S	HTB1	General engineering castings suitable for all casting methods. Good resistance to corrosion. Frequently used for marine components including propellers.
CuZn37Al1-C CC766S	–	General purpose die casting brass.
CuZn38Al-C CC767S	DCB1	General purpose high quality engineering die castings.

Case Histories

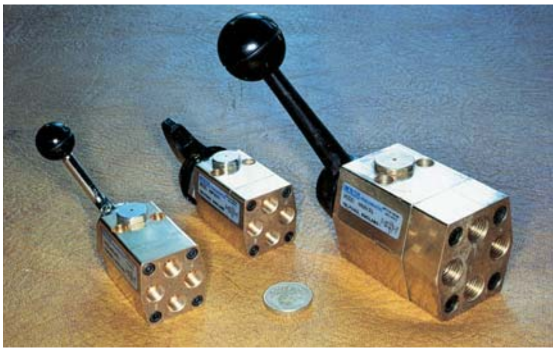
Handle for Rolls Royce car, hot forged from brass

Brass was found to be the material of choice, for longevity and reliability, for exterior door handles for the 'Silver Spirit'.

Handles made from a zinc based material had failed to meet the standards for which Rolls Royce is noted. A brass forged handle was designed and developed with the co-operation of a major hot brass stamper, whose involvement from an early stage resulted in substantial cost savings over the original concept. By switching to brass, a potential problem was removed without cost penalty, with retooling costs low and implementation of change achieved quickly.

(Rolls Royce)

A selection of Vickers' valves



(Vickers Systems Division Trinova Ltd)

A cost comparison favours brass rather than aluminium for the manufacture of Vickers' 4-way semi-rotary slide valves.

These valves operate in harsh and rugged environments such as quarries and mines, and in railway wagons, military vehicles and brewery handling equipment. The valves need to be manufactured from a corrosion resistant, low friction, self-lubricating and easily machined material, the obvious choice of material being a free-machining brass in extruded rod form. Material choice depends not only on properties, but also on cost-effectiveness. A possible alternative choice might be extruded aluminium, which has a lower raw material cost.

A full cost analysis shows that the finished cost of the valve body in brass is 15% cheaper than the same component made in aluminium, due to:

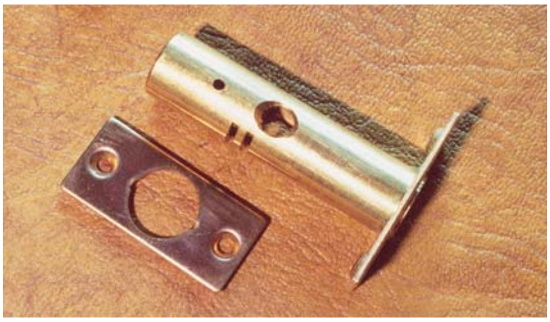
- *lower production costs, since brass machines faster than aluminium*
- *higher resale value of brass swarf*
- *no finishing requirement, since aluminium has to be hard anodised to have the same wear properties as brass.*

Concealed security bolt

Replacement of the steel tubular housing of this security bolt with brass has led to the production of a superior, all brass product, with no increase in cost.

The assembly consists of a round sliding bolt housed in a tube, the bolt being driven backwards and forwards with a splined key in the tube which mates with a rack on it. The assembly is fitted into the edges of doors and windows for additional security. The steel tube had to be machined, painted and then brazed to an end plate.

The following problems were encountered using steel: the tube and end plate had to go off site for brazing and the machining required a drilling operation where break-out of the drill left a flap on the bore.



(J E Reynolds & Co Ltd)

These manufacturing problems using steel led to brass being considered as an alternative material. Even though brass tube is five times the price of steel the switch to brass proved to be cost-effective. The brass tube does not need painting, due to its good corrosion resistance, and can be secured to the end plate without the need for brazing, due to the high degree of formability of brass. The brass tube machines quicker and a clean break-through on drilling enables all burrs to be removed easily by the reaming operation required to finalise the size of the bore. The whole process is now carried out on site and production rates have increased by over 300%.

Tungum tube preferred to stainless steel

(Tungum Hydraulics Ltd)

The Tungum tube (top sample) is expected to serve for 20 years marine exposure on a Shell semi-submersible support vessel. The stainless steel section (lower sample), from a southern North Sea gas platform in the Lima field, shows both crevice corrosion and chloride pitting after barely 5 years in the same environment.

Failure of stainless steel instruments and hydraulic tubing in these aggressive environments has necessitated replacements after only five years on platforms with a life expectancy of 20 years. This has had serious cost implications, not only in replacement materials, but in the higher labour costs involved in working offshore. An alternative material was sought and Tungum, CW700R (CZ127), a high copper brass containing aluminium, nickel and silicon, was found to be the most cost-effective. Tungum has a high strength-to-weight ratio, good ductility, excellent corrosion resistance (especially to seawater in the 'splash zone'), excellent fatigue properties and is non-magnetic and non-sparking. In tube form it exhibits clean bore features making it ideal for hydraulic and pneumatic applications. Shell's Southern Business Unit in Lowestoft now specifies Tungum tubing on all new platforms and is replacing existing stainless steel during platform refits. Despite Tungum being initially more expensive to buy, lifetime costing shows it to be the most cost-effective material for tubing in the oil/gas/petrochemical industry.

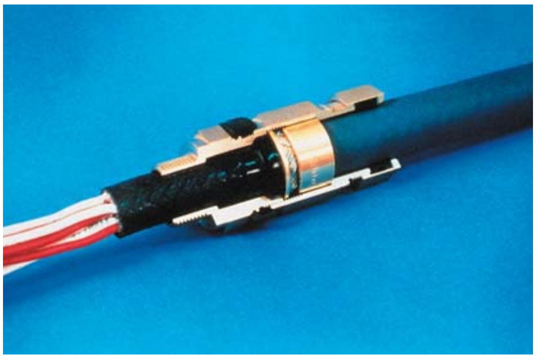
Automatic door closer

End and anchor plates made from brass last fifty times longer than steel and are cheaper to produce.

The ‘Perkomatic’ concealed door closer is secured to a door and door frame by end and anchor plates respectively. Twin chains connect the hydraulic cylinder mechanism in the door to the anchor in the frame, passing through the end plate and rubbing against it every time the door opens and closes. Brass stampings were chosen for the end and anchor plates as these were cheaper than forged steel plates, required no protective finish and also looked attractive. The self lubricating and low friction properties of brass give a life of 500,000 operations compared to 10,000 for steel.

(Samuel Heath & Sons plc)

Universal cable gland



(Hawke Cable Glands Ltd)

Brass cable glands are strong, high quality, high performance products made at low cost, with exceptional electrical, mechanical and corrosion resistant properties, ideally suited for a long life of use in all situations.

They are machined from extruded bar, with a cross-sectional profile designed to give optimum shape for minimum metal removal. Brass machines at exceptionally high rates, many times that of steel, giving short, economical cycle times. The swarf produced comes away in chip form rather than spiral, thus eliminating the need for chip breakers, and commands a high scrap value. The minimum cost of tooling required for machining brass makes it ideal for short runs or specials and modifications can be made at short notice. Brass cable glands are therefore cost-effective to manufacture.

Brass cable glands meet all the necessary safety regulations enabling them to be used with wire screened and armoured cable, they are much stronger than plastic, have better impact resistance and can be used at sub-zero temperatures. They have superb corrosion resistance, without the need for protective finishes, enabling them to be used in the offshore industry.

Control valves for pneumatically powered tools

The valve on the left incorporates more brass and yet is 17% cheaper to produce than the old design of valve on the right.

The control valve of a pneumatic tool consists of a valve body and a valve stem. Operation of a hand lever, attached to the valve body, pushes the valve stem down allowing compressed air to flow through the valve and operate the tool. The original design had a steel valve body into which a brass seat was inserted and machined, and a steel valve stem. Problems arose when the valve seat needed to be replaced during servicing. Machining the valve seat in situ, without factory tooling, was then necessary. This could be done incorrectly, causing loss of performance of the valve and damage to the company’s reputation. The company’s engineers came up with a new design which eliminated the need for machining in situ in the field, was totally interchangeable with existing models and was cost-effective. This design proposed a steel valve body with the seat machined in and a valve stem manufactured as a turned part from brass rod.

(Trelawny Products Ltd)

60mm bore bearing used in aircraft generators

(MPB Corporation)

Brass has the desirable properties that make it ideal for use as a rolling element cage material, such as good frictional properties against hardened steel components, reasonable strength, high toughness and excellent thermal conductivity. In addition, brass has good machining and joining characteristics that help to make it very cost-effective.

Bearings can range in size from the larger commercial bearings, such as heavy duty ones for use in rolling mills, to the high precision bearings custom produced for the aircraft industry. In both these types of application, the finished cost of bearing cages made from brass is significantly cheaper than if other materials were specified, due to the ease with which brass can be formed and machined.

Brass and stainless steel hose couplings

The brass fitting shown cost a quarter the price of an identical stainless steel one.

Brass is cheaper to buy than stainless steel but an even greater saving is made in the cost of machining. Free-machining brass is easier to machine than stainless steel (machinability rating of brass is 100% compared with 12% for 316 stainless steel), therefore production costs are much lower.

(Hydrapower Dynamics Ltd)

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.

Section 6 – TYPES OF BRASS

Brasses are copper alloys in which the principal alloying constituent is zinc. Their properties depend primarily upon the proportion of zinc present but can be usefully modified by the introduction of additional elements to further improve specific characteristics such as strength, machinability or resistance to particular forms of corrosion.

The principal wrought and cast brass compositions in commercial use are listed in *Tables 19 and 20 on pages 24 - 26* with an indication of the forms in which they are available. The tables include two groups of alloys not commonly described as brasses: the nickel silvers (which, except for the 20% nickel versions, contain more zinc than nickel) and the so-called bronze-welding filler alloys. In the USA an alloy containing 5% each of zinc, tin and lead is known as ‘red brass’, but in the UK this alloy is classified as a leaded gunmetal with the EN designation CC491K (LG2). Gunmetals are not covered in this publication.

Effect of zinc content

The problem of selecting the appropriate brass for any particular service from the range presented is simplified by division into alpha and alpha-beta brasses.

When up to about 35% zinc is added to copper it dissolves to form a solid solution of uniform composition. Further increase in zinc content produces a mixture of the original solid solution (alpha phase) and a new solid solution of higher zinc content (beta phase).

Brasses containing between 35% - 45% zinc consist of mixtures of these two phases and are known as alpha-beta or duplex brasses, the ratio of alpha to beta phase depending principally upon the zinc content. The inclusion of certain third elements - particularly aluminium, silicon or tin - has the effect of increasing the beta phase content for any particular zinc content.

The presence of the beta phase in the alpha-beta brasses gives reduced cold ductility but greatly increased amenability to hot working by extrusion or stamping and to die casting without hot cracking, even when lead is present. The alpha-beta alloys are also stronger and, since they contain a higher proportion of zinc, cheaper than the alpha brasses. However, they do show higher susceptibility to dezincification corrosion and are therefore less suitable for service under conditions where this type of attack is likely to occur.

Alpha brasses

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

For long production runs of deep-drawn components it is essential to keep the process well monitored. The tooling and lubrication must be well maintained and arrangements made to ensure a consistent supply of feedstock. Deep drawing properties are controlled by alloy composition and trace impurities (lead and iron) and mechanical and thermal history during manufacture. Good agreement should be reached with reputable suppliers regarding quality assurance.

Tubes for heat exchangers are frequently manufactured from the alpha brasses, normally of 70/30 composition but often containing alloying additions which enhance corrosion resistance. Substantial quantities of alpha alloys are also used for the manufacture of fasteners such as wood screws, rivets and zip fasteners.

For less demanding fabrications such as spring contacts in a domestic electrical socket, an alloy with a higher zinc content (and hence lower price) can be used, such as CuZn33 (2/1 brass), CuZn36 and CuZn37 (common brass). These alloys are not quite as ductile as CuZn30, although other mechanical properties are similar. They are perfectly adequate for all but the most severe cold working operations.

Gilding metals and cap copper

Alpha brasses with higher copper contents (80 to 90%), which closely match gold in their colour, are known as ‘gilding metals’, CuZn10, CuZn15 and CuZn20 (CW501L-CW503L, CZ101-CZ103). They are used for the manufacture of decorative metalware and roll-formed sections for architectural applications, as well as costume jewellery, badges, buttons etc. For this latter use they are often chemically toned to a ‘bronze’ finish. They are sometimes known as ‘architectural bronzes’. This term can cause confusion with the high tensile brass extrusions normally made for architectural purposes (the ‘manganese brasses’) and the EN designation should therefore be quoted; see the tables of compositions (*Tables 19 and 20 on pages 24 –26*).

Cap copper CW500L (CZ125) is a 95/5 brass, CuZn5, with good ductility and corrosion resistance, only rarely used other than for caps for ammunition.

Duplex brasses

The ‘alpha-beta brasses’, ‘duplex brasses’ or ‘hot working brasses’ usually contain between 38% and 42% zinc. In contrast to the alloys of the first group, their ability to be deformed at room temperature is more limited. They are, however, significantly more workable than the alpha brasses at elevated temperatures and can be extruded into bars of complex section, either solid or hollow, and hot forged in closed dies (hot stamped) to complex shapes.

The ideal hot working temperature range is whilst the brass is cooling, between 750ºC and 650ºC, during which the alpha phase is being deposited ***(see Figure 4)***. The mechanical working process breaks down the alpha phase into small particles as it is deposited, resulting in good mechanical properties.

Note the need for careful control of annealing temperature and cooling rate if it is required to obtain a single-phase alpha structure in a brass of high zinc content such as common brass and dezincification-resistant brass. Current use of continuous annealing techniques for sheet, strip, wire and tube gives a much quicker cooling rate than previous batch annealing in controlled atmosphere bell furnaces. For brasses of the CuZn37 type this resulted in a greater tendency to retain some of the beta phase and the standard composition has therefore now been adjusted to CuZn36.

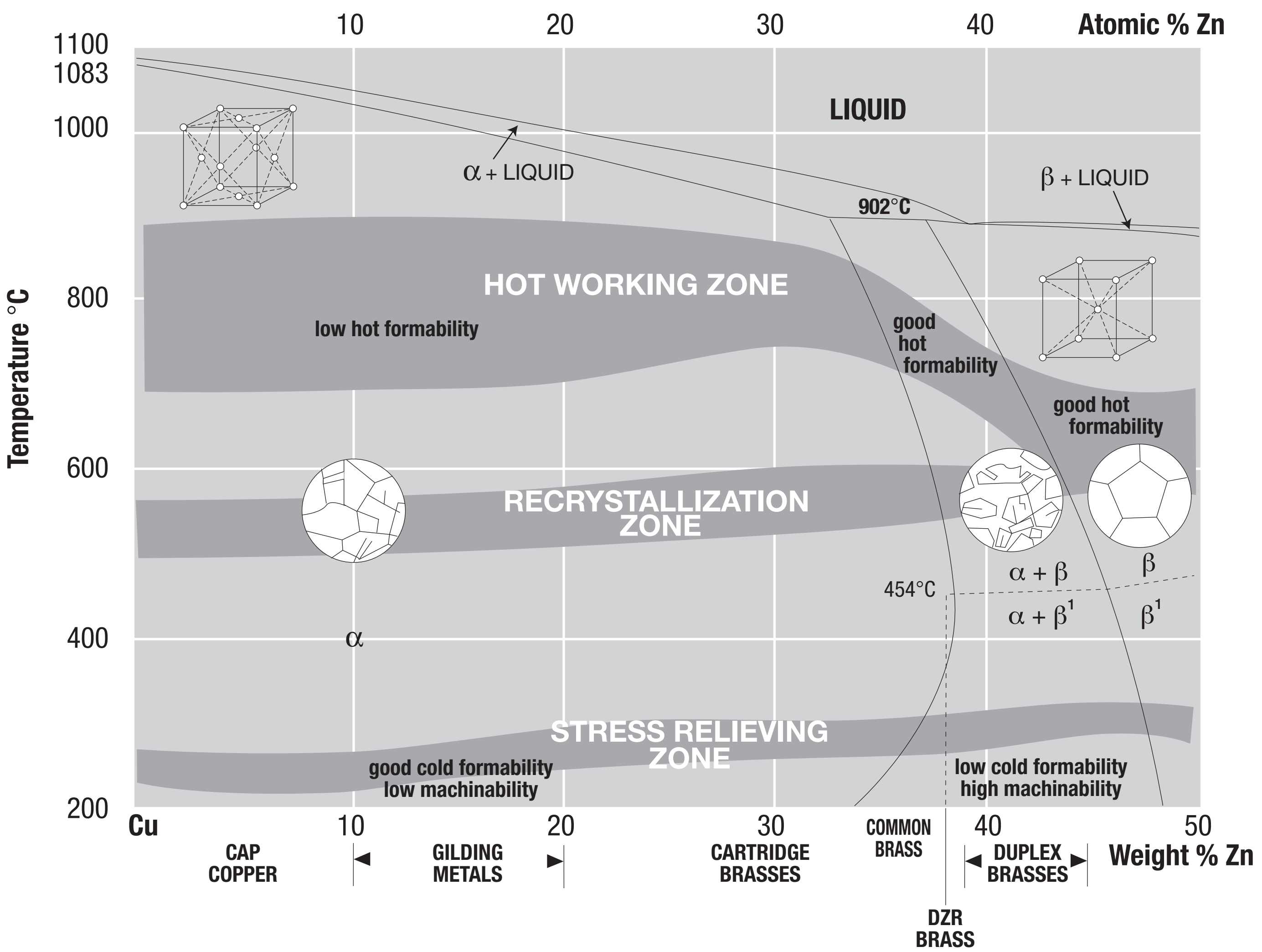
These brasses are available as extruded rods, bars and sections, which in turn are the starting stock for the manufacture of a vast range of engineering components and accessories (*see page 44*). Hot stampings are used in virtually every industry: pipe fittings, domestic taps, radiator valves, gas appliances, window and door furniture being merely a few typical examples of the products which can be manufactured by this process (*see page 59*).

Good tolerances are maintained during manufacture, minimising the need for machining during the final component production.

The addition of lead to these alloys aids chip breakage during machining, producing short broken chips which are easily cleared from the cutting area to improve machinability.

Since the cost of zinc is lower than that of copper, brasses of higher zinc content have a lower first cost. This may be significant in assessing manufacturing and total-lifetime costs.

FIGURE 4 – Copper-zinc partial phase diagram (after Struers Scientific Instruments)



EFFECT OF ALLOYING ADDITIONS

Alloying additions are made to the basic copper-zinc alloys for a variety of reasons:-

- *to improve machinability*
- *to improve strength and wear resistance*
- *to improve corrosion resistance*
- *for other special reasons*

The very wide variety of standard brass compositions that are available reflect the many ways in which an optimum combination of properties can be tailored to ensure fitness for the desired application.

Effects of alloying elements

Lead

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

Tin

1% tin is included in the composition of Admiralty brass CW706R (CZ111) and Naval brass CZ112 (nearest CW712R). As their names indicate, these brasses were developed originally for seawater service, the tin being added to provide improved corrosion resistance. Nowadays Aluminium brass CW702R (CZ110) has replaced Admiralty brass for marine service but Admiralty brass is used for fresh water. Naval brass retains some important applications in seawater service.

Silicon

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

Arsenic

Arsenic is often added in small amounts to alpha brass alloys to provide protection against dezincification corrosion as discussed in ***Section 3***.

Nickel silvers

The range of copper-nickel-zinc alloys containing from 10 to 20% nickel and known as nickel silvers can be regarded as special brasses. They have a silvery appearance rather than the typical brassy colour. In most respects they show similar corrosion characteristics to alpha brasses but the higher nickel versions have superior tarnish resistance and resistance to stress corrosion cracking.

Guillet zinc equivalent

With the exception of lead, most of the common addition elements enter into solid solution in brass and the simple binary copper-zinc equilibrium diagram is no longer valid. If it is required to estimate whether a brass will be all alpha or duplex in character, it is necessary to allow for additions using the Guillet zinc equivalent factor, multiplying the content of silicon by 10, aluminium by 6, tin by 2, lead by 1, iron by 0.9 and manganese by 0.5. Subtract double the nickel content from the total and use the formula:

$$\text{Zinc equivalent} = \frac{A}{B} \times 100$$

where A = sum of (zinc equivalent factor x % of each alloying element) + zinc
and B = A + % copper

This method gives good accuracy for high tensile brasses provided that alloying elements do not exceed 2% each.

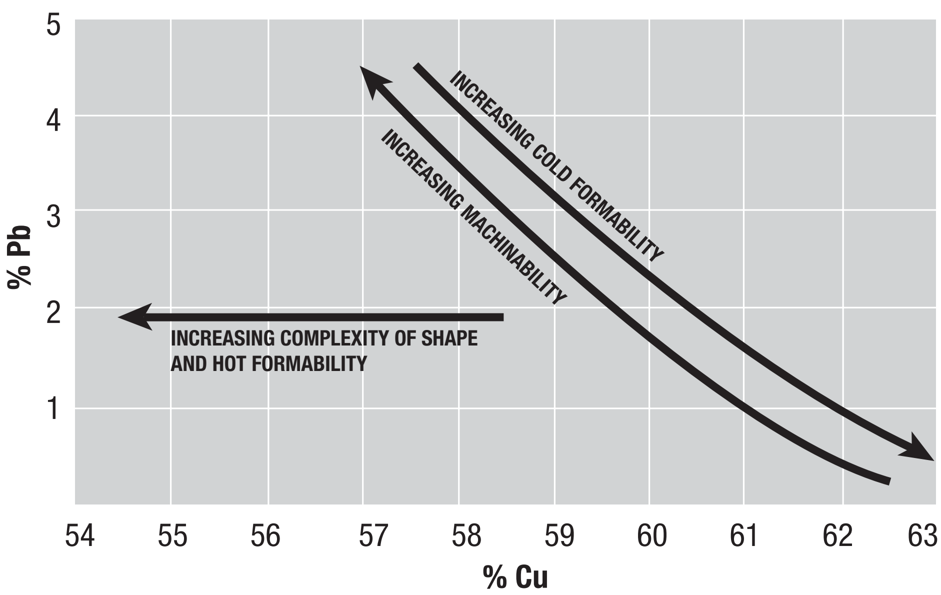
FREE-MACHINING BRASSES

Typically, free-machining brass contains about 58% copper and 39% zinc. Lead is added to improve machinability; other alloys, required to be free-machining and yet having sufficient ductility for riveting or other cold work, contain less lead and more copper.

Additions of other elements such as manganese, tin, aluminium, iron, silicon and arsenic may be used to improve strength and corrosion resistance. This gives rise to a very wide selection of alloys, see ***Table 19 on pages 24 & 25***.

The choice of alloy to use for an application depends on balancing the range of properties required including machinability, extrudability of shape and cold ductility for post forming after machining. There are many standard materials suited to specific end uses. The EN standards recognise categories of material classified by copper, zinc and lead content. The effects are summarised in ***Figure 5*** and the materials now available shown in ***Figure 6***.

FIGURE 5 – Effect of copper and lead content on free-machining brass



Lead-free machining brasses
Some concern has been expressed regarding the possibility that lead could be leached from water fittings in aggressive supply waters. Generally this does not cause a long-term problem, but some work has been done to investigate alternative additions able to produce the required insoluble globules of good lubricity. One of the additions suggested is bismuth but, as yet, no alternative materials have been standardised in Europe.

The EU End of Life Vehicle (ELV) Directive, adopted in September 2000, includes provision for phasing out metals such as lead used in automotive components. However, copper alloys containing up to 4% lead are exempt from the Directive. Applications for these copper alloys include bearing shells and bushes (phosphor bronze), nozzles, connection parts, fixtures and locks (leaded brass).

HIGH TENSILE BRASSES

The high tensile brasses are usually duplex or alpha-beta brasses. Alloying additions are made to attain this structure and achieve the required enhanced properties for this series of alloys (***see Table 10 on page 17***).

Iron and **manganese** are the most common additions, combining to confer increased hardness, proof strength and tensile strength, with only slightly reduced ductility.

Aluminium has the greatest effect in increasing hardness, proof strength and tensile strength. Due to its effect on ductility and microstructure, close control is necessary to obtain the optimum combination of properties. Corrosion resistance is improved by the self healing oxide film aluminium confers.

Tin may be added to enhance the corrosion resistance in marine and mining environments. It gives a small increase in hardness and tensile strength.

Silicon is alloyed in combination with manganese to produce a very hard intermetallic compound, **manganese silicide**, in the basic matrix, which imparts excellent wear resistant properties to these alloys.

Lead has no effect on hardness or tensile strength. Some reduction in ductility occurs, but significant improvement in machinability results.

Nickel improves hardness and tensile strength without significant effect on ductility, conferring improved properties at elevated temperatures.

Shape memory effect brass (SME alloy)
Some copper alloys, including certain copper-zinc-aluminium compositions, exhibit a metallurgical transformation which is temperature dependent and reversible. Great use can be made of the forces available during consequent dimensional changes in suitably designed components for temperature sensitive actuators. This type of material can be produced to a primary shape such as a spring or torsion rod. It is heat treated to give the required metallurgical condition and then strained beyond its elastic limit to a secondary shape. Warming the component through its transition temperature will cause it to regain the original shape and it will revert to the secondary shape upon cooling.

If the alloy composition, fabrication and heat treatment are all closely controlled, then the component can be used as a temperature sensitive actuator to give a predictable mechanical performance. The force produced can be up to 200 times that of a bimetallic element of similar size. A variety of materials are available with controlled transition temperatures between −70ºC and +150ºC.

EFFECT OF PROCESSING ON PROPERTIES

As shown in *Figure 7*, brass components can be produced by a wide variety of techniques. Besides the effects of composition, processing history will have a significant effect on properties.

Hot working is commonly carried out either by hot rolling of slabs or by extrusion or forging of billets. The basic effect of hot working on the brasses is to break up the original cast structure which improves mechanical properties and modifies directionality. The properties will then correspond to the annealed (O) state. If, however, the final working temperature is below that needed for full recrystallisation, then some cold working occurs. Material in the ‘as manufactured’ (M) condition is therefore generally stronger than in the annealed (O) condition.

FIGURE 6 – Range of copper and lead contents available in EN standards

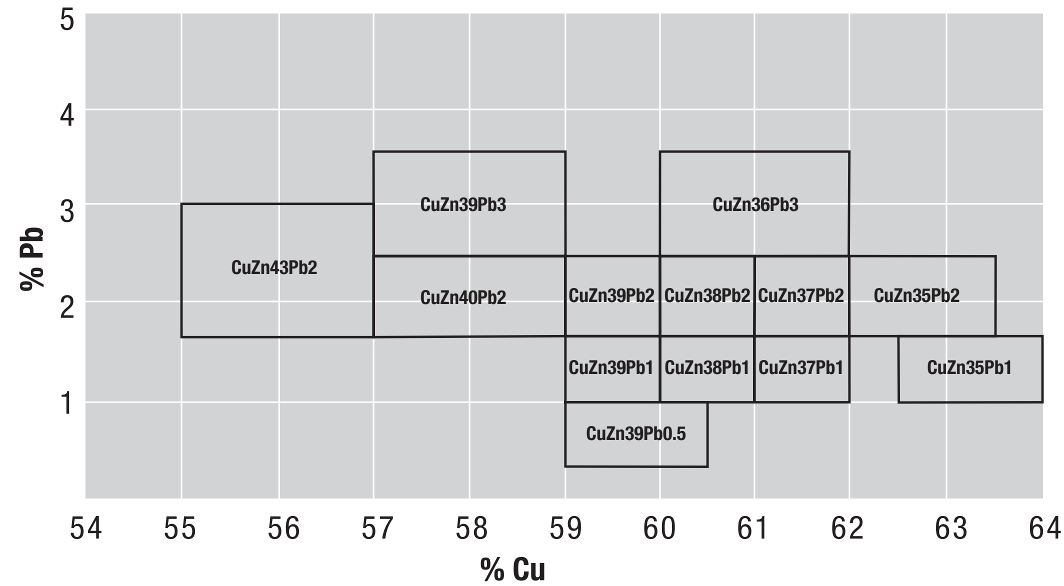
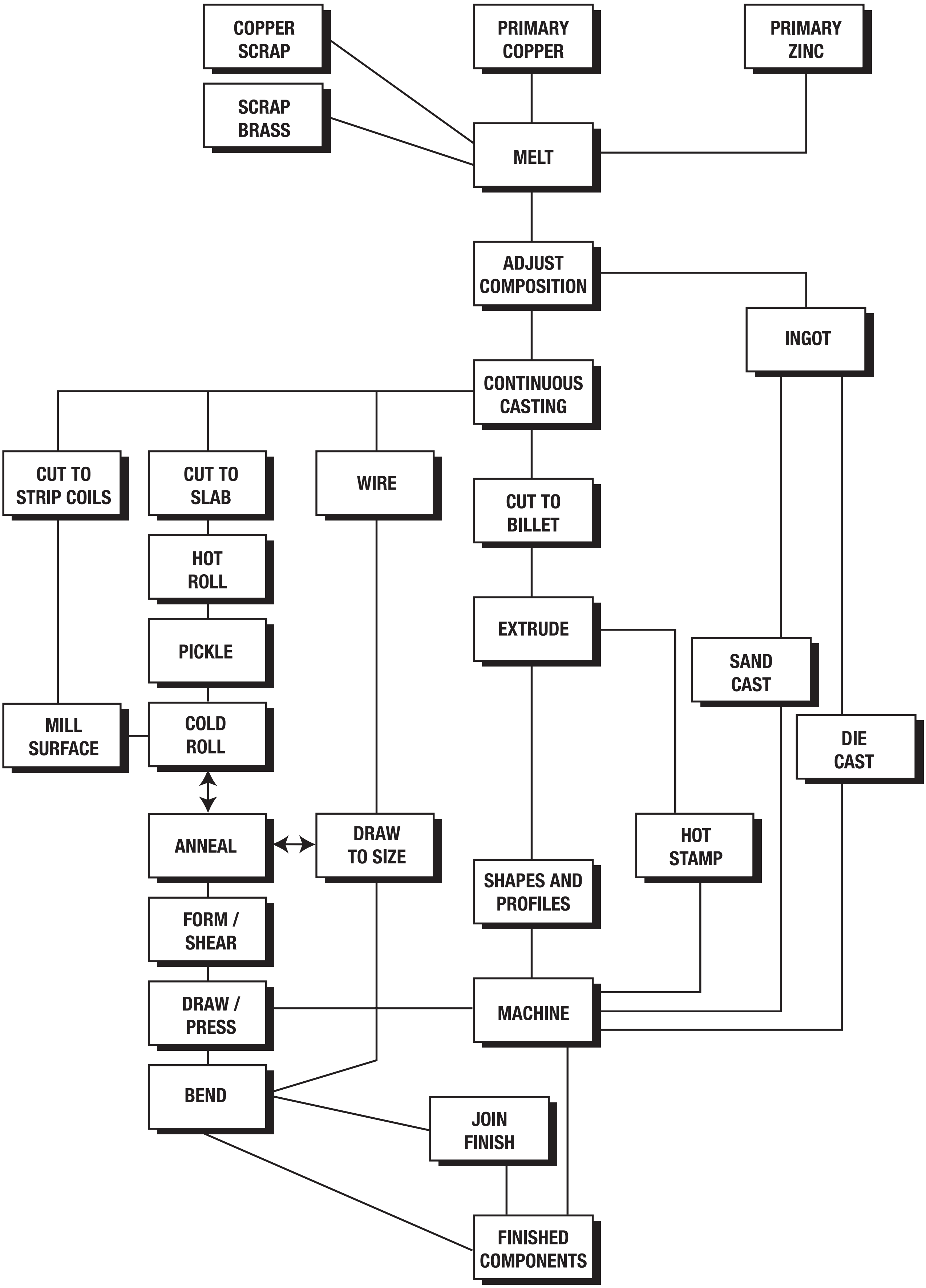


FIGURE 7 – Simplified flowchart for brass component production



Acknowledgements to Keith Ingram

The strength of most of the commercially available brasses cannot be improved by heat treatment. Any improvement in properties over the soft, annealed condition is obtained by cold working. In the case of extruded products such as rods, bars, sections, tubes and wire, the cold reduction is applied by drawing through dies, while in the case of sheet and strip it is applied by cold rolling.

Temper Grade

Progressive amounts of cold working increase the tensile strength, proof strength and hardness of the alloy, with a consequent reduction in ductility, as measured by elongation. Material available from manufacturers has been subjected to various amounts of cold reduction; referred to as the temper grade and designated in the old BS for sheet, strip and wire as ¼H, ½H, H, extra hard, spring hard and extra spring hard. These terms are not used in the EN standards but are included for information purposes to allow comparison with BS standards. In EN standards alloys are supplied to a material condition ***(see page 22)***, namely H for a minimum hardness value or R for a minimum tensile strength value.

Example: brass wire CW508L (CZ108) in EN 12166 material condition R560 (tensile strength 560-700 N/mm^2) or H160 (hardness 160-190 HV)

Both these conditions are approximately equivalent to the half hard/hard condition in the old BS 2873 Standard.
Note - *It is much easier to measure tensile strength in wire than hardness.*

Not all brasses or forms are available in all temper conditions. Hard rolled brasses have better ductility longitudinally in line with the rolling direction rather than in the transverse direction. Advantage of this can be taken when designing springs or other flexible parts.

The temper grade specified when ordering material must be based on the degree of forming necessary to produce the finished component. With experience, alpha brasses can be temper-annealed within a wide variety of combinations of properties such as hardness and grain size suitable for differing end-uses. Hardnesses may vary from about 55HV up to about 100HV with corresponding grain sizes from 0.08 down to 0.01 mm. The softer the brass, the better the ductility, but a small grain size is needed for the good surface finish required after deep-drawing operations (***see Figure 12 on page 42***).

EFFECT OF ZINC CONTENT ON PROPERTIES

Figure 8 shows the effect of variations in zinc content on tensile strength and elongation of brass wire. It highlights reasons for the natural popularity of the 70/30 composition since it combines the properties of good strength and maximum ductility.

Figure 9 shows that both the modulus of elasticity and the modulus of rigidity decrease progressively, but not too significantly, with increasing zinc content. These values are used in the design of spring applications for calculating elastic deformation.

Conductivity of both heat and electricity usually vary in similar fashion according to effects of composition and strain hardening by cold work. ***Figure 10*** shows the significant effect that additions of zinc to copper have on electrical resistivity and thermal conductivity. These values help to explain the many successful applications of the brasses in electrical applications and heat exchangers.

When brass rod or wire is to be upset to form a head for a rivet, fastener or similar application, good ductility is essential. ***Figure 11*** shows that the 80/20 gilding metal CuZn20 has optimum properties for this process. **Heading limit** is the ratio of the maximum head diameter to the original wire diameter.

FIGURE 8 – Effect of composition on mechanical properties of brasses

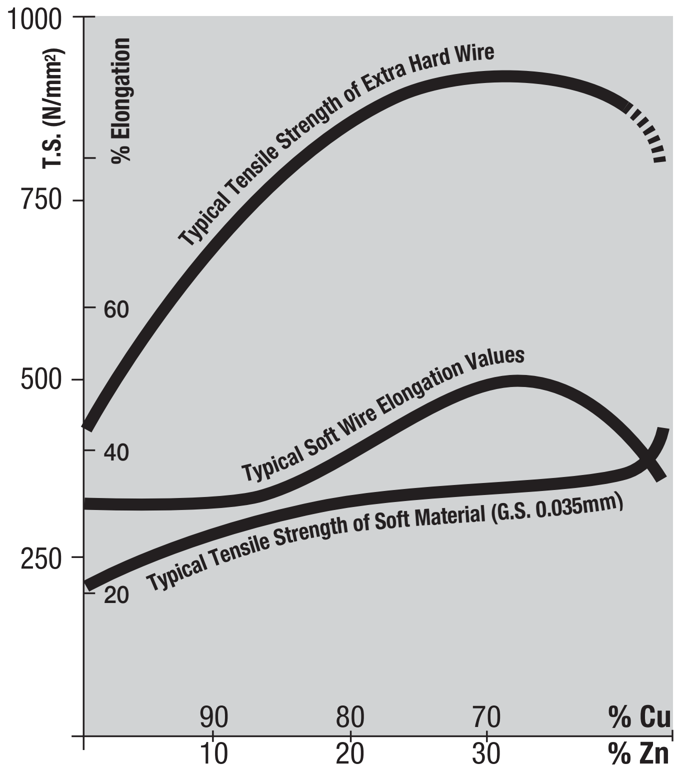


FIGURE 9 – Effect of composition on moduli of brasses

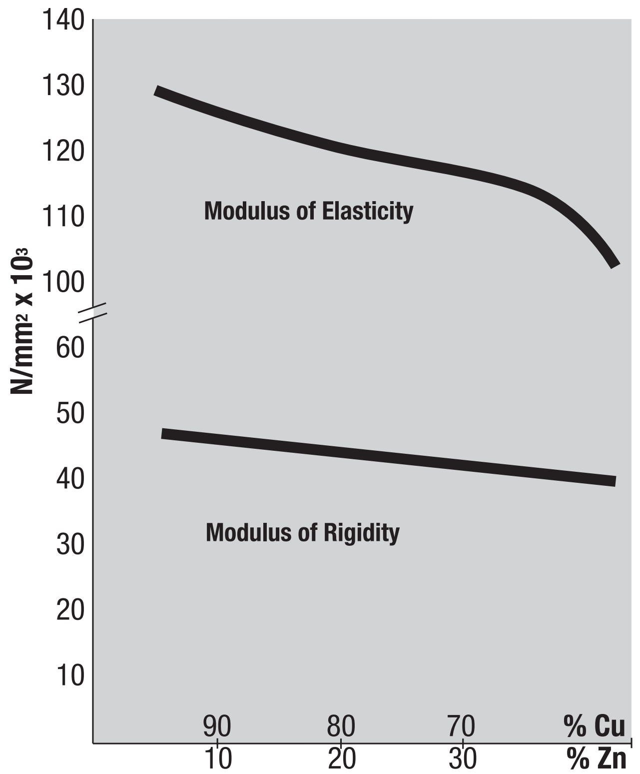


FIGURE 10 – Effect of composition on thermal conductivity and electrical resistivity of brasses

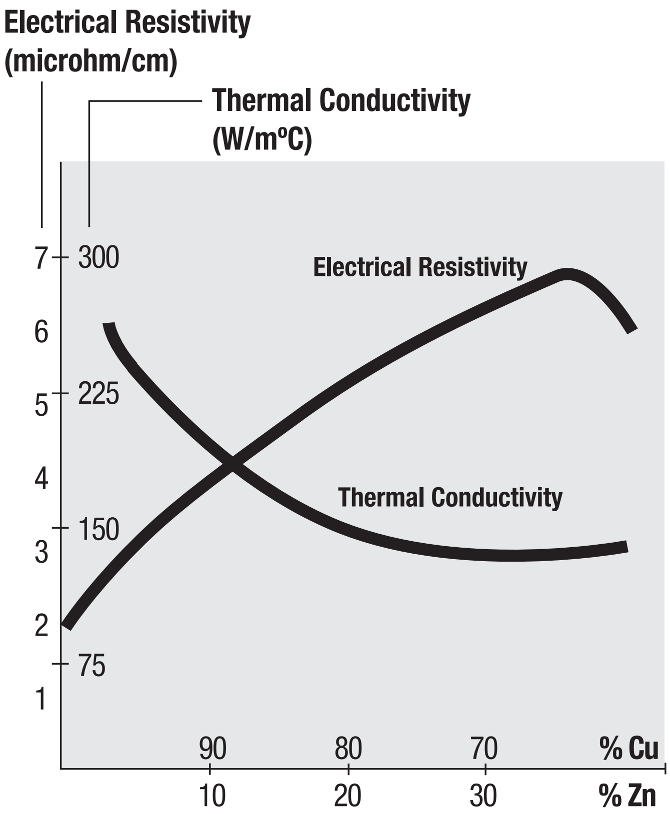
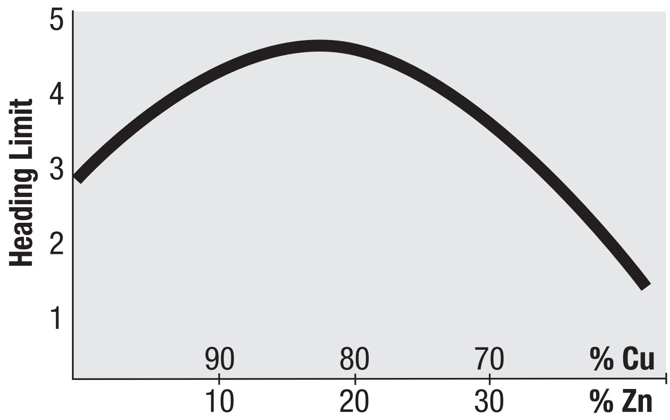


FIGURE 11 – Effect of composition on heading limit



CASTABILITY

All brasses can be readily cast for a wide variety of end uses giving strong, sound castings (***see examples page 43***). The EN 1982 specification covers a selection of the most frequently used alloys, some with additions of lead to improve machinability, and tin to improve corrosion resistance and strength (***see Table 20 on page 26***). Manganese is a useful deoxidant, as little as 0.02% present giving stronger, sound castings. For diecasting the 60/40 type alloys are used. The higher zinc content lowers the casting temperature and gives essential hot ductility. Aluminium is added to form a protective oxide film to keep the molten metal clean and reduce the attack on the die materials. This type of alloy with a suitably controlled composition may also be used for castings required to be resistant to dezincification.

The high tensile brasses can be sand cast and CC765S (HTB1) is also used for gravity diecasting.

The casting process is ideal for the production of complex shapes. End uses range from pipeline valves and electrical switchgear components, which require high soundness and strength, a long operating life and, in the case of components for mines and the petrochemical industry, spark-resistant characteristics, to non-critical ornamental applications where the requirement is for a good surface finish as well as a long service life.

AVAILABLE FORMS AND PROPERTIES

Being easily shaped by hot and cold working processes, the brasses are manufactured in a wide variety of forms. Semi-fabricated stock is available as rolled plate, sheet, strip and foil and as extruded and drawn bars, shaped sections, hollow rods, tubes and wire. Intermediate products can be obtained as hot stampings, forgings, sand castings, shell moulded castings, gravity and pressure diecastings, and investment castings. The availability of these items to specific composition and size specifications may be dependent on quantity requirements. Dimensional tolerances suitable for most general engineering applications are quoted in the relevant EN Standards for the wrought products. Any special requirements should be discussed with manufacturers.

Brass compositions and product forms are included in various EN Standards, detailed in ***Tables 19 and 20 on pages 24–26***. Also included are typical mechanical properties of the brasses for the product forms covered by the Standards. For more detailed information on composition limits, minimum mechanical properties, tolerances and other requirements, the relevant standards should be consulted. For castings, relatively wide ranges of properties are shown because of the variations due to casting design, section thickness and foundry variables. Close collaboration between designer and founders can help minimise the influence of casting variables.

The commonly used brasses are available from manufacturers and stockists in the size ranges shown in ***Table 22 on page 42***.

The EN Standards introduce a wider range of available tolerances than previously included in British Standards and are shown in ***Table 23 on page 42***.

Mechanical and physical properties

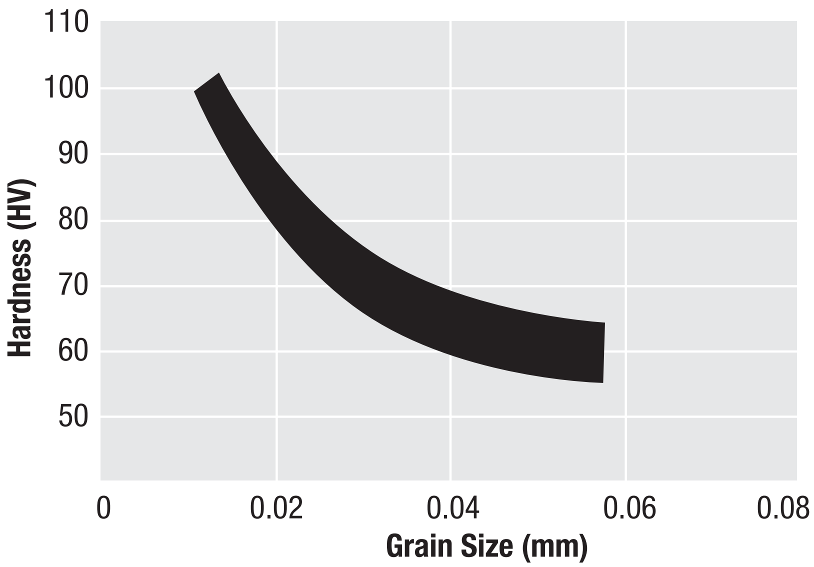
The property data included in the EN Standard specifications for wrought products is based on room temperature tensile testing and hardness determinations for quality control purposes. A limited amount of test data, often required for design purposes, such as creep, fatigue, elevated temperature strength and impact properties, is available from CDA. Physical property data is given in ***Table 26 on page 58***.

Many other national and international specifications exist; many of these have much in common as a result of agreements reached within the International Standards Organisation. Advice on all Standard Specifications can be obtained from CDA .

TABLE 22 – Common size ranges of wrought and cast brasses (UK)	
Form	**Size Range**
Rod and Bar	Up to 127mm diameter for rod Up to 90mm across flats for square section Up to 110mm across flats for hexagons
Sections	Shape that falls within a 127mm diameter circumscribing circle
Hollows	Up to 127mm diameter, 110mm across flats for hexagons, etc.
Hot Stampings	Up to 22kg weight
Forgings	Up to 750kg weight
Sheet	Up to 2500 x 1250mm
Plate	Up to 125mm thick, 2m x 1m
Foil and Strip	From 0.05mm to 4mm thickness in widths from 3mm to 400mm
Wire	From 0.02 to 6mm diameter
Castings	From grammes up to several tonnes, dependent on casting technique

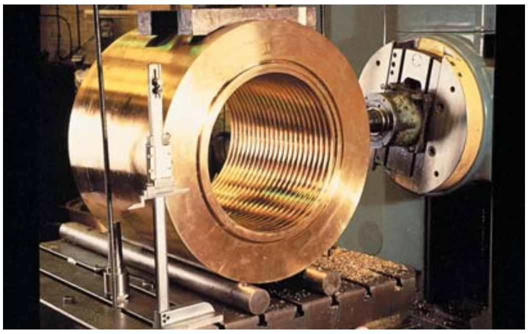
TABLE 23 – Tolerance classifications in EN specifications – *Note: 'A' is the widest tolerance in each standard.*	
Product Type	**Tolerance Classes in EN Standards**
Rod for Free-machining	A and B for round rods
Hollow Rod for Free-machining	A, B and C for outside dimension A and B for inside dimension A and B for wall thickness A and B for eccentricity
Forging Stock	A, B and C for round products
Rectangular Bar	A, B and C
Wire for General Engineering Purposes	A, B, C, D and E for round products A, B and C for regular polygons
Rod for General Purposes	A and B for round and polygonal products

FIGURE 12 – Hardness v grain size for annealed CuZn30 brass sheet and strip



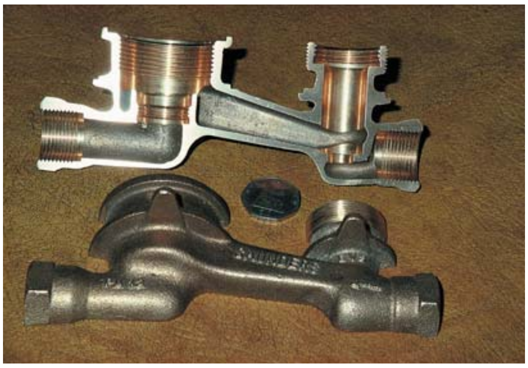
Castings – examples

Adjusting nut for a rolling mill cast in high tensile brass to EN 1982 CC7625 (HTB3)
This brass is relatively easily cast and machined to close tolerances to give a strong component resistant to wear and shock.



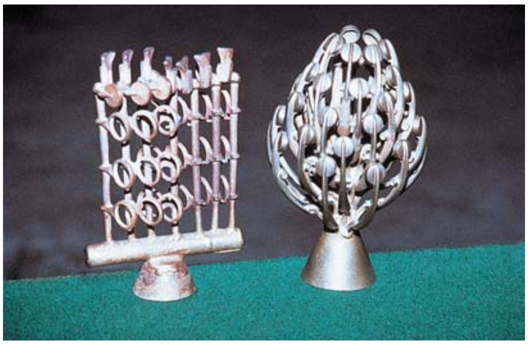
(Westley Brothers plc)

Valve - sectioned to show internal structure
An elaborately cored shell moulding is used to make this valve. Machining is then only required on mating surfaces and for threading.



(Saunders Valve Co Ltd)

Clarinet keys
Clarinet keys are now precision cast (right) to a near-net-shape that needs little finishing beyond fettling, polishing and decorative plating. Even the pivot holes are cored into place. Previously these keys were made from a silver-soldered assembly of several components (left). This economy in production methods has enabled the manufacturer to meet stiff competition from elsewhere.



(Boosey & Hawkes Ltd)

Pressure die cast brass components
For relatively long runs, this process gives excellent products with good properties and accurate reproduction. Production rates are higher than in gravity die casting and closer tolerances can be achieved.

(J W Singer Ltd)

Breather valve guard casting
This sandcasting is made as a complete unit with the efficient and economical runner and riser system attached. Fettling is simple and there is minimal scrap.

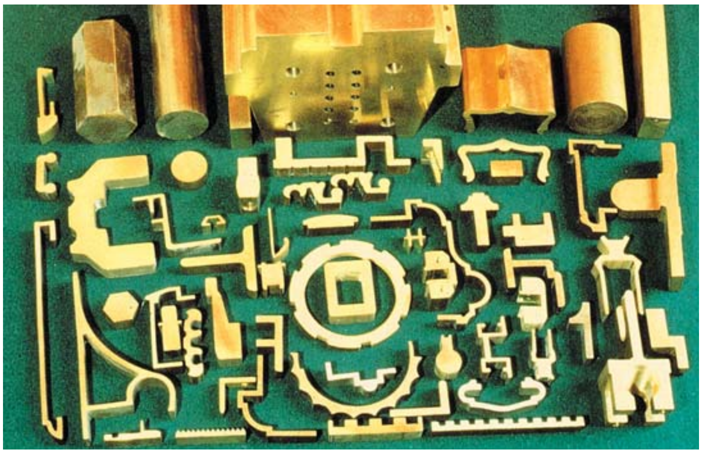
(The Enfield Foundry Co Ltd)

Profiles and Extrusions – examples

(Delta Extruded Metals Co Ltd)

Turned brass components

These components are all made rapidly and economically on automatic lathes from extruded high-speed machining brass rods and hexagonal sections.



(Boliden MKM Ltd, Delta Extruded Metals Co Ltd and others)

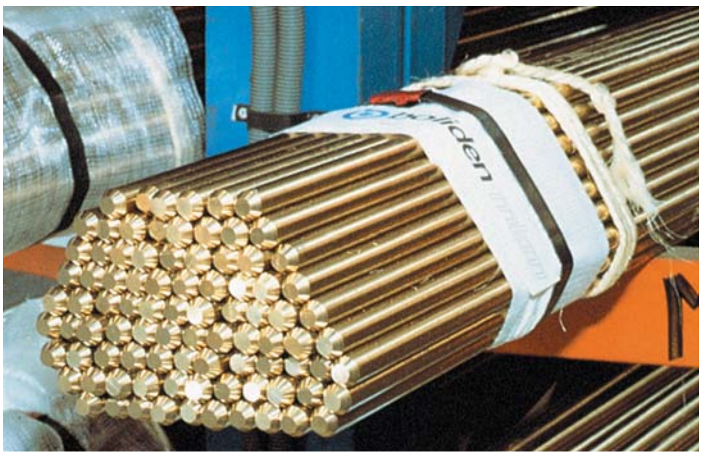
A selection of extruded profiles

Complex profiles can be extruded to order. In many cases the die costs are quickly repaid by savings in machining time and the reduction in material wastage. The components made from this high speed machining rod are shown alongside the bar stock, emphasising the efficient use of material.

(Metamec)

Reproduction carriage clock

The case pillars on this clock are extruded in CW614N (CZ121) brass to a precision shape that will retain the glass securely, cut to length, tapped and polished. Top and bottom sections can be formed from sheet or cut from extrusions according to design. The handles may be turned from hexagonal extruded rod and then formed to shape or cut from extruded profile section. During the development of production techniques for this range of reproduction clocks, handles were initially cut from an existing section, originally designed to make architectural balustrades, before it was shown to be economical to finance extrusion die costs for a shape that needed even less finish machining.



(Boliden MKM Ltd)

Chamfered high-speed machining brass rods ready for despatch

The chamfered ends facilitate entry of bars into automatic lathes.

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.

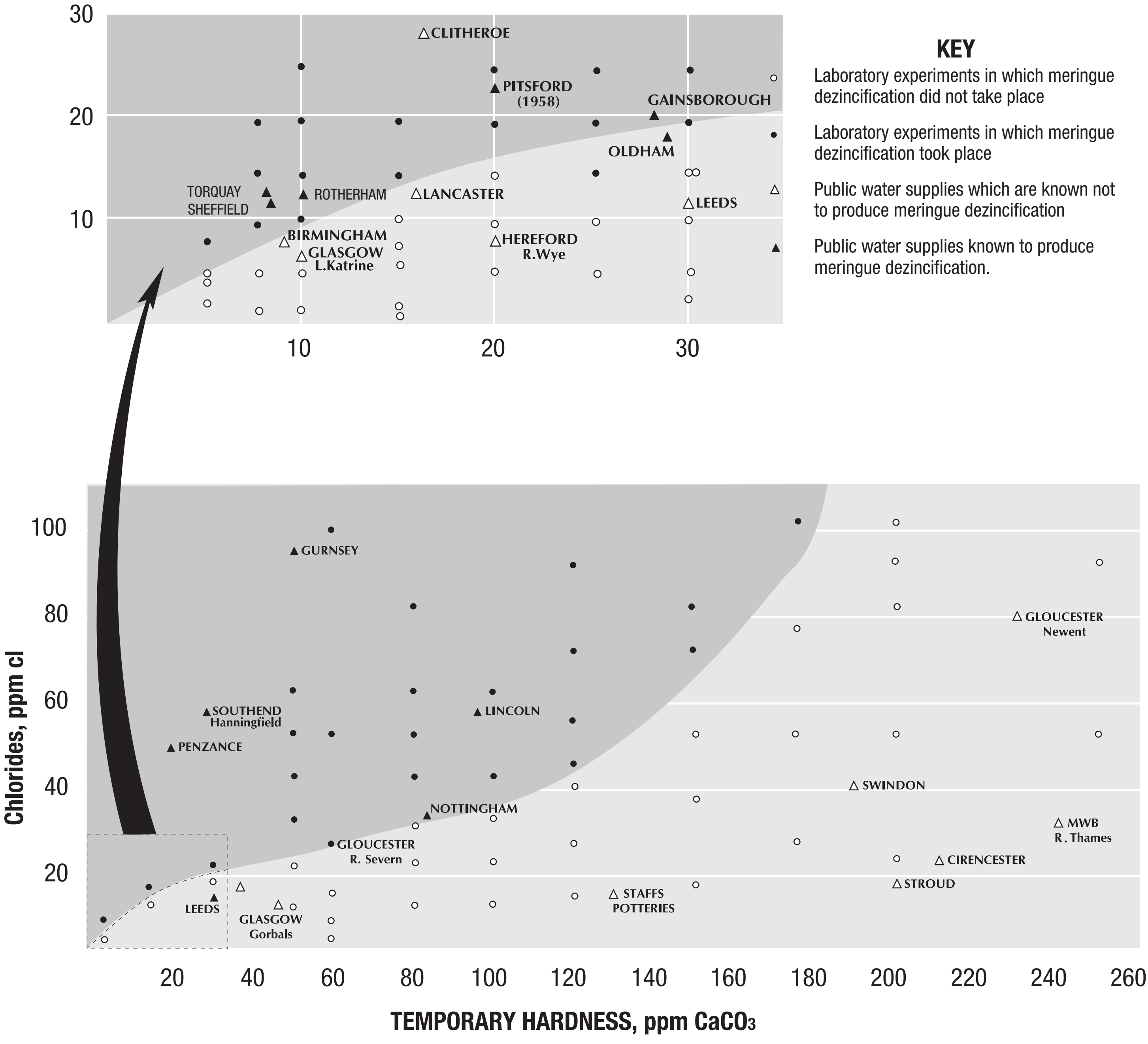
Conditions for dezincification

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

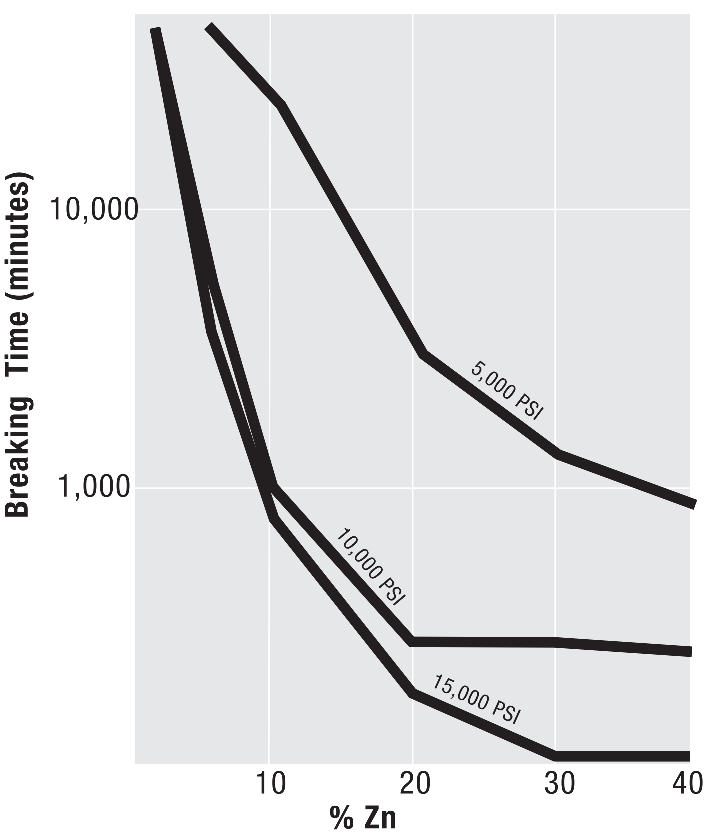
D H Thompson and A W Tracey made a detailed study of the effect of stress level and zinc content on the time for failure by stress corrosion cracking to take place in axially loaded specimens exposed to air containing 10% ammonia and 3.7% water vapour at 35ºC. This is an accelerated test giving failures 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%.

TABLE 26 – Physical properties of brasses

		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.

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)

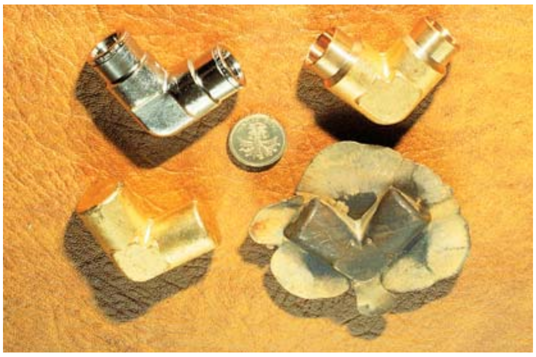
Union nut

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)

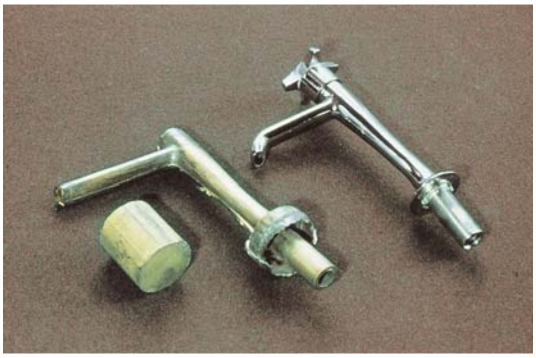
Dezincification-resistant brass – stop tap and tee

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

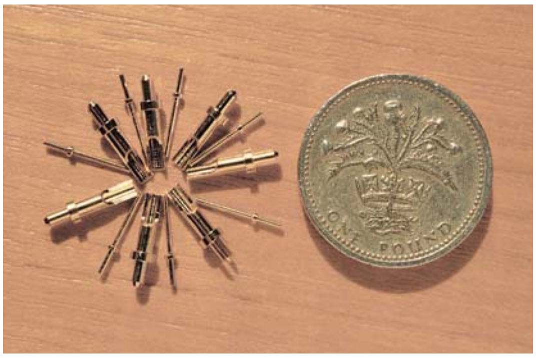
Selection of fasteners made from drawn wire stock

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

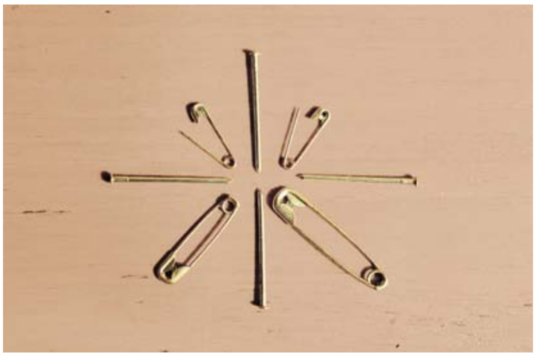
These miniature electronic terminals are made cheaply but to a high standard of precision and reliability by the million to meet the needs of manufacturers of quality electronic equipment.



(Greenpar Jubilee Ltd)

Pins and safety pins

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



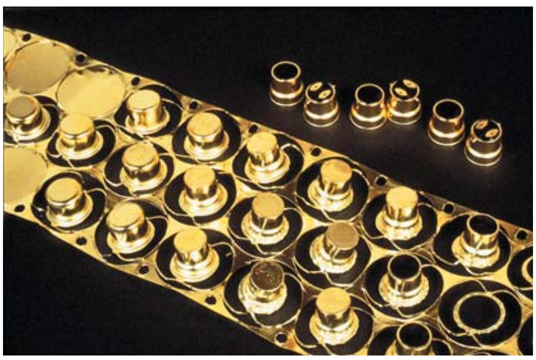
(United Wire Ltd)

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)

Section 8 – BRIEF HISTORY OF BRASS

Brass has been made for almost as many centuries as copper but has only in the last millennium been appreciated as an engineering alloy. Initially, bronze was easier to make using native copper and tin and was ideal for the manufacture of utensils. Pre-dynastic Egyptians knew copper very well and in hieroglyphs copper was represented by the ankh symbol, also used to denote eternal life, an early appreciation of the lifetime cost-effectiveness of copper and its alloys. While tin was readily available for the manufacture of bronze, brass was little used except where its golden colour was required. The Greeks knew brass as 'oreichalcos', a brilliant and white copper.

Several Roman writers refer to brass, calling it 'Aurichalum'. It was used for the production of sesterces and many Romans also liked it especially for the production of golden coloured helmets. They used grades containing from 11 to 28 per cent of zinc to obtain decorative colours for all types for ornamental jewellery. For the most ornate work the metal had to be very ductile and the composition preferred was 18%, nearly that of the 80/20 gilding metal still in demand.

Before the 18th century, zinc metal could not be made since it melts at 420ºC and boils at about 950ºC, below the temperature needed to reduce zinc oxide with charcoal. In the absence of native zinc it was necessary to make brass by mixing ground smithsonite ore (calamine) with copper and heating the mixture in a crucible. The heat was sufficient to reduce the ore to metallic state but not melt the copper. The vapour from the zinc permeated the copper to form brass which could then be melted to give a uniform alloy.

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

One of the principal industrial users of brass was the woollen trade, on which prosperity depended prior to the Industrial Revolution. In Shakespearean times, one company had a monopoly on the making of brass wire in England. This caused significant quantities to be smuggled in from mainland Europe. Later the pin trade became very important, about 15-20% of zinc was usual with low lead and tin to permit significant cold working to size. Because of its ease of manufacture, machining and corrosion resistance, brass also became the standard alloy from which were made all accurate instruments such as clocks, watches and navigational aids. The invention by Harrison of the chronometer in 1761 depended on the use of brass for the manufacture of an accurate timekeeper that won him a prize of £20,000. There are many examples of clocks from the 17th and 18th centuries still in good working order.

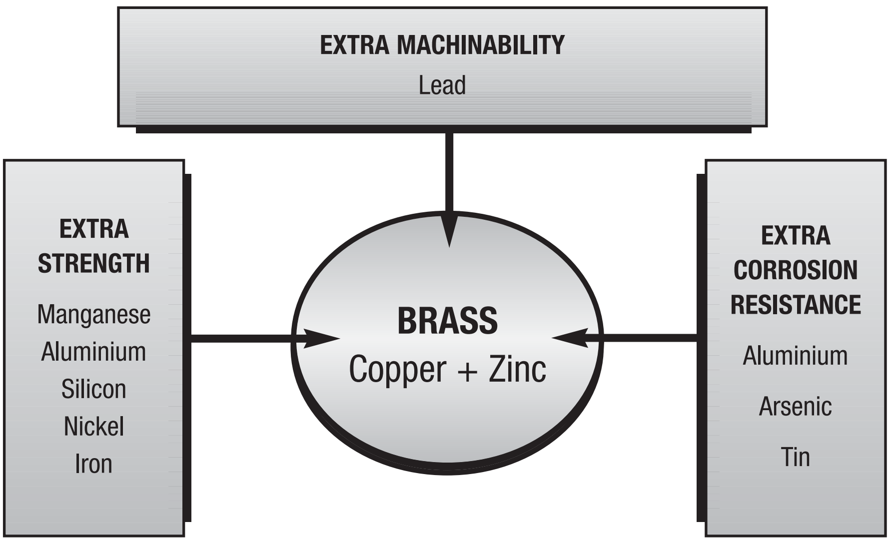
With the coming of the Industrial Revolution, the production of brass became even more important. In 1738, William Champion was able to take out a patent for the production of zinc by distillation from calamine and charcoal. This gave great impetus to brass production in Bristol.

Wire was initially produced by hand drawing and plate by stamp mills. Although the first rolling mill, Dockwra was installed at Esher, Surrey in 1697, it was not until the mid-19th century that powerful rolling mills were generally introduced. The Dockwra works specialised in the manufacture of brass pins, the starting stock being a plate weighing about 30kg. This was cut into strips, stretched on a water powered rolling mill and given periodic interstage anneals until suitable for wiredrawing.

With the invention of 60/40 brass by Muntz in 1832 it became possible to make cheap, hot workable brass plates. These supplanted the use of copper for the sheathing of wooden ships to prevent biofouling and worm attack.

Muntz metal plates were used for sheathing the wooden hull of the Cutty Sark, built in 1869 and presently in dry dock in Greenwich, South London since 1954. The Cutty Sark is currently undergoing restoration and regeneration.
See www.cuttysark.org.uk

With improvements in water communications, the centre of the trade moved to Birmingham to be nearer to fuel supplies and to facilitate central distribution round the country. Here in 1894, Alexander Dick invented the extrusion press that revolutionised the production of good quality cheap rods. Subsequent developments in production technology, mentioned in many of the references given, have kept pace with customers' demands for better, consistent quality in larger quantities.



Section 9 – INDEX

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