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.

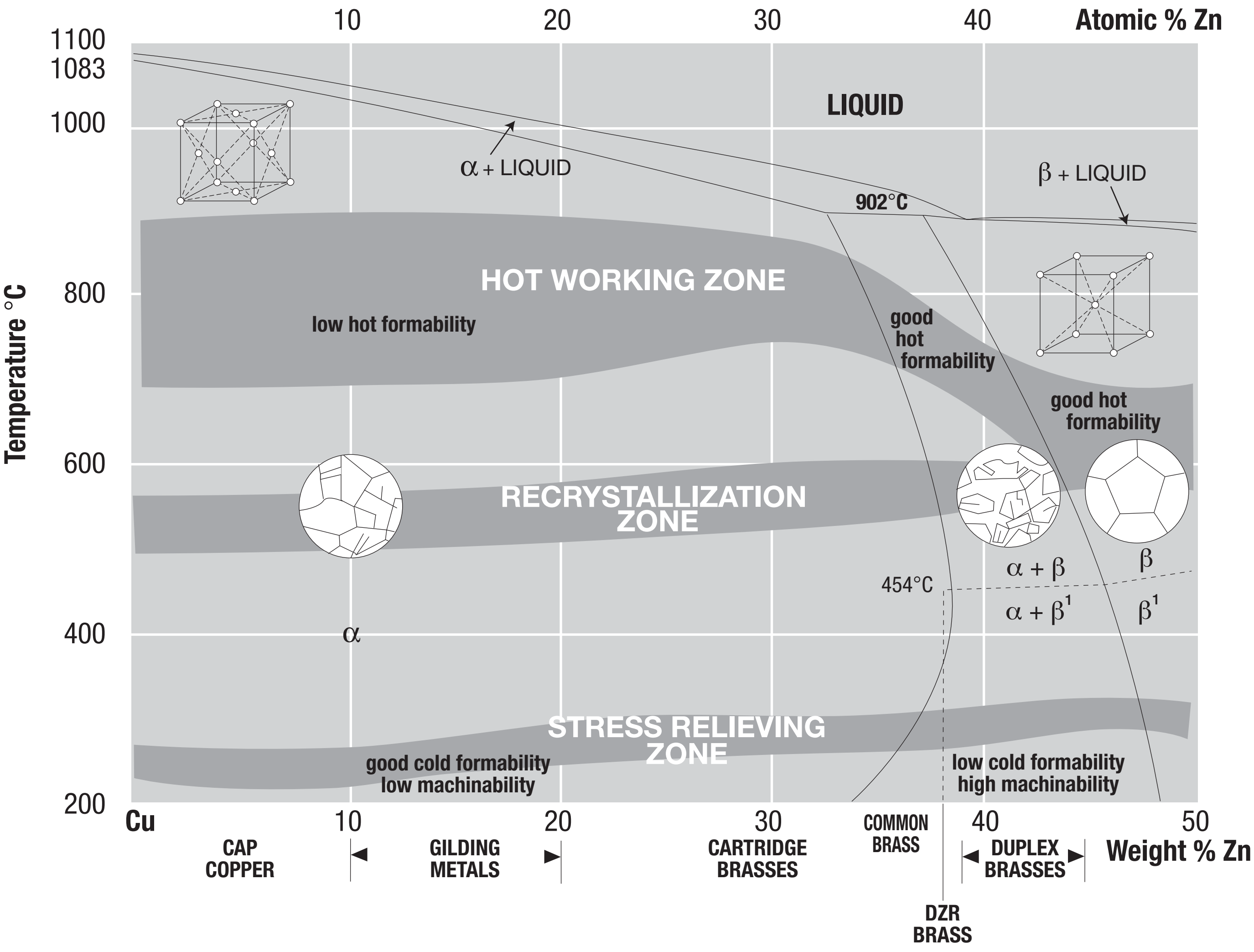
These brasses are available as extruded rods, bars and sections, which in turn are the starting stock for the manufacture of a vast range of engineering components and accessories (***see page 44***). Hot stampings are used in virtually every industry: pipe fittings, domestic taps, radiator valves, gas 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.

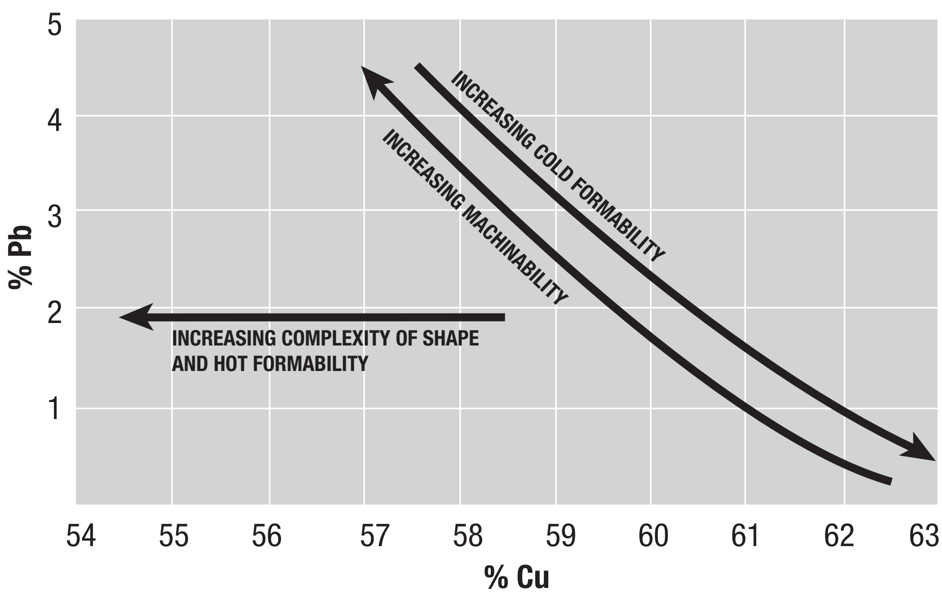
FREE-MACHINING BRASSES

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

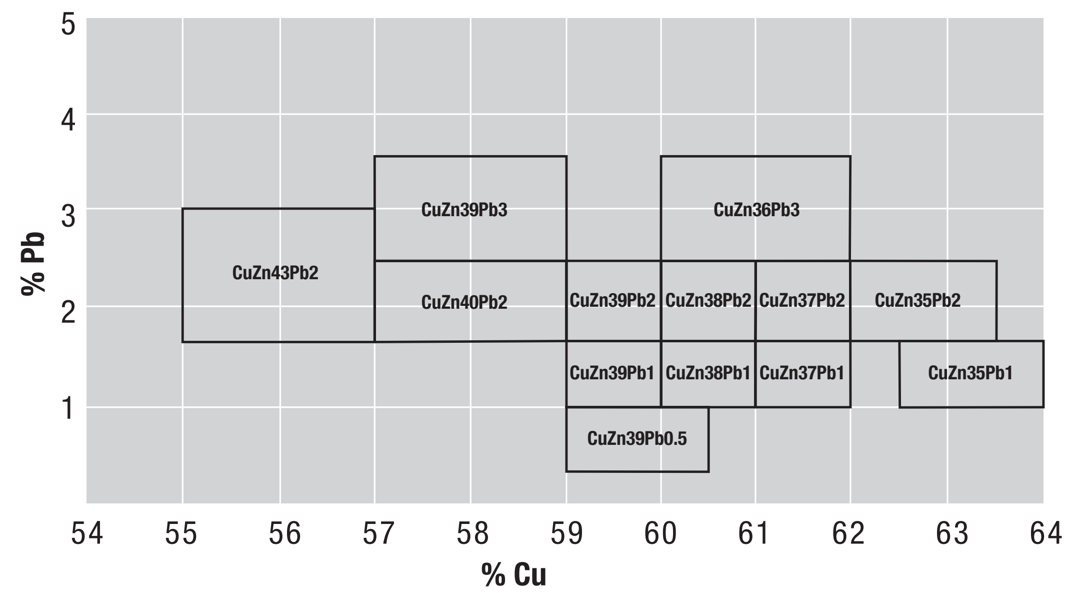
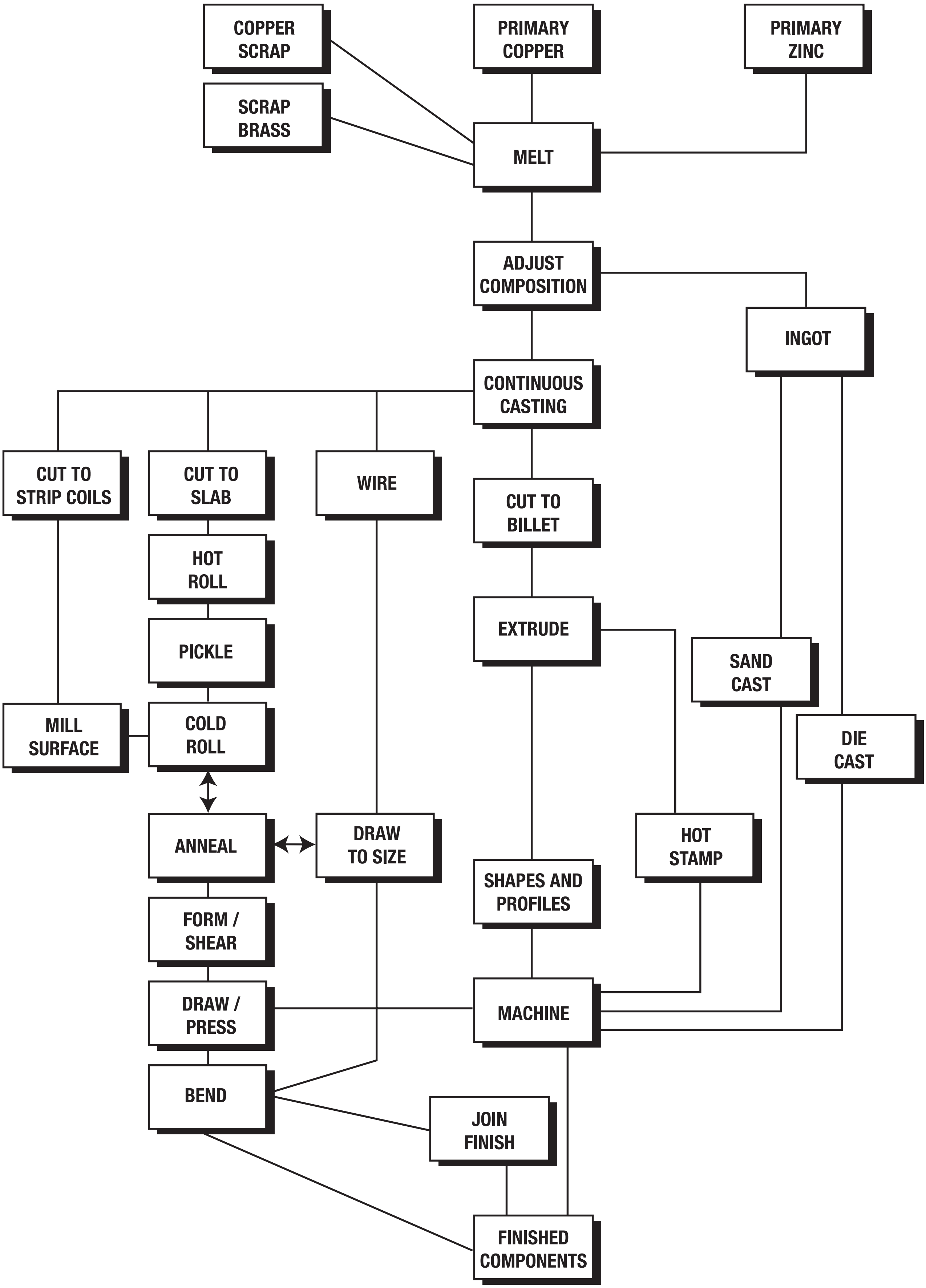


FIGURE 7 – Simplified flowchart for brass component production



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

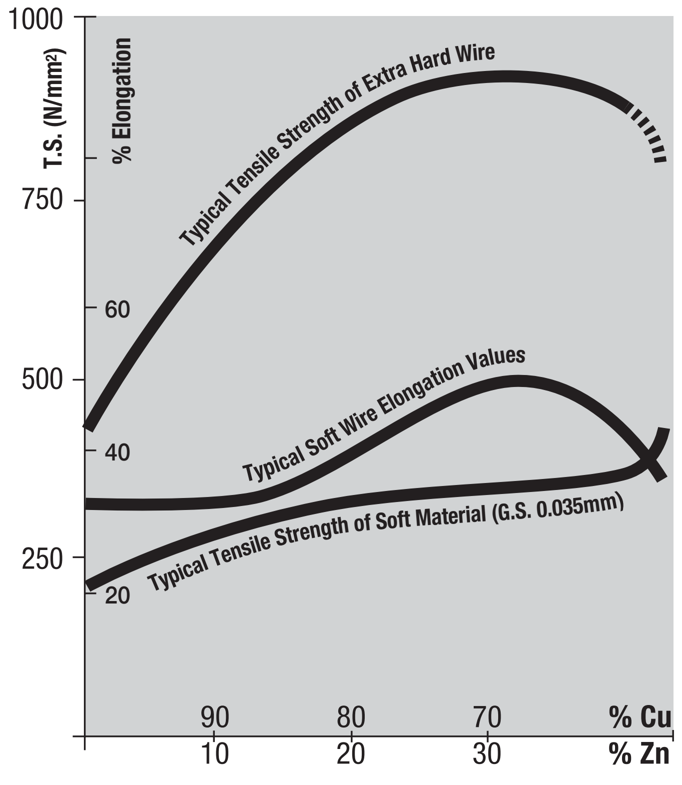


FIGURE 9 – Effect of composition on moduli of brasses

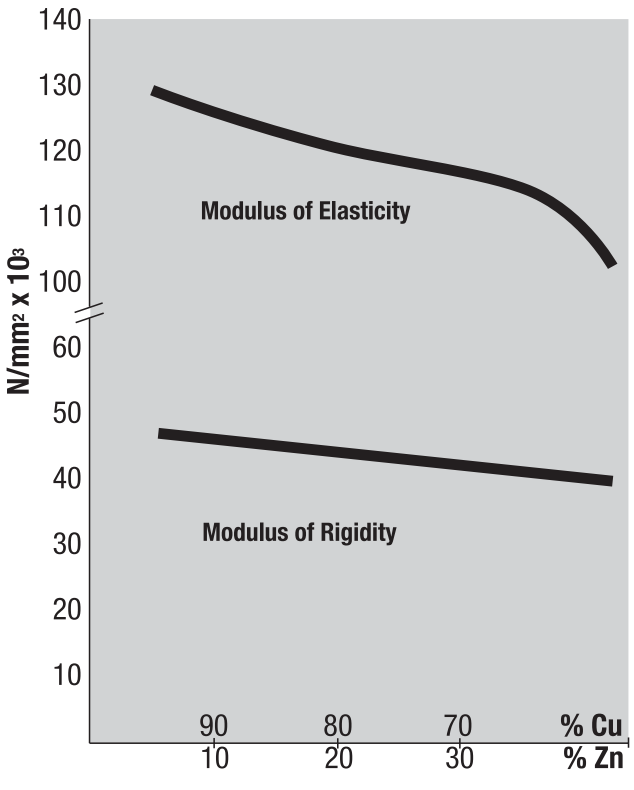


FIGURE 10 – Effect of composition on thermal conductivity and electrical resistivity of brasses

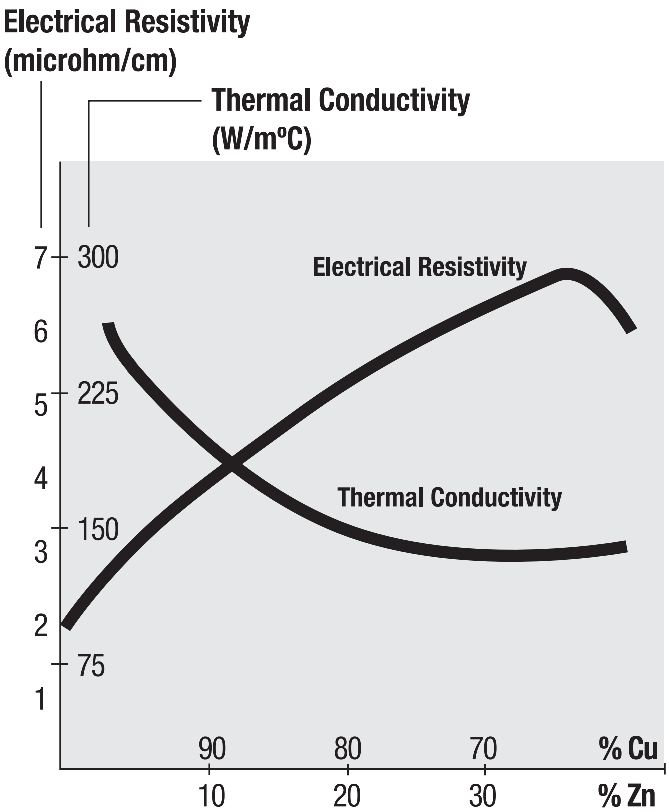
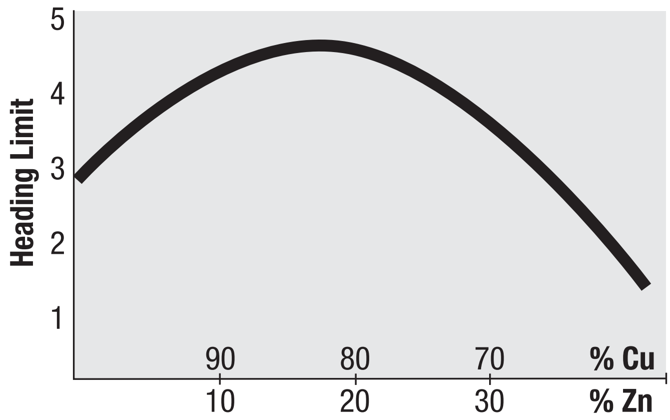


FIGURE 11 – Effect of composition on heading limit



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

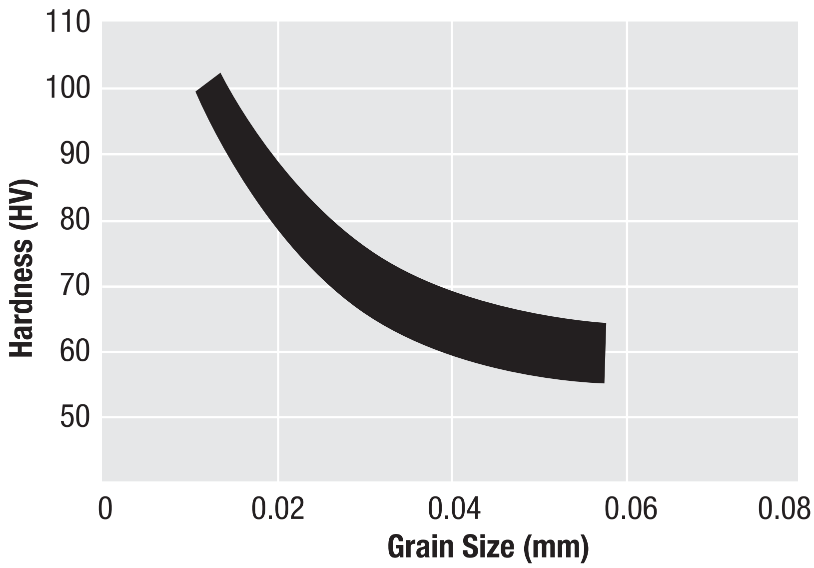
The property data included in the EN Standard specifications for wrought products is based on room temperature tensile testing and hardness determinations for quality control purposes. A limited amount of test data, often required for design purposes, such as creep, fatigue, elevated temperature strength 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

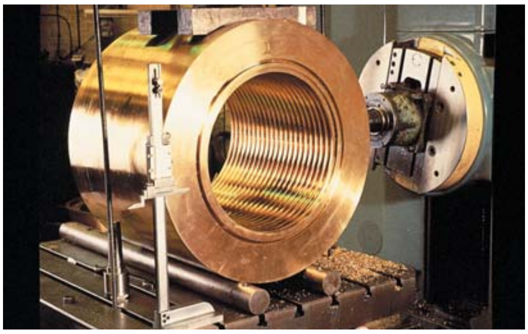
FIGURE 12 – Hardness v grain size for annealed CuZn30 brass sheet and strip



Castings – examples

Adjusting nut for a rolling mill cast in high tensile brass to EN 1982 CC7625 (HTB3)

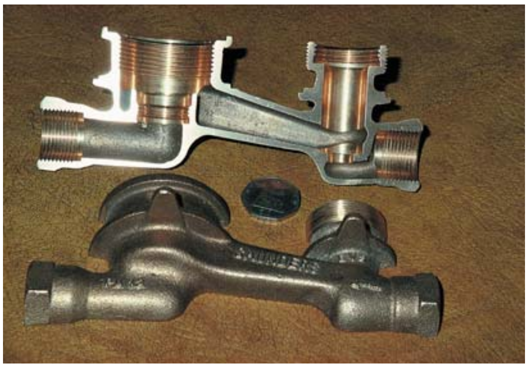
This brass is relatively easily cast and machined to close tolerances to give a strong component resistant to wear and shock.



(Westley Brothers plc)

Valve - sectioned to show internal structure

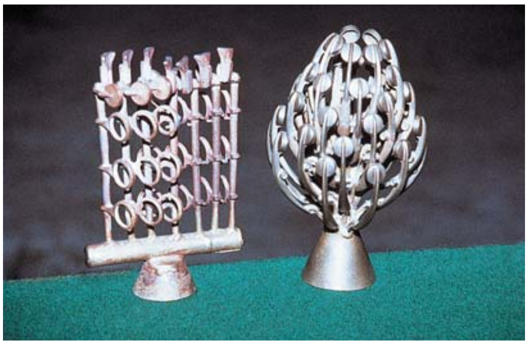
An elaborately cored shell moulding is used to make this valve. Machining is then only required on mating surfaces and for threading.



(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.

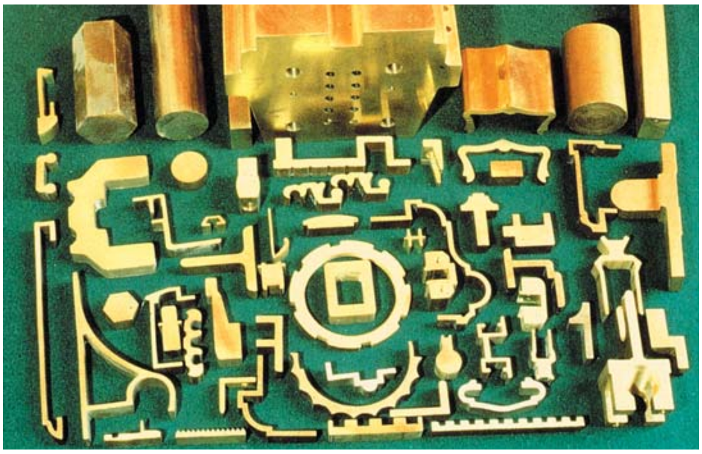
(The Enfield Foundry Co Ltd)

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)

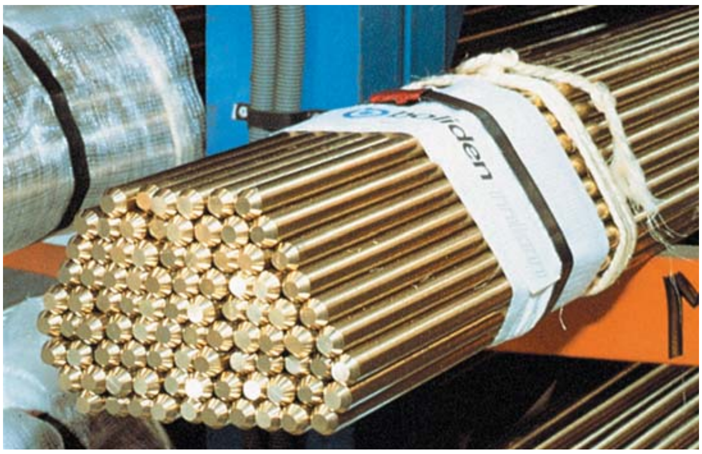
A selection of extruded profiles

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.