Copper & Copper Alloy Castings

Properties & Applications

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Copper & Copper Alloy Castings – Properties & Applications

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Copper Development Association

Copper Development Association is a non-trading organisation sponsored by the copper producers
fabricators to encourage the use of copper and copper alloys and to promote their correct and effic
application. Its services, which include the provision of technical advice and information, are availabl
those interested in the utilisation of copper in all its aspects. The Association also provides a link betv
research and user industries and maintains close contact with other copper development associat
throughout the world.

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Preface

A European Standard (EN) is being compiled for Copper and Copper based materials intended for the manufacture of shaped castings - near net shape components normally only requiring finishing by machining. The Standard will supersede BS 1400:1985 "Copper alloy ingots and copper alloy and high conductivity copper castings" but contains most of the BS1400 materials and also contains some additional alloys commonly used in other European countries. The range of available materials is quite large and this technical note has been prepared to guide the design engineer in the selection of the alloy appropriate for the purpose in mind and to the most economic production route.

It is conceived around functions a designer will want a casting to fulfil which might be, for example, resistance to corrosion under specific conditions or to act as a bearing or to conduct heat. The appropriate alloys in each case are discussed. Obviously as often an optimum combination of functions has to be met, some cross referencing is necessary.

A section devoted to manufacturing practices discusses the available casting processes, their applicability to the different alloys, their relevance to the quantities involved and relative costs. Also included are data on machinability and joining techniques.

In this interim stage of the development of common European standards, and pending an agreement on a common system of numbering, it has been thought advisable to adhere to the existing BS 1400 designations for the alloys, these and additional alloys commonly available in Europe are also designated by the ISO/CEN system using the chemical symbols of the main constituents. However, there is not necessarily an exact equivalence between the BS 1400 alloy and the corresponding alloy in the European Standard.

A CEN common numbering system for all coppers and copper alloys is under development. CDA will be able to provide a supplement to this publication when the numbers are allocated.

Note regarding designations

The British Standard Designations referred to are based on abbreviations of the type of material, i.e.

SCB	sand casting brass
DCB	die casting brass
HTB	high tensile brass
DZR	dezincification resistant brass
HCC	high conductivity copper
CC	copper-chromium
CT	copper-tin (bronze)
PB	copper-tin-phosphorus(phosphor bronze)
LB	leaded bronze
LG	leaded gunmetal
G	gunmetal
AB	aluminium bronze
CMA	copper-manganese-aluminium
CN	copper-nickel

These have been used for many years in BS 1400 but will be superseded by new designations in forthcoming European CEN standards.

The compositional designations also used are based on ISO practice with the base metal first followed by the major alloying elements, i.e. CuSn10P is a phosphor bronze containing 10% of tin. It is probable that a six-digit alphanumerical CEN numbering system will be introduced to cover these materials in a computer-friendly technique.

Designations for casting processes are from ISO 1190/1 may be used in forthcoming CEN standards. The prefix 'G' is used to indicate a cast metal, the next letter indicates the process:

GS	Sand casting
GZ	Permanent Mould casting
GP	Centrifugal casting
GM	Continuous casting
GC	Pressure die casting

(The 'G' prefix, from the German 'Guss', was chose instead of 'C' to avoid confusion with other designation systems.)

Introduction

1. Advantages of Copper Alloy Castings

1.1. Good Castability

The technology of copper alloy founding has advanced considerably in recent years and castings are produced to a high degree of integrity to fulfil many critical applications where inspection requirements are particularly onerous.

The most flexible casting technique uses sand moulds. It is applicable equally to one-offs or to long runs of castings and is suitable for castings from a few grams in weight to several tonnes. Diecasting, which uses permanent moulds usually of iron, is more suited to long runs of castings.

Both sand and diecasting allow low cost production of complex near net-shape components, minimising machining costs and avoiding difficult fabrications.

Rings and discs for the manufacture of products such as gears or valve seatings and tubes or flanged pipes as well as other symmetrical shapes are available as centrifugal castings.

Closely dimensioned bars, sections and hollows are available as continuous castings.

The casting process is far more versatile than fabrication in that it imposes fewer limitations on shape. The parallel-sided and right-angled component, which is the cheapest to fabricate, can also be obtained in a casting, but it should be noted that the pleasing appearance which stems from smoothly flowing outer surfaces costs no more and adds considerably to sales appeal. It can also make a valuable contribution to strength and rigidity.

The potential of a great many engineering components can be increased without restricting their service performance by redesigning as a casting, a strategy which frequently results in a reduction in cost.

1.2. In-built Corrosion Protection

No protective treatments against corrosion are necessary with copper alloys. Slow tarnishing occurs in moist air but this is superficial. Most alloys are resistant to attack in fresh waters and general corrosion rates are typically less than 0.05mm/year in sea water. Alloys recommended for sea water applications generally have better resistance to pitting attack in high chloride situations than stainless steels. There are also many uses in chemical plant.

1.3. Low Frictional Properties and Good Resistance to Wear

Journal and other solid bearings, worm wheels, automobile gear selector forks and many other components where low friction and good wear resistance are required are commonly made from copper alloy castings.

1.4. Non-Sparking Characteristics

Because copper alloy castings are non-sparking they are chosen for housing much electrical equipment where there is an explosion or fire hazard. Non-sparking tools are manufactured from the harder alloys.

1.5. High Electrical and Thermal Conductivity

Cast copper itself has an electrical conductivity of 90% IACS or more and has many electrical applications in heavy switch gear, for connecters, electrode holders and in motors. There are also many thermal applications in heat exchange plant and for heat sinks. Most other cast alloys have conductivities between 15 and 20% of copper which is considerably greater than cast iron or stainless steel and still adequate for many electrical and thermal purposes.

1.6. Good Mechanical Properties at Ambient and High Temperatures

Coppers and copper alloys can be chosen to give an optimum combination of strength in tension and compression, hardness, ductility and resistance to impact to suit most applications. Strengths equivalent to many stainless steels are available at lower cost and, in many applications, improved corrosion resistance.

Properties at elevated temperatures are significantly better than other non-ferrous metals and data is available to facilitate design for short- and long-term use in high-temperature processes with confidence.

1.7. Enhanced Low Temperature Properties

No embrittlement of copper alloy castings occurs at sub-zero temperatures; tensile properties are in fact enhanced. Therefore castings may safely be used down to the temperature of liquid helium.

1.8. Machinability

Many of the alloys contain an addition of lead which ensures excellent machinability with easy chip formation. Even the stronger lead-free alloys present no problems in machining.

1.9. Recycling

Copper alloy castings are completely recyclable. Machine shop scrap, if segregated from ferrous material, has a high value and this is also true of scrapped obsolete components.

1.10. Cost-Effectiveness

The reliability of copper alloys is such that, when the total lifetime cost of a component is estimated, it is often more cost effective to specify a copper alloy than a material apparently cheaper in first cost. The cost of a component is broadly made up of the metal cost plus the foundry costs and finish machining costs. The good foundry characteristics and ease of machining favour the copper alloys over many other materials. The long lifetime of the copper alloys, especially in corrosive environments, means that little allowance has to be made for expensive service failures when estimating lifetime costings.

2. Applications of Main Alloy Groupings

There are several families of alloys used for copper alloy castings. Each has properties uniquely appropriate to particular fields of use, although many have also general applications. Some can only be obtained as castings since these alloys do not readily lend themselves to manufacture in wrought forms.

2.1. High conductivity coppers

These are used chiefly for their high electrical and thermal conductivities. A "thermal grade" of copper, thermal conductivity 58% of copper, is intended mainly for water cooled components in hot blast systems.

Several alloyed coppers retain high conductivity and are used where this property is required together with enhanced strength, especially at elevated temperatures. Notable amongst these is copper-chromium used for resistance welding electrodes and other heavy duty applications.

2.2. Brasses - copper-zinc alloys where zinc is the major alloying element

Sand and diecast brasses such as SCB3 and DCB3 are of low cost and have a very wide range of uses as small to medium sized castings. They are easy to cast, have excellent machinability, moderate strength and good resistance to corrosion in air or fresh waters. This makes them a first, economic, choice for applications requiring the useful range of properties of the copper alloys. Other copper alloys have been developed with even better properties tailored for heavier duty applications in more aggressive environments.

Applications for the brasses range from small decorative castings to medium sized engineering components. An important use is for plumbing fittings. These castings take a good polish and are readily electroplated.

A higher purity, grain-refined version of DCB3 is available for applications involving thinner sections, superior strength or finer finishes.

Special brasses are available for the manufacture of plumbing fittings for areas where selective dezincification of duplex brasses such as SCB3 and DCB3 may occur.

Where the presence of lead in a material is undesirable a silicon brass may be substituted for lead-containing brasses or gunmetals. Its uses are mainly for valves and other water fittings although its good mechanical properties and machinability makes it attractive for general engineering castings.

High tensile brasses, HTB1 and 3, are more highly alloyed and have considerably higher mechanical properties. HTB1 has good corrosion resistance and finds many uses in marine engineering as well as in general engineering. HTB3 is among the hardest of the copper alloys. Its main use is for wear resistance at slow rubbing speeds. It is not recommended for marine use or where conditions are likely to be corrosive.

2.3. Tin bronzes - copper-tin alloys where tin is the major alloying element

With tin contents of 10-12% and fairly low impurity limits, tin bronze castings are considerably more expensive than brass castings. Their chief uses relate to their intrinsically high corrosion resistance. They are suitable for handling acidic waters, boiler feed waters, polluted in-shore waters and those contaminated with abrasive sand or silt. Tin bronzes especially those with higher tin contents are also used in wear resistant applications as an alternative to phosphor bronzes.

2.4. Phosphor bronzes - copper-tin alloys with an addition of phosphorus usually in the range 0.4 - 1.0%

The properties depend considerably on the actual phosphorus content, but usually they are harder than tin bronzes, but with lower ductility. Essentially they are for bearings where both loads and running speeds are high and for other wear resistant parts such as gears, especially worm wheels.

They are frequently chill cast, centrifugally cast or continuously cast, processes which give enhanced properties to suit the application.

2.5. Lead bronzes - copper-tin-lead alloys where lead is a substantial part of the alloy

These are used almost exclusively for bearings, generally for cases where loads and speeds are more moderate than would be suitable for phosphor bronzes. The greater the lead content, the greater is the tolerance for indifferent lubrication. The high lead alloys also have tolerance for embedding safely any abrasive particles which may have contaminated the lubricant and may be used with water lubrication.

2.6. Gunmetals - copper-tin-zinc-lead alloys where all are alloying elements

These are favourite alloys for making sand castings. They are of relatively low cost and have a good combination of castability, machinability and strength. Their resistance to most forms of corrosion is excellent and in this respect they are superior to the brasses. Gunmetals G1 and G3 are no longer listed in the new standards, having been largely superseded by other materials. Foundries may still be able to supply to special order.

While gunmetals have a great variety of uses, they are noted for the manufacture of intricate castings required to be pressure tight such as valves, pipe fittings and pumps. They are also frequently used for bearings where loads and speeds are moderate. Another use is as a backing for white metal bearings.

2.7. Aluminium Bronzes - copper-aluminium alloys where aluminium is the major alloying element

They combine high strength with high resistance to corrosion, the latter depending largely on a thin surface film of alumina. This also confers resistance to tarnishing and to high temperature oxidation.

Applications range from decorative architectural features for the simpler alloys to highly stressed engineering components and those requiring a high degree of corrosion resistance. They have many marine uses including propellers and those where water speeds are high. Most have good wear resistance and some are used for the manufacture of non-sparking tools.

Specialist publications giving more details on the availability, properties, corrosion resistance and applications of the aluminium bronzes are available from Copper Development Association.

2.8. Copper-nickels - copper-nickel alloys where nickel is the major alloying element

These recent introductions are intended chiefly for marine castings where service conditions are exceptionally severe, for instance where there are high water speeds with high turbulence or shielded areas provide conditions likely to allow selective attack with other alloys or where inspection or servicing is very infrequent. Uses are for valves, pumps, pipe fittings and the like rather than for marine propellers. The low volume of production and the high cost of the alloys inevitably result in rather high cost castings.

2.9. Available Coppers and Copper Alloys

The available coppers and copper alloys are listed in Table 2.1 which gives their approximate compositions, densities and specified minimum mechanical properties together with examples of typical applications, more details of which may be found in the sections referenced.

The alloy designations used include those in BS 1400:1985 and in addition the abbreviated nominal chemical composition already used in ISO and many European National standards and forthcoming CEN standards. Other alloys which are commonly available in Europe and likely to be included in the European Standard are identified by their nominal chemical compositions. A numbering system for these materials will shortly be introduced; allocated numbers may be inserted in the table when available.

The compositions and minimum properties are for general information only. For actual 'minimum' values, reference should be made to the latest edition of the appropriate standard. 'Typical' values, often significantly higher than minima, are very dependant on variables such as section thickness and casting techniques, reference to a specialist is needed to check design considerations relating to individual products.

DZR 1 and 2 relate to dezincification resistant diecasting brasses which are covered at present by the BS Draft for Development, DD 187. Materials with similar properties will be included in CEN specifications.

Abbreviations used in Table 2.1:

Sand	Sand casting
Die	Permanent mould casting – usually gravity diecasting, but may also include chill casting
PDC	Pressure diecasting
Cent	Centrifugal casting
Cont	Continuous casting

Table 2.1 Summary of Alloys, Properties and Applications

CEN No	ALLOY TYPE BS 1400 Designation	CEN/ISO Designation	Main elements (% range or max) Cu	Sn	Zn	Pb	Ni	Fe	Al	Mn	Si	P	Density g/cc	Casting Process	Minimum mechanical properties 0.2%PS N/mm^2	UTS N/mm^2	Elong-ation%	Hardness HB	Typical Applications (paragraph references)	CEN/ISO Designation	ALLOY TYPE BS 1400 Designation
HIGH CONDUCTIVITY COPPERS	HCC1	Cu	(Purity to give 86% IACS min conductivity)										8.9	Sand	40	150	25	40	Electrode holders, switch gear, connectors Heat sinks. (7.1 & 7.2)	Cu	HCC1
	(Thermal)		(Purity to give 55% IACS min conductivity)										8.9	"	"	"	"	"	Water cooled hot blast equipment. (7.1 & 7.2)		(Thermal)
	CC1-TF	CuCr1	77% IACS min (0.4-1.2% Cr)										8.9	"	250	350	10	95	Electrical gear where strength & wear resistance is needed	CuCr1	CC1-TF
BRASSES	SCB3	CuZn33Pb2	63-67	1.5	Rem	1-3	1.0	0.8	0.1	0.2	0.05	0.05	8.5	Sand Cent	70 70	180 180	12 12	45 50	General purpose castings for less onerous duties, gas & water fittings. Good machinability. (3.2, 3.3, 5.1, 6, 7.1)	CuZn33Pb2	SCB3
	DCB3	CuZn39Pb1Al	58-63	1.0	Rem	0.5-2.5	1.0	0.7	0.1-0.8	0.5	0.05	0.02	8.4	Die PDC Cent	120 250 120	280 350 280	10 4 10	70 110 70	As for SCB3. Used extensively for plumbing fittings.	CuZn39Pb1Al	DCB3
	DCB3a (Fine grained)	CuZn39Pb1Al(B)	59.5-61	0.35	Rem	1.2-1.7	0.2	0.2	0.4-0.7	0.05	0.05	-	8.4	Die PDC	180 250	350 380	13 4	90 110	As for SCB3 but where superior strength, thinner sections or finer finishes are required.	CuZn39Pb1Al(B)	DCB3a (Fine grained)
	DCB1	CuZn38Al	59-64	0.1	Rem	0.1	1.0	0.5	0.1-0.8	0.5	0.2	-	8.5	Die	130	380	30	75	General purpose high quality engineering castings	CuZn38Al	DCB1
		CuZn37Al	60-64	0.5	Rem	0.50	2.0	0.5	0.3-1.8	0.5	0.6	-	8.5	Die	170	450	25	105	As for DCB1	CuZn37Al	
	(Arsenical Brass)	CuZn15As (As 0.15)	83-88	0.3	Rem	0.5	0.1	0.15	0.01	0.1	0.02	-	8.7	Sand	70	160	20	45	Good corrosion resistance, suitable for brazing	CuZn15As	(Arsenical Brass)
	DZR1	CuZn35Pb2Al (As 0.15)	61-64.5	0.4	Rem	1.5-2.5	0.25	0.35	0.3-0.5	0.15	0.01	-	8.5	Die PDC	120 215	280 370	10 5	70 110	Mainly for water fittings for areas subject to dezincification. (3.3.1) Properties similar to SCB3	CuZn35Pb2Al	DZR1
	DZR2	CuZn33Pb2Si	63.5-66	0.8	Rem	1.3-2.2	0.8	0.5	0.10	0.15	0.65-1.1	-	8.4	PDC	280	400	5	110	As for DZR 1	CuZn33Pb2Si	DZR2
HIGH TENSILE BRASSES	HTB1	CuZn35Mn2Al1Fe1	57-65	1.0	Rem	0.5	6.0	0.5-2.0	0.5-2.5	0.5-3.0	0.1	0.03	8.5	Sand Die Cent Cont	170 200 200 200	450 475 500 500	20 18 18 18	110 110 120 120	General engineering castings. Good resistance to to corrosion.Frequently used for marine components including propellers. (3.4, 3.7)	CuZn35Mn2Al1Fe1	HTB1
	(HTB1(Pb))	CuZn32Al2Mn2Fe1	59-67	1.0	Rem	1.5	2.5	0.5-2.0	1-2.5	1-3.5	1		8.6	Sand PDC	150 330	430 440	10 3	100 130	Lead containing version of HTB1 used mainly where friction & wear occurs, eg. valve spindles.	CuZn32Al2Mn2Fe1	(HTB1(Pb))
		CuZn34Mn3Al2Fe1	55-56	0.3	Rem	0.3	3.0	0.5-2.5	1-3	1-4	0.1	0.03	8.5	Sand Die Cent	250 260 260	600 600 620	15 10 14	140 140 150	General high tensile brass	CuZn34Mn3Al2Fe1	
	(HTB3)	CuZn25Al5Mn4Fe3	60-67	0.2	Rem	0.2	3.0	1.5-4.0	3-7	2.5-5	0.1	0.05	8.0	Sand Die Cent Cont	450 480 480 480	750 750 750 750	8 8 5 5	180 180 190 190	Good resistance to wear under high load at low speeds such as rolling mill slipper pads, screwdown nuts, etc. Unsuitable for marine conditions. (5.1, 5.2)	CuZn25Al5Mn4Fe3	(HTB3)
		CuZn37Pb2Ni1AlFe	58-61	0.8	Rem	1.8-2.5	0.5-1.2	0.5-0.8	0.4-0.8	0.2	0.05	0.02	8.5	Die	150	300	15	90	Die casting brass, fine grained and freely machinable.	CuZn37Pb2Ni1AlFe	
	(Silicon brass)	CuZn16Si4	78-83	0.3	Rem	0.8	1.0	0.6	0.1	0.2	3-5	0.03	8.6	Sand Die PDC	230 300 370	400 500 530	10 8 5	100 130 150	General purpose castings particularly valves & water fittings. Low lead content. (2.2, 3.3.1)	CuZn16Si4	(Silicon brass)
TIN & PHOSPHOR BRONZES	PB1	CuSn11P	87-89.5	10-11.5	0.05	0.25	0.10	0.10	0.01	0.05	0.01	0.5-1.0	8.8	Sand Die Cent Cont	130 170 170 170	250 310 330 350	5 2 4 5	60 85 85 85	Critical bearings running with hard shafts. Good lubrication & alignment essential. (4.4)	CuSn11P	PB1
	CT1	CuSn11	87-89.5	10-11.5	0.05	0.25	0.10	0.10	0.01	0.05	0.01	low P	8.8	Sand	130	250	5	60	High resistance to acidic,alkaline & polluted waters, also where there is contamination with sand or silt.Load bearing components. (3.2, 3.3)	CuSn11	CT1
		CuSn10	88-90	9-11	0.5	1.0	2.0	0.20	0.01	0.10	0.02	0.2	8.8	Sand Die Cont Cent	130 160 170 160	250 270 280 280	18 10 10 10	70 80 80 80	Similar uses to CT1 but possibly slightly less corrosion resistant (3.2 & 3.3)	CuSn10	
	PB2	CuSn12	85-88.5	11-13	0.5	0.7	2.0	0.2	0.01	0.2	0.01	0.6	8.7	Sand Die Cent Cont	140 150 150 150	260 270 280 300	7 5 5 6	80 80 90 90	Mainly for gears especially worm wheels. Also heavily loaded rotating nuts, coupling components. (5.1, 5.2)	CuSn12	PB2
		CuSn12Ni2	84.5-87.5	11-13	0.4	0.3	1.5-2.5	0.20	0.01	0.2	0.01	0.40	8.7	Sand Cent Cont	160 180 180	280 300 300	12 8 10	85 95 95	High resistance to wear & corrosion. Worm wheels, heavily loaded spindle nuts, couplings. (5.1, 5.2)	CuSn12Ni2	
	(PB4)	CuSn11Pb2	83.5-87	10.5-12.5	2.0	1-2.5	2.0	0.20	0.01	0.2	0.01	0.40	8.7	Sand Cent Cont	130 150 150	240 280 280	5 5 5	80 90 90	Bearings with high load, moderate sliding velocity. More tolerant of boundary lubricant conditions & inaccurate fit than PB1. (4.4)	CuSn11Pb2	

Table 2.1 Summary of Alloys, Properties and Applications

CEN No	ALLOY TYPE BS 1400 Designation	CEN/ISO Designation	Main elements (% range or max) Cu	Sn	Zn	Pb	Ni	Fe	Al	Mn	Si	P	Density g/cc	Casting Process	Minimum mechanical properties 0.2%PS N/mm^2	UTS N/mm^2	Elong-ation%	Hardness HB	Typical Applications (paragraph references)	CEN/ISO Designation	ALLOY TYPE BS 1400 Designation
LEAD BRONZES	LB4	CuSn5Pb9	80-87	4-6	2.0	8-10	2.0	0.25	0.01	0.2	0.01	0.10	8.9	Sand Cent Cont	60 90 100	160 200 200	7 6 9	55 60 60	Moderately loaded bearings, tolerant of indifferent lubrication. Good embeddability. (4.6)	CuSn5Pb9	LB4
	LB2	CuSn10Pb10	78-82	9-11	2.0	8-11	2.0	0.25	0.01	0.2	0.01	0.10	9.0	Sand Die Cent Cont	80 110 110 110	180 220 220 220	8 3 6 8	60 65 70 70	Bearings with moderate load, moderate to high sliding velocity.Adequate lubrication needed but tolerates boundary conditions.Hot mill bearings. (4.5)	CuSn10Pb10	LB2
	LB1	CuSn7Pb15	74-80	6-8	2.0	13-17	0.5-2.0	0.25	0.01	0.20	0.01	0.10	9.1	Sand Cent Cont	80 90 90	170 200 200	8 7 8	60 65 65	Bearings for moderate loads.Tolerant of poor or water lubrication.Accomodates grit or dust. Suitable for cold rolling mills. (4.6)	CuSn7Pb15	LB1
	LB5	CuSn5Pb20	70-78	4-6	2.0	18-23	0.5-2.5	0.25	0.01	0.20	0.01	0.10	9.3	Sand Cent Cont	70 80 90	150 170 180	5 6 7	45 50 50	Bearings with moderate loads, high sliding velocities. Tolerant of poor or water lubrication. For more extreme conditions than LB1. (4.6)	CuSn5Pb20	LB5
GUNMETALS	LG1	CuSn3Pb5Zn8	81-86	2-3.5	7-9.5	3-6	2.0	0.5	0.01	-	0.01	0.05	8.8	Sand Cent Cont	85 100 100	180 220 220	15 12 12	60 70 70	Lower duty castings especially thin walled fittings for for various water services. Suitable up to 250°C (3.3.1, 4.7)	CuSn3Pb5Zn8	LG1
	LG2	CuSn5Pb5Zn5	83-87	4-6	4-6	4-6	2.0	0.3	0.01	-	0.01	0.10	8.8	Sand Die Cent Cont	90 110 110 110	200 220 250 250	13 6 13 13	60 65 65 65	Good general purpose alloy. Corrosion resistant including sea water. Water & steam fittings to 275°C Moderate duty bearings. Intricate pressure tight castings. (3.2, 3.3, 3.4, 3.6, 4.7, 5.1, 6, 8.1, 9)	CuSn5Pb5Zn5	LG2
	LG4	CuSn7Pb3Zn2	85-89	6-8	1.5-3	2.5-3.5	2.0	0.2	0.01	-	0.01	0.10	8.7	Sand Die Cent Cont	130 130 130 130	230 230 260 270	14 12 12 12	65 70 70 70	Good constructional material, suited to thicker sections. Many marine uses including pump bodies & other sea water handling components. (3.2, 3.3, 3.4, 3.6, 4.5, 6, 7.1, 8)	CuSn7Pb3Zn2	LG4
		CuSn7Pb7Zn4	81-85	6-8	2-5	5-8	2.0	0.2	0.01	-	0.01	0.10	8.8	Sand Die Cent Cont	120 120 120 120	230 230 260 260	15 12 12 12	60 60 70 70	Main use is for moderate duty bearings for general engineering, cranks, slides, marine shaft sleeves & cylinder liners. (4.5)	CuSn7Pb7Zn4	
ALUMINIUM BRONZES	AB1	CuAl10Fe2	83-89.5	0.20	0.50	0.10	1.5	1.5-3.5	8.5-10.5	1.0	0.2	-	7.5	Sand Die Cent Cont	180 250 200 200	500 600 550 550	18 20 18 15	100 130 130 130	Stressed castings requiring good corrosion & wear resistance. Synchromesh rings,gear selector forks, bushings & housings in machinery. (3.2, 3.3, 3.7, 5.2, 5.3, 7.2, 8.2).	CuAl10Fe2	AB1
		CuAl10Ni3Fe3	80-86	0.20	0.50	0.10	1.5-4	1-3	8.5-10.5	2.0	0.2	-	7.5	Sand Die Cent Cont	180 250 220 220	500 600 550 550	18 20 20 20	100 130 120 120	Corrosion resistant constructional alloy suitable for use in seawater & in food & chemical industries.	CuAl10Ni3Fe3	
	AB2	CuAl10Fe5Ni5	76-83	0.1	0.50	0.03	4-6	4-5.5	8.5-10.5	3.0	0.1	-	7.6	Sand Die Cent Cont	250 280 280 280	600 650 650 650	13 7 13 13	140 150 150 150	High strength & excellent corrosion resistance. Many marine uses including propellers.Heavy duty pumps. Petro-chemical engineering. Superheated steam. Oxidation resistant. Non-sparking tools. (3.2-3.6, 4.8, 5.1-5.3, 7.1, 8.1, 8.2, 9)	CuAl10Fe5Ni5	AB2
		CuAl11Fe6Ni6	72-78	0.2	0.50	0.05	4-7.5	4-7	10-12	2.5	0.1	-	7.6	Sand Die Cont	320 380 380	680 750 750	5 5 5	170 185 185	Hard, strong constructional material, very resistant to wear. Bearings with slow speeds & high shock loads. High cavitation resistance. Non-sparking tools. (4.8, 5.2, 5.3)	CuAl11Fe6Ni6	
	CMA1	CuMn11Al8Fe3Ni3	68-77	0.5	1.0	0.05	1.5-4.5	2-4	7-9.0	11-15	0.15	0.05	7.5	Sand	275	630	18	150	Seawater handling components, propellers. (3.4)	CuMn11Al8Fe3Ni3	CMA1
		CuAl9	88-92	0.30	0.50	0.30	1.0	1.2	8-10.5	0.50	0.20	-	7.4	Die Cent	180 160	500 450	20 15	100 100	Mainly building & decorative components. High resistance to tarnishing. (3.2)	CuAl9	
COPPER-NICKEL ALLOYS	CN1	CuNi30Cr2FeMnSi (1.5-2.0% Cr)	Rem	-	0.2	0.005	29-32	0.5-1.0	0.01	0.5-1.0	0.15-0.5	0.01	8.8	Sand	250	440	18	115	High strength & excellent corrosion resistance to seawater. Mainly for most arduous marine applications. (3.3, 3.4)	CuNi30Cr2FeMnSi (1.5-2.0% Cr)	CN1
	CN2	CuNi30Fe1Mn1NbSi (0.5-1.0% Nb)	Rem	-	0.5	0.01	29-31	0.5-1.5	0.01	0.6-1.2	0.3-0.7	0.01	8.8	Sand	230	440	18	115	High strength & excellent corrosion resistance to seawater. Mainly for most arduous marine applications; weldable. (3.3, 3.4)	CuNi30Fe1Mn1NbSi (0.5-1.0% Nb)	CN2
		CuNi10Fe1Mn1	Rem	-	0.5	0.03	9-11	1.0-1.8	0.01	1.0-1.5	0.10	-	8.8	Sand Cent Cont	120 100 100	280 280 280	20 25 25	70 70 70	Good corrosion resistance to sea water. Suitable for pipe flanges, etc.	CuNi10Fe1Mn1	
		CuNi30Fe1Mn1	Rem	-	0.5	0.03	29-31	0.5-1.5	0.01	0.6-1.2	0.10	-	8.8	Sand Cont	120 120	340 340	18 18	80 80	Excellent resistance to sea water. Pipe fittings in marine & chemical engineering.	CuNi30Fe1Mn1	

Applications

3. Resistance to Corrosion

3.1. General

Corrosion is an important aspect of the use of copper alloy castings. This is not because they are prone to corrode, rather because their excellent record of corrosion resistance leads to their use in corrosive, often very corrosive, situations. This is without any protection such as painting or other surface treatments. In this respect they are rather like stainless steels although more versatile in their applications and usually considerably less costly.

In air most of the copper alloys tarnish, but unlike iron or steel this tarnish film is protective and it slows down or completely inhibits further corrosion. Resistance to corrosion by fresh waters is also very good, the rate of attack under normal conditions being similar to that in air.

Copper alloy castings are also a natural choice for service in sea water where in addition to good corrosion resistance most possess good anti-fouling properties (resistance to the attachment of marine biofouling). In some marine applications particularly severe forms of corrosion may be encountered but casting alloys can be selected appropriate to the conditions.

Cast copper alloy components also have many uses in the chemical industry. They are suitable for handling non-oxidising acids and their salts and also some alkaline solutions. They are generally not recommended for use with strong oxidising acids and they are not generally suitable for applications involving ammonia or ammoniacal solutions.

All common metals are subject to corrosion to a greater or less extent given the right conditions. Where corrosion does occur, it can take many forms including pitting under deposits, crevice corrosion, selective phase attack, stress corrosion, impingement attack, erosion, cavitation and corrosion fatigue. A more detailed account of these different forms of corrosion in the context of the applications of copper alloy castings is given in Appendix A.

3.2. Alloys for Atmospheric Corrosion Resistance

3.2.1. Indoors

Under reasonably dry conditions all alloys are satisfactory and only slight surface dulling occurs. It is most pronounced with High Conductivity copper. If appearance is significant, the component can be repolished occasionally or polished, cleaned and protected with a suitable lacquer.

Brightness is best retained by alloys containing aluminium such as diecast brass, DCB3, or aluminium bronzes. CuAl9 is particularly recommended for bright decorative features.

3.2.2. Outdoors

i. Rural sites

All alloys tarnish but corrosion rates are negligible. Brightness is best retained by diecast brass, DCB3, or aluminium bronze such as CuAl9.

The well known 'bronze' patina that develops on some of the alloys is a useful feature for statuary and plaques. This finish may be formed artificially. Gunmetals are most frequent for such applications although for less prestigious items cast brasses are often used.

ii. Marine sites

Unless regularly cleaned, castings in all alloys gradually develop a green patina. Surface attack is slight, no more than 0.002-0.003mm penetration per year.

iii. Polluted urban or industrial sites

The presence of sulphur compounds results in a darker tarnish film, but surface attack is unlikely to exceed 0.007mm penetration a year.

Brightness is best retained by aluminium bronzes such as CuAl9.

iv. Heavy sulphur dioxide pollution

For high concentrations of combustion products such as sulphur dioxide, for example in the vicinity of chimneys, use aluminium bronze such as AB1 or AB2.

3.2.3. Load bearing applications

While most brasses have good corrosion resistance in normal atmospheres, they are less suitable for use in aggressive environments as they are subject to stress corrosion cracking in some circumstances. Special brasses such as silicon brass and arsenical brass are more resistant.

Aluminium bronzes such as AB1 or AB2 have high strength and low susceptibility to stress corrosion. AB2 has been used for access fittings for chimneys and as reinforcing fixings in the repair of old stone work. Experience has shown that the large volume expansion occurring when iron rusts can cause severe damage to stone work.

Alternatively gunmetals, or tin bronzes such CT1 or CuSn10 are suitable. Although of lower strength they also have high resistance to stress corrosion.

3.3. Service in fresh waters

3.3.1. Pumps and other plumbing fittings

For many plumbing fittings such as valves, tees and branches, brasses to SCB3 and DCB3 specifications are used extensively. They have good castability, are inexpensive, easily machined and they may be electroplated without difficulty for decorative purposes. Alternatively gunmetals LG1 and LG2 are used.

Where dezincification is likely to be a problem, either of the brasses DZR1 or DZR2 should be used in preference to SCB3 or DCB3, or alternatively gunmetals LG1 or LG2. These materials are also suitable for underground fittings where attack from acidic waters is a possibility.

In circumstances where the presence of lead may be undesirable, silicon brass is recommended. It has excellent casting qualities for both sand and diecasting, good resistance to corrosion and satisfactory machinability although it is more expensive than other brasses.

3.3.2. Higher duty pumps and valves

The design of heavy-duty pumps needs significant expertise, especially if the fluid is corrosive and contains abrasive suspended solids. Due to the severe turbulence experienced, flow rates are not easy to predict. Impellers can be subject to cavitation corrosion and the bodies to erosion. Where electrolytic corrosion is possible, such as in most aqueous liquids, it is normal to make the impeller of an alloy that is more noble than the body so that the much larger mass of the body can be sacrificial. Similar considerations apply to other small parts such as sealing rings and bearings.

For larger higher duty pumps and valves LG2 or LG4 are recommended. LG4 is more suitable where water speeds are high. For pump parts such as impellers or bodies, LG2 is satisfactory for lower water velocities and LG4 where impeller peripheral velocities are higher (up to 25m/sec). For still higher velocities, aluminium bronze AB2 impellers may be used for peripheral velocities up to 45m/sec often with LG4 pump bodies. Gunmetal impellers are also frequently used in conjunction with cast iron bodies.

3.3.3. Mine waters and other acidic or turbid waters

Gunmetals LG2 or LG4 are sometimes used but tin bronze such as CT1 is preferred because of its intrinsically higher corrosion resistance in acid conditions. CuSn10 is an alternative somewhat less costly alloy.

Aluminium bronze AB2 is also suitable in the absence of abrasive particles. However its corrosion resistance depends on the presence of a thin protective surface film of alumina and although this is self healing constant abrasion leads to fairly rapid erosion.

3.3.4. Boiler feed waters

Tin bronzes are a good choice for components handling boiler feed waters. Aluminium bronze is also used, AB2 being the recommended choice.

3.4. Service in sea water

3.4.1. Comparative corrosion rates

The corrosion rates under various conditions for the casting alloys normally considered for service in sea water are summarised in Table 3.1. Comparative figures for austenitic cast iron and austenitic stainless steels are also included where available. These results have been obtained from several sources and the test conditions may not always be strictly comparable but the table well illustrates the relative performance of the materials.

The lower cost brasses such as SCB3 and DCB3 are not recommended for immersed conditions except possibly for non critical applications such as small boats which are frequently hauled out for inspection. These alloys suffer selective dezincification of the beta phase. While the high tensile brass HTB1 is suitable and is used for many under water fittings, the higher strength brass HTB3 can suffer intercrystalline corrosion in marine conditions and cannot be recommended.

3.4.2. Sea water handling components

For pumps, valves, pipe fittings and other components handling sea water, gunmetals LG2 and LG4 are used unless the conditions are unusually severe or the part is of critical importance when aluminium bronze AB2 would be a suitable choice. An example would be where water velocities are exceptionally high. Manganese aluminium bronze CMA1 is an alternative although it is now less frequently used.

LG4 castings have rather better properties in thick sections than LG2 castings and also have better resistance to impingement attack and erosion so that LG4 would have the advantage for larger higher duty components. In the case of centrifugal pump impellers recommended maximum peripheral velocities are similar to those for fresh water.

Table 3.1 Summary of Performance of Castings in Sea Water

Alloy Type	Designation	General Corrosion Rate in Sea Water mm/y Water Speed Static <0.5m/s	Slow 3m/s	Fast 10m/s	Crevice Corrosion mm/y	Impingement Depth mm penetration 28 day test	Cavitation Depth mm 3% NaCl	Corrosion Fatigue Strength N/mm^2 10^8 cycles
Brasses	SCB3 Not recommended for immersed conditions							
	DCB3 Not recommended for immersed conditions							
Gunmetal	G1[1]	0.025	0.06	0.30	<0.025	0.02	-	-
	LG2	0.04	0.09	0.69	<0.04	0.23	-	-
High Tensile Brass	HTB	1 0.18	0.0	0.30	0.25	0.03	0.280	70
Aluminium Bronze	AB1	0.06	0.07	0.08	<0.06	0.04	-	-
	AB2	0.05	0.02	0.08	<0.5[2]	nil	<0.025	90
Manganese Aluminium Bronze	CMA1	0.04	0.02	0.05	3.8	0.01	-	60
Austenitic Cast Iron	AU202	0.075			nil	-	-	46
Austenitic Stainless Steel	304	<0.025	-	-	0.25	-	-	-

1) Largely replaced by LG4 which is only slightly inferior in its resistance to impingement attack.
2) Corrosion by selective de-alloying in narrow bands on a microscale with minimal effect on properties. This effect is reduced if the casting is heat treated suitably before entering service.
The lower cost brasses such as SCB3 and DCB3 are not recommended for immersed conditions except possibly for non-critical applications such as small boats which are frequently hauled out for inspection. These alloys suffer selective dezincification of the beta phase. While the high tensile brass HTB1 is suitable and is used for many under water fittings, the higher strength brass HTB3 can suffer intercrystalline corrosion in marine conditions and cannot be recommended.

3.4.3. Underwater fittings.

For underwater fittings, gunmetals or tin bronze may be used, but where higher strength is required aluminium bronze AB2 or CMA1 are recommended. High tensile brass HTB1 is a less costly alternative for less critical circumstances.

AB2 has relatively good resistance to crevice corrosion and is generally considered to be superior to stainless steel in this respect. Such attack as does occur takes the form of narrow bands which have minimal effect on strength or performance. CMA1 and HTB1 are more susceptible to selective corrosion in shielded areas and perform best under conditions of free exposure. Both AB2 and CMA1 have high corrosion fatigue properties.

Tail shaft liners are usually made from LG2 or LG4. For bearings for rudders and the like where loading tends to be high but velocities low, aluminium bronze AB2 is often used. Structural members are made from AB2, CMA1 or HTB1.

The high strength copper-nickels, CN1 and CN2, are superior to aluminium bronze as regards susceptibility to crevice corrosion and resistance to impingement attack and are being introduced for extremely critical conditions. Castings in these alloys are considerably more costly and at present they are used primarily for naval purposes.

3.4.4. Marine propellers.

Because of the complex shape of propellers, the alloys have to have good castability and a tolerance for repair by welding is also a useful attribute. Most marine propellers, the hubs, thrusters etc. are now made from aluminium bronze AB2. CMA1 is also used, but less frequently. There is also a demand for high tensile brass HTB1 propellers, usually for smaller vessels. Propellers for small boats are sometimes made from tin bronze.

The resistance to corrosion fatigue of AB2 is nearly twice that of HTB1 and it is also superior in its resistance to corrosion/erosion and cavitation so that it is more suitable for higher duty operation. Nevertheless, HTB1 was the standard propeller alloy for many years and it is still widely used. It is easier to cast and a less expensive alloy. CMA1 has similar properties to AB2 although slightly inferior in corrosion fatigue and resistance to cavitation.

All three alloys may be welded, but a post welding heat treatment is advisable to ensure that the metallurgical structure is the optimum for satisfactory performance in sea water.

3.5. Resistance to chemical solutions

Brasses are not usually considered suitable for handling acids or alkalies, but gunmetals, tin bronze and aluminium bronze castings are extensively employed in the chemical industry for valves, pumps, flow meter bodies, pipeline fittings, stirrers and beaters. They are serviceable for handling non-oxidising acids, such as acetic, formic, oxalic, citric, and carbolic acids, sulphite liquors as used in paper making, tannic acid in the leather industry and crude fatty acids as used in soap manufacture. Details of tolerable solution concentrations and temperatures are included in the book 'Corrosion Guide' by E. Rabald, see Appendix B.

Table 3.2 shows corrosion rates determined experimentally for gunmetal and tin bronze castings for several solutions. Corrosion rates are usually in the range 0.1 - 0.2mm penetration per year. With aluminium bronze the rates would be expected to be similar or lower.

Table 3.2 Corrosion resistance of gunmetal and tin bronze to some chemical solutions

Duration of tests 600 hrs. Tests conducted in aerated solutions at 15°C

Corrosive Environme	Penetration in mm/year		
		Gunmetal	90/10 tin bronze
5%	Sulphuric acid	0.6	0.4
10%	" "	0.2	0.25
25%	" "	0.15	0.08
50%	" "	0.005	0.02
75%	" "	0.02	0.01
Concentratedacid		0.4	0.25
5%	Acetic acid	0.08	0.06
10%	" "	0.08	0.06
25%	" "	0.08	0.06
50%	" "	0.18	0.17
75%	" "	0.31	0.30
Concentratedacid		0.2	0.2
6%	Sulphurous acid	< 0.01	< 0.01
5%	Carbolic acid	< 0.01	< 0.01
5%	Citric acid	0.3	0.2
5%	Sodium hydroxide	0.18	0.16
10%	" "	0.11	0.10
25%	" "	0.05	0.05

Gunmetal or tin bronze castings may be used with sulphuric acid although aluminium bronze is probably superior. This is also preferred for handling phosphoric acid. Hydrofluoric acid is also satisfactorily handled with castings in these alloys.

Alkaline salts may be handled, but not ammoniacal compounds.

Copper alloy castings are attacked by hydrochloric acid although aluminium bronze hooks (AB2) are used successfully for pickling steel wire rod in moderately concentrated hydrochloric acid. Nitric acid attacks copper alloys rapidly.

3.6. Superheated steam and industrial gases

Gunmetals LG2 and LG4 are commonly used for valves and similar fittings handling superheated steam. Corrosion rates are negligible, but there are temperature limitations (see 7.1)

Aluminium bronze AB2 is also suitable for steam services but its superior strength over gunmetals falls rapidly as temperatures rise above 300°C. Dry industrial gases such as oxygen, nitrogen, carbon dioxide and natural gas can be safely handled with brass, gunmetal, tin bronze or aluminium bronze castings as can dry sulphur dioxide and the halogen gases. Slight corrosion may occur in the presence of moisture although aluminium bronze pumps and valves have been used successfully for handling moist sulphur dioxide up to 100°C.

Ammonia and hydrogen sulphide gas cannot be satisfactorily handled. For acetylene gas it is essential that the copper content of the alloy should not exceed 65% so that only certain brasses are suitable.

3.7. Food products

The rate of attack of most foodstuffs on copper alloy castings is generally very low. This does not present a health hazard as copper is non-toxic in small concentrations and is in fact an essential dietary trace element. However, traces of copper can affect the taste, colour or the onset of rancidity of many food products. Such contamination can be detected by taste long before it reaches toxic proportions. It is therefore usually necessary to coat copper alloy castings with a non-porous layer of tin or nickel to guard against copper pick-up. With uncoated castings, contamination is least likely with aluminium bronzes.

If dry products are to be handled it is advisable to select an alloy with a low lead content such as phosphor bronze, aluminium bronze or high tensile brass to avoid contamination with traces of lead by abrasion.

4. Bearings

4.1. Relevant basic properties

Copper alloy castings are well established for plain bearings, having several advantages over alternative materials that make them ideal for heavy-duty applications. Although they do not possess quite such a low coefficient of friction as white metal bearings they have much superior resistance to fatigue which is a common cause of failure and also higher thermal conductivity. They also resist corrosion by lubricant breakdown products or by the working regime.

The alloys most frequently used are the phosphor bronzes, which possess high resistance to wear, the leaded bronzes and the gunmetals. Choice depends partly on the service conditions, but also on the cost and the expected life of the bearing. Lead containing brasses such as SCB3 and DCB3 are also used. An important application is for the cages of ball and roller bearings. Aluminium bronzes also have special bearings uses.

Table 4.1 summarises the applications of the principle bearing alloys.

Table 4.1 Summary of Bearing Alloy Applications

Application	Alloy	Comments	Minimum Shaft Hardness HB
High load,high sliding velocity, impact loading or pounding.	PB4 PB1	Good lubrication & good alignment essential.	300
Moderate loading,moderate to high velocity,impact loading or pounding.	LB2	Adequate lubrication required but tolerant of boundary conditions & inaccuracies of fit.	250
Moderate loading & sliding velocities. Less critical functions.	LG4 CuSn7Pb7Zn3	Embraces majority of bearing uses. Need adequate lubrication but tolerant of boundary conditions & inaccuracies of fit.	280
Moderate loads & moderate to high sliding velocities. Possibility of indifferent lubrication & dust or grit.	LB4 LB1 LB5	All have good embeddability. Tolerant of water lubrication.	200 150
Low loads,non-critical uses.	LG2 SCB3 DCB3	Need adequate lubrication but good embeddability.	250
Ball & roller bearing cages.	SCB3 DCB3		
High loads with low sliding velocities.	AB2 CuAl11Fe5Ni5 HTB3	Suitable for marine uses. Very hard. Poor embeddability. Unsuitable for marine uses.	300

4.1.1. Loading

The function of a bearing is to support the load of the shaft and its associated rotating machinery and to permit motion. The compressive load over the projected area of the bearing must be within the compressive load limits of the casting. Ideally this should be calculated from the proof stress of the casting material in compression. However, there are practical difficulties in this determination and as the proof stress in compression is virtually the same as that in tension, the latter is normally used. Minimum specified values for the 0.2% proof stress are given in Table 2.1. Hardness ranges for the alloys most frequently used for bearings and other wear resistant parts are included in Table 4.2. This also includes the elastic moduli of the alloys.

Adequate resistance to fatigue is necessary to avoid surface cracking which is a cause of bearing failure and Table 4.2 also contains available fatigue data.

The higher hardness values are typical of sections of 15mm or less and lower values sections upwards of 30mm. The hardness of permanent mould castings and centrifugal castings are usually similar. Fatigue limites are for 108 cycles from Wohler type fatigue tests.

It will be noted that the tensile properties and hardness of the bearing alloys are considerably greater when these are in the form of permanent mould, centrifugal or continuous castings than for sand castings. Size or shape makes it necessary for some bearings to be made as sand castings, but most bearings are of simple symmetrical shapes which readily lend themselves to chill (permanent mould) casting, centrifugal casting or continuous casting. These are the preferred methods of manufacture as they usually produce a finer and denser structure with a better, easily machined, surface finish.

4.1.2. Thermal conductivity

Table 7.1 contains thermal conductivity data. Those alloys most used for bearings have conductivities falling in the range 50-70 Watts/m°C. This relatively high value enables the heat generated by friction or by the shear of lubricant films to be efficiently dissipated and the tendency of the bearing surface to suffer thermal fatigue is diminished.

Breakdown of the lubricant film can rapidly lead to overheating and ultimate failure through wear or thermal fatigue. Overheating also results in oxidation of the lubricant causing corrosive residues. Heat can also soak from the machine to the bearing or shaft and if the flow of lubricant is inadequate to conduct the heat away this can also result in overheating.

4.1.3. Thermal expansion

The cast copper alloys used for bearings generally have higher coefficients of thermal expansion than the steels normally used for shafts, 17 - 19 x 10-6 as compared with 11.5 - 13.0 x 10-6. Allowance is made for this in designing the fit of the bearing and Table 4.2 lists thermal expansion values.

Table 4.2 Hardness, Fatigue, Limit, Eastic Modulus and Linear Coefficient of Expansion

Alloy Type	Casting Process	Typical Hardness HB	Fatigue Limit N/mm²	Elastic Modulus kN/mm²	Coefficient of Expansion $x10^{-6}$ 0-250°C
PB1	Sand	70/100	110	95	18
	Cent	95/150	110		
	Cont	95/150			
PB2	Sand	80/110	-	95	19
	Cent	90/150	-		
	Cont	90/150	-		
CuSn10Pb (PB4)	Sand	80/95	-	95	19
	Cent	90/120	-		
	Cont	90/120	-		
LB4	Sand	55/75	-	85	18
	Cent	60/80	-		
	Cont	60/80	90		
LB2	Sand	60/85	80	90	19
	Cent	70/90	80		
	Cont	70/90	150		
LB1	Sand	60/70	-	85	19
	Cent	65/90	-		
	Cont	65/90	-		
LB5	Sand	45/65	-	75	19
	Cent	50/70	-		
	Cont	50/70	-		
LG2	Sand	60/75	70	90	18
	Cent	65/95	-		
	Cont	65/95	110		
LG4	Sand	65/85	80	90	18
	Cent	70/95	-		
	Cont	70/95	-		
CuSn7-Pb7Zn3	Sand	60	-	85	18
	Cent	70	-		
	Cont	70	-		
SCB3	Sand	45/65	70	95	20
DCB3	Die	70	110	95	21
AB1	Sand	100/140	200		17
	Die	130/160	200		
AB2	Sand	140/180	220	120	17
	Die	150/190	-		
HTB1	Sand	110/150	140	95	21
	Cent	120/150	-		
HTB3	Sand	180/230	170	105	21
	Cent	190/230			

4.2. Shaft materials

Obviously the strength of the shaft has to be adequate for the load it has to sustain, but it is well recognised that to achieve optimum performance the shaft also needs to be considerably harder than the bearing. Ideally it should have a hardness at least three times that of the bearing. Hardness is normally measured for copper alloy castings on the Brinell scale since the large ball indenter gives more accurate results on these materials than the smaller Vickers diamond indenter.

Usually the shaft will be of hardened steel. If it is too soft in relation to the bearing there is a danger of the bearing scoring the shaft or of the two surfaces momentarily welding together locally. Seizure can occur if the conditions of lubrication are poor.

4.3. Backing for bearings.

Bearings form only part of the machine and have to be rigidly housed in the rest of the structure. The housing, which ultimately carries the load, may be of steel, cast iron or aluminium alloy. In the case of phosphor bronzes, low lead bronzes and gunmetals, unless the bearing has been machined to a thin shell the cast bearing itself will usually have sufficient strength to render the backing material unimportant provided that the assembly is rigid. However, the high lead bronzes have lower strength and require good support from the backing assembly to avoid the possibility of distortion.

Gunmetal castings are frequently used as backings for composite bearings largely on account of their ability to conduct away heat generated.

4.4. Alloys for high duty bearings with high load and high sliding velocities

For critical applications when the loading is high or where there is the possibility of impact loading or pounding and where sliding velocities are high, it is usual to specify a high tin phosphor bronze such as PB1. An alternative is PB4. These alloys have high proof stress and hardness with excellent wear resistance. They are for applications where good lubrication can be assured. Running clearances should be such as to ensure continuity of the lubricant film. Good alignment is essential as because of their hardness and strength they have relatively poor embeddability compared with softer alloys.

PB1 is a high performance, high purity alloy with a tight limit on the zinc content in order to reduce friction. It is intended for the most critical applications.

PB4, which is less expensive, is an alternative choice. The specifications allows for some lead which exists in the alloy as discrete globules. This is possibly an advantage in guarding against seizure in periods of minimal lubrication as in start-up, as lead tends to reduce the coefficient of friction under dry conditions but this must be regarded only as a very temporary palliative.

Hardened steel shafts are essential. A minimum hardness of at least 300 HB is recommended.

These alloys contain a hard copper-tin eutectoid phase supported in a strong but softer matrix. This heterogeneous structure is common among bearing materials. The eutectoid phase has a hardness of about 300 HB and it is obvious that unless the shaft mating with the bearing is at least as hard it is liable to suffer scoring.

The practice in the UK is to increase the proportion of the hard phase for a given tin content by making phosphorus additions up to 1%. In some countries higher tin contents are employed, sometimes augmented with nickel as in CuSn12Ni2 to achieve similar results, albeit at greater expense.

4.5. Alloys for moderate loading and less critical applications

For conditions of moderate loading and high to moderate sliding velocities, LB2 is sometimes used. It is possibly more tolerant of lubricant deficiencies and of foreign particles than are the phosphor bronzes. However, the alloy is more difficult to cast and this plus the high tin content are likely to be reflected in the cost of the bearings.

The minimum recommended shaft hardness is 250HB.

For conditions of moderate loading and moderate sliding velocities, a category that embraces probably the majority of bearing uses, a rather less expensive alloy such as LG4 is suitable. Hardness and tensile properties are somewhat lower than those of the high tin alloys. As a consequence there is not the need for quite the same degree of precision fit of the shaft and bearing and there is somewhat better embeddability although at some sacrifice of wear resistance.

While there is still the need for adequate lubrication there is greater tolerance for boundary conditions.

The recommended minimum shaft hardness is 280 HB.

An alternative alloy is CuSn7Pb7Zn3 which has only slightly inferior properties.

4.6. Alloys for moderate loading and/or poor lubrication

For low to moderate loading and moderate to high sliding velocities where there is a possibility of deficient lubrication, there is a range of leaded bronze bearing alloys. Lead contents range from 9% for LB4 to 20% for LB5.

These alloys are accommodating as regards misalignment and are also tolerant of foreign particles entering the bearing. These become embedded in the lead phase and so cause little damage. Those with the higher lead contents at least may be used in dusty or gritty environments. The alloys with 15% or 20% lead are also tolerant of water lubrication.

Bearings made from these alloys are not so suitable for applications involving impact loading or pounding as the matrix is relatively soft; good backing is advisable.

Relatively soft mild steel shafts can be used. For LB4 the minimum shaft hardness recommended is 200 HB. For higher lead contents the shaft hardness may be as low as 150 HB.

The alloys occupy a special niche in the field of bearing applications and are not in such high volume production as the other groups of alloys. The maintenance of a satisfactory dispersion in the casting of a large proportion of lead creates problems for the foundryman and the production of such bearings is a rather specialised activity suitable only for well-controlled centrifugal or continuous casting techniques.

4.7. Alloys for low loads in non critical applications

LG2 is often employed, or less frequently LG1. Leaded brasses such as SCB3 are also sometimes used for small bearings in non critical applications.

Bearings made from these alloys still require adequate lubrication.

The lower hardness of these alloys permits the use of softer shafts.

A minimum shaft hardness of 250 HB is recommended.

4.8. Aluminium bronze bearings

Aluminium bronzes are not usually considered as bearing materials but there are circumstances where their high strength and hardness plus their excellent corrosion resistance leads to their selection. Applications in plant and equipment are of the kind where there is heavy loading but the rubbing speeds are low. A wrought alloy similar to AB2 is used for bearing bushes in aircraft frames where working conditions are of this type. In this case the high corrosion resistance of the alloy is important.

Aluminium bronze AB2 is very suitable for use in marine environments and is a good choice where its high strength is needed to sustain heavy loads at relatively low rotational speeds. A minimum shaft hardness of 300 HB is recommended to avoid excessive shaft wear.

Aluminium bronze is also used as the hard, strong base material in some composite bearings where inserts of anti-friction material are arranged in a checker pattern at the bearing surface.

Copper-chromium, CuCr1, has also been suggested as a bearing material on account of its high hardness coupled with good thermal conductivity. A possible application is in conjunction with hard chromium plated shafts where its high thermal conductivity would assist in avoiding thermal fatigue cracking of the plating.

Further information on copper and copper alloy bearings is obtainable in a separate publication from Copper Development Association

5. Gears and other Wear Resistant Applications

5.1. Gears

5.1.1. Design Criteria

Gear teeth are subject to fatigue by bending and to wear through the rubbing of mating surfaces. Wear will obviously be reduced by a low coefficient of friction and in many respects the qualities required from a material for gears are similar to those looked for in heavy duty bearing materials. For highly stressed gears the alloys most frequently used are the phosphor bronzes.

In the design of gears, the first parameter of importance is the bending stress applied to the gear teeth. In the case of worm gearing, permissible bending stress factors have been determined from data derived from conventional fatigue tests and factors for several materials are given in Table 5.1. These factors are not absolute values but are intended for insertion in formulae for the design of worm gears which are based on an expected total running life of 26,000 hours (see BS 721:Part 2:1983). The Table is included here to give a comparison of the relative performances of different combinations of materials. Fatigue data for several copper casting alloys are given in Table 4.2

The second important parameter is the surfaces stresses generated by the rubbing of the mating surfaces which ultimately results in wear and/or the break up of the surfaces. Surface stress factors are derived from wear tests in which rollers or plates of the harder material rub against a lubricated disc of the material under investigation. By varying the load and surface velocities, the conditions causing failure may be determined and safe surface stresses derived. Failure may take the form of furrows generated in the surface of the disc by wear or by surface pitting or scuffing. Some recommended surface stress factors for worm gear design for various combinations of materials are also shown in Table 5.1.

The service performance of gears is much dependent on the quality of the material, particularly freedom from defects such as porosity or inclusions. For this reason, many copper alloy gear wheels of larger sizes are machined from blanks centrifugally cast usually in forged steel dies. The combination of the centrifugal force and the high rate of chill helps to produce a sound, fine grained structure in the important peripheral layers. For unusual sizes or for very large rings a sand mould may be used sometimes with chills to form the rim in which the gear teeth are to be cut. Smaller wheels may be machined from thick walled tube cast either centrifugally or continuously.

Table 5.1 Basic Stress Factors for Worm Gears (based on BS721 pt2 1983)

		PB2		
Material	**Centrifugally cast**	**Sand cast chilled**	**Sand cast**	**Grey Iron**
Bending stress factor	69	63	49	40
Surface stress factor running with :-				
Grey iron	8.3 *	6.2 *	4.6 *	4.1 *
0.4% normalised C-steel	8.3	6.2	4.6	4.1 †
0.55% normalised C-steel	9.0	6.9	5.3	4.1 †
Case hardened steel	15.2	12.4	10.3	5.2 †

* Maximum permissible running speed 2.54 m/sec

† Permissible for hand motions only.

5.1.2. Alloy selection

For high duty gear wheels particularly worm wheels the alloy most frequently specified is PB2. Its hardness provides good wear resistance and it possesses high mechanical strength particularly when centrifugally or continuously cast.

Mostly, worm gears will be mating with steel gears and these must be of appropriate hardness. A minimum of 700HV is recommended.

PB1 is an alternative to PB2 although it is generally considered to have slightly inferior resistance to wear in gear applications. The nickel containing alloy CuSn12Ni2 is another possibility. Its mechanical properties are marginally higher than those of PB2, but the nickel addition makes it a more expensive alloy and its use is small compared to PB2.

Except with small gears, the phosphor bronze casting is in the form of a ring in which the teeth are machined and this is attached to a hub usually of steel sometimes by spines or by bolts or by welding. Electron beam welding has occasionally been used for very critical components. It is usual to make the total depth of the ring at least twice that of the teeth.

For high loads but low surface velocities it is possible to substitute a high strength brass such as HTB1 or HTB3 or aluminium bronze such as AB2 for the phosphor bronze. AB2 in particular has greater resistance to fatigue than phosphor bronze as well as considerably greater hardness. The mating material has to be chosen with care if excessive wear is to be avoided. However, the use of these alloys as gear materials is limited.

For small gears and where the loading is light, leaded brasses such as SCB3 or DCB3 can be used and leaded gunmetals such as LG2 or LG4 are another possibility for lightly loaded gears in non critical applications.

5.2. Other wear resistant applications

In addition to the use in bearings and gears there are many other cases where the good frictional properties, resistance to wear and resistance to corrosion of the cast copper alloys makes them the preferred material. A few are mentioned below. Most involve relatively low speed sliding movements often with heavy loading and in conditions of indifferent lubrication or corrosive environments.

Where the compressive loading is within its capabilities a phosphor bronze such as PB2 may be used, but where high strength together with high hardness are required there are alloys such as the high strength brasses HTB1 and 3 or aluminium bronzes AB1 or AB2. An aluminium bronze with still greater hardness, CuAl11Fe5Ni5, is also available for applications involving even greater resistance to deformation or wear. These aluminium bronzes are suitable for expansion bearings on structures such as bridges or for rolling mill slipper pads. They also have uses as feeder worms in chemical plant and the like handling abrasive materials. HTB3 is also used for slipper pads and for large screwdown nuts on rolling mills. Another application for these hard alloys is as expanders for the mandrels of coilers in strip and wire mills.

Selector forks for automobile gear boxes are commonly made from aluminium bronze AB1 or a leaded high tensile brass HTB1(Pb). These are usually gravity diecast. Gear selector forks are also pressure diecast using a leaded high tensile brass combining good strength and hardness with good machinability although in strength and ductility it is inferior to AB1.

Valve spindles are another application involving wear resistance plus good resistance to corrosion. Continuously cast bar is often used which may be of gunmetal, phosphor bronze or aluminium bronze according to the strength requirements. Leaded high tensile brass is also used as a valve spindle material. Cast iron or steel valves will no doubt cathodically protect the alloy against the risk of dezincification.

Valve seatings for steel and cast iron valves are often made from gunmetals, phosphor bronzes or aluminium bronze. The rings forming the seatings may be sand cast or machined from centrifugally or continuously cast stock.

Slip rings for electrical machines are often made from a copper-nickel alloy with about 4% nickel. These are frequently cut from centrifugally cast tubes. Another wear resistant use for copper alloy castings is welding electrodes and holders, for which copper-chromium CuCr1 is used because of its good conductivity and excellent high-temperature properties.

5.3. Non-sparking tools

Non-sparking tools used to be made from a copper-beryllium alloy but the health hazards associated with melting the alloy prevent it being cast under normal foundry conditions. Instead non-sparking tools are now mostly cast from aluminium bronze, either AB1, AB2 or the higher aluminium content bronze CuAl11Fe5Ni5 according to the strength or hardness required. With the increasing awareness of explosion hazards in the gas, oil and associated industries, the manufacture of these tools is becoming of considerable importance.

The non-sparking characteristics of the cast copper alloys is obviously of value in many other circumstances where there is a fire or explosion hazard.

6. Pressure-tight Castings

Many applications require that castings are pressure tight as well as strong and resistant to corrosion. Most metals contract on solidification which can lead to internal cavities. Where this is isolated there may be no problems but if it is continuous, porous castings can result. Good choice of casting process, casting design and alloy selection can avoid the problem as is discussed in relevant sections.

Pressure diecastings solidify so quickly that feeding is impossible. Some porosity may then be present but this is rarely a problem. Continuous castings solidify directionally and when made under well controlled conditions, feeding is excellent and no porosity encountered. Sand castings need careful design in order to ensure directional solidification with good feeding arrangements.

Alloys most easily sand cast to give pressure-tight castings are the leaded brasses, SCB1 and SCB3 and the leaded gunmetals LG2 and LG4, the latter of these two being most suitable for thicker sections. Pressure-tight castings can also be produced in the high-strength alloys such as the aluminium bronzes and high tensile brasses provided that good foundry techniques are used to avoid dross entrapment and promote good feeding during solidification.

Sand castings in lead-free gunmetals and phosphor bronzes are not easily produced with good pressure tightness.

Testing for pressure tightness is easily carried out to an agreed specification using suitable jigs, fixtures and calibrated test equipment. The cost is to be considered. Other tests such as dye penetration and radiography may be relevant but reveal discontinuous as well as continuous porosity.

7. High Conductivity Applications

7.1. Electrical

Typical values for electrical conductivity and resistivity are contained in Table 7.1. The highest electrical conductivity is provided by HCC1 which is normally made from cathode copper with the addition of a deoxidant chosen to have minimal effect on the conductivity. This material is usually sand cast. Being almost pure copper it has relatively low strength and hardness. Consequently designs for components need to have generous section thicknesses.

High conductivity copper castings are used for all manner of heavy duty electrode holders, switch gear, connectors, parts of squirrel cage motors and the like. HCC1 may be brazed without difficulty and there are no problems with the embrittlement sometimes experienced when brazing wrought high conductivity copper.

Slightly higher conductivity is obtainable from permanent mould castings to the HCC1 specification. However, it should be noted that to achieve this it is necessary to omit the deoxidant and thus there is a potential liability to embrittlement if the castings are subjected to torch brazing.

Where greater hardness and strength are required, copper-chromium castings CC1-TF may be used with only a small loss of conductivity. This alloy requires to be heat treated to realise its full properties. Typically it will then have a hardness in the range 100-120 HB, a tensile strength of 270-340 N/mm^2 and a 0.2% proof stress of up to 250 N/mm^2. In the fully heat treated condition it has a softening temperature of 475°C.

This alloy is employed for spot welding electrodes for mild steel and for holders,shafts and back-ups, also for seam welding mild steel and for large dies for projection welding. Another use is for dies and inserts for flash butt welding and for stressed current carrying parts for HF welding. It is also used for contact mechanisms where a combination of good conductivity and high hardness and strength are needed.

Although it has relatively low conductivity aluminium bronze AB2 is used for electrode holders for spot welding on account of its high softening temperature, 650°C, and also for shafts and bushings for seam welding.

There are many current carrying applications where a lower conductivity is permissible and for these sand cast or die cast brass is suitable. These have conductivities in the region of 20% IACS; they have good mechanical properties and excellent machinability, attributes combined with low cost.

Tin bronzes and gunmetals have somewhat lower conductivity although they compare favourably with cast iron and stainless steel and are sometimes employed for electrical components. Phosphor bronze, PB4, is used for slip rings, an application involving wear resistance,although an alloy of copper with a small addition of nickel, usually about 4%, is more common. It has a conductivity of about 20% IACS.

7.2. Thermal

Table 7.1 also contains thermal conductivity data for many of the cast copper alloys. In general alloys with high electrical conductivity have matching high thermal conductivity. An interesting point is that thermal conductivity tends to increase with rise in temperature.

Copper castings to specification HCC1 are preferred where heat transfer is of paramount importance unless there is a requirement for greater strength or hardness when CC1-TF1 is more suitable.

The brasses also have relatively good thermal conductivity combined with reasonable strength. For applications at more elevated temperatures where resistance to oxidation is a consideration aluminium bronze AB1 is a possible choice.

In many applications, particularly in the electronics industry, it is necessary to dissipate energy released as heat and the good thermal properties of copper and brass castings are put to use to provide heat sinks.

A traditional use for copper castings is as water cooled hot blast components in blast furnaces and converters. These include tuyeres, coolers, hot blast valve parts and oxygen lance nozzles. The shapes of many of these introduce some severe contraction stresses during the cooling of the castings and to overcome the possibility of hot cracking it is usual to make these castings of copper with a small alloying addition. The resulting lowering of the thermal conductivity has been found by experience to be acceptable for efficient transfer of heat to the cooling water.

Another application where high thermal conductivity is essential is for the liners of moulds for the continuous casting of steel and copper. Copper-chromium is a frequent choice as both good conductivity and resistance to wear are needed. Liners for moulds having a circular cross-section may conveniently be machined from centrifugally cast tubes to specification CC1-TF1.

It must also be remembered that one of the reasons for the good performance of many copper alloy castings as bearings is their ability to conduct away heat generated at the mating surfaces and so reduce the occurrence of thermal fatigue cracking of the bearing surface or sometimes, in the case of hard chromium plated shafts, of the chromium plating.

Table 7.1 Typical Electrical and Thermal Properties

Alloy	Electrical conductivity % IACS 15°C	Electrical conductivity % IACS 200°C	Resistivity micro-ohm/m 15°C	Resistivity micro-ohm/m 200°C	Thermal conductivity % of copper	Thermal conductivity W/m°C 15°C	Thermal conductivity W/m°C 200°C
HCC1	90	54	0.019	0.032	97	372	372
HCC thermal	55	39	0.040	0.044	58	227	258
CC1-TF	80	51	0.022	0.034	82	312	317
SCB3	20	16	0.08	0.11	23	90	109
DCB3	18	15	0.09	0.11	21	81	100
HTB1	22	16	0.08	0.10	22	87	107
HTB3	8	7	0.22	0.25	10	42	55
CuZn15Si4	4					35	
PB1	9	8	0.17	0.19	12	47	59
PB1(low P)	11	10	0.16	0.17	13	50	62
PB4	9	8	0.17	0.19	12	47	59
PB2	9	8	0.17	0.19	10	45	55
LB1	11	10	0.16	0.17	12	47	90
LB2	9	8	0.17	0.19	12	47	59
LB4	17	15	0.11	0.13	18	71	90
LG1	16	14	0.11	0.12	21	81	100
LG2	15	13	0.11	0.11	18	71	90
LG4	13	11	0.13	0.16	16	61	78
AB1	13	11	0.13	0.16	16	61	78
AB2	8	7	0.22	0.15	10	42	55
CMA1	3	2	0.58	0.15	4	14	21
CN1	5	4	0.35	0.39	6	23	33
Cast Iron	3		0.58			48	
18/8 Stainless Steel	2.5	2.0	0.70	1.00		16	18

Note: In most cases the compositions of the alloys cover a fairly wide range and variations within the range will be reflected in the properties. Hence the above values may not be exact for a particular batch of material.

Note: In most cases the compositions of the alloys cover a fairly wide range and variations within the range will be reflected in the properties. Hence the above values may not be exact for a particular batch of material

8. Elevated Temperature Uses

8.1. Mechanical properties

While the design stress levels for most components are based on the 0.2% proof stress, for high temperature applications it is more usual and certainly safer to use long term creep data. The stress to cause 0.1% plastic strain in 10,000 hours at the designated temperature is frequently used. This value for several alloys over a range of temperatures is listed in Table 8.1.

Table 8.1 Elevated Temperature Creep Properties

Alloy	Temperature	Stress to cause 0.1%plast strain in 10,000 h
	°C	N/mm2
LG1	232	46
	288	27
LG2	232	70
	288	31
LG4	232	54
	288	23
LB2	176	70
	232	31
	288	11
AB1 (die cast)	204	132
	315	38
AB2 (die cast)	204	200
	315	38
AB2 (sand cast)	204	190
	315	65
SCB1	176	77
	232	55
	288	11
HTB1	176	38
	204	23
	232	15
HTB3	176	124
	204	62
	232	4

With copper alloys the resistance to deformation under load diminishes fairly rapidly over the temperature range 200 - 300°C. The fall is particularly marked in the case of the brasses and these cannot be recommended for uses involving sustained stresses above 150°C.

The gunmetals are satisfactory up to about 300°C. LG2 shows the best resistance to creep and it is used for valves and similar components handling super heated steam and other hot gases.

The aluminium bronzes, despite their considerably higher room temperature properties, are only marginally better than gunmetals as temperatures approach 300°C.

Over the temperature range of interest for stressed components, the impact properties of the alloys do not change significantly. Mean figures are shown in Table 8.2.

Table 8.2 Impact Properties at Normal and Elevated Temperatures of some Alloys

Alloy		**Temperature**	**Impact Value**
		°C	Joules
Gunmetal	LG2	20	26
		200	20
		300	18
	LG4	20	26
		100	19
		200	18
		300	16
Aluminium bronze	AB1	20	41
		100	45
	AB2	20	24
		200	38
		300	35
	CMA1	20	41
		100	49
High tensile brass	HTB1	20	26
		100	24

8.2. Oxidation resistance

It is the resistance to deformation under load that limits the useful temperature range of the cast copper alloys rather than resistance to oxidation which in the case of aluminium bronzes is very good. In fact aluminium bronze castings have been shown to be superior to cast iron as moulds for the manufacture of glass bottles as they are less liable to surface crazing. The high tensile brasses and diecast brasses also have good resistance to oxidation but high temperature uses must be confined to very low loading.

9. Low Temperature Uses

Most of the properties of copper alloys improve as the temperature falls below normal and there is no embrittlement down to the temperature of liquid helium. Usually the tensile properties, modulus of elasticity and fatigue strength all increase as the temperature falls. As may be seen from Table 9.1, in most instances there is some reduction of impact strength but it remains high compared with the low temperature impact values of most engineering materials.

The good low temperature properties are exploited in many cryogenic applications, in particular valves for handling liquefied gases.

Table 9.1 Low temperature impact data

Alloy	Temperature	Impact value
	°C	Joules
LG2	20	26
	- 74	18
	- 188	15
LG4	20	26
	- 78	19
	- 196	18
AB1	20	41
	- 196	34
AB2	20	24
	- 60	24
	- 130	22
	- 188	16
CMA1	20	41
	-50	31
	- 100	22
	- 180	14
HTB1	20	26
	- 74	26
	- 188	16

10. Casting Design Stresses

10.1. Assessment of tensile properties

As is the case with most cast materials, the strength of copper alloy castings is strongly dependent on the thermal history after the metal has been poured into the mould. The amount of superheat over the freezing temperature of the alloy, the mould medium and the section thickness all affect the rate at which the metal freezes and its consequent structure. This in turn has an influence on the strength, ductility and hardness of the casting.

The only certain way in which the strength of a particular part of a casting can be determined is by taking test pieces from that part of the casting itself. This can often be done with chill castings or centrifugal and continuous castings but for complex shaped sand or diecastings destructive testing of this kind is rarely practicable. Attaching test pieces to the castings is not a reliable method of assessing their properties as the section thicknesses and cooling rates of test bars will rarely be similar to those of the castings and this has long been abandoned.

The normal practice, therefore, in the case of sand and diecastings which are usually of complex shape is to base design stresses on the properties of test bars cast separately under carefully standardised conditions and to make allowances where necessary for possible differences between the properties of test bars and those of the actual castings they represent.

10.2. Test bar properties

The minimum mechanical properties of test bars for the casting alloys are shown in Table 2.1. In the case of sand castings these refer to test bars cast in sand moulds similar to the castings and from the same lot of metal. For diecastings, chill moulds are used. For chill castings and centrifugal castings, test pieces are normally taken from the castings themselves, or, if this is not practicable, chill moulds are used. Continuous castings are sampled from the actual cast metal and the results are therefore truly representative.

There is a spread of properties in castings which reflects the effect of section thickness. Section thicknesses of the order of 15mm or less will tend to have higher values while thicker sections will generally have lower tensile strengths.

10.3. Allowance for casting structure

It is normal practice for design purposes to base permissible stresses on the 0.2% proof stress rather than on the tensile strength unless there is some other over-riding factor such as fatigue strength or creep strength. Because of the possible differences in structure between test bars and castings, it is recommended that the values of 0.2% proof stress quoted for test bars should be divided by the factors given in Table 10.1. The factor of safety appropriate to the design in question should then be applied to the resulting figure. It will be noted that the 'dividing factor' varies with the type of alloy as well as with the casting process, reflecting the differing effects of temperature gradients in the casting on different alloys.

Table 10.1 Dividing factors for casting structure

Alloy group	**Casting process**	**Dividing factor**
HC coppers	Sand	1.4
Brasses & Aluminium bronzes gunmetals	Sand	1.4
	Chill & Die	1.0
	Centrifugal	1.2
	Continuous	1.0
Tin bronzes, phosphor bronzes, lead bronzes gunmetals	Sand	1.6
	Chill	1.4
	Centrifugal	1.2
	Continuous	1.0
Copper-nickels	Sand	1.4

10.4. Elastic modulus

In some cases an important consideration may be the possibility of elastic deformation of the casting rather than plastic or permanent distortion. The modulus of elasticity appropriate to the different groups of alloys is shown in Table 4.1

10.5. Working stresses in castings

Strength is usually a secondary consideration when selecting a copper alloy casting although the tensile properties of the higher strength alloys such as the aluminium bronzes, high tensile brasses and copper-nickels compare well with the austenitic stainless steels. Usually the primary reason for the choice is to take advantage of one of the unique characteristics like corrosion resistance, high conductivity or ease of manufacture.

In practice, the constraints on design imposed by the casting process itself usually ensure that the casting has adequate strength and rigidity for the purpose in view. The chief constraint is often the minimum wall thickness of the casting permitted by the method of mould production and assembly and the fact that the molten metal has to flow to all parts of the mould cavity without premature freezing. Even in small castings, wall thicknesses can rarely be less than 3mm, and for castings weighing a few kilograms, minimum wall thicknesses of at least 5mm are more typical.

If one takes a casting in the form of a cylinder, say 5mm wall thickness and 50mm external diameter, sand cast in gunmetal LG2 with a 0.2% proof stress of 100N/mm2, it may be calculated that after applying the 'dividing factor' from Table 10.1 it would require an internal pressure of 154 atmospheres for the hoop stress to approach the level of the proof stress. Allowing a factor of safety of x2, the casting could be used with an internal pressure of up to 75 atmospheres. With a higher strength alloy such as aluminium bronze AB2 having a 0.2% proof stress of 250 N/mm2 and a smaller 'dividing factor', again allowing a factor of safety of x2, the corresponding acceptable internal pressure would be about 220 atmospheres.

This is not to suggest that stresses should be ignored when designing castings. Rather that it will usually be found that the strength of the casting is rarely the factor of main concern. The fact is that few castings fail because they are over stressed.

If the casting has to operate under conditions of fatigue, the design must obviously be based on fatigue properties. Table 4.1 gives data for several alloys. These results have been obtained from specially cast round test pieces the structure of which may differ from those of typical castings of more complex shape. It is suggested that the values in Table 4.1 should be halved if they are to be used for the calculation of design stresses.

For elevated temperature applications, stresses should be based on the creep data in Table 8.1. However, for sub-zero temperatures normal temperature properties may be used, as the tensile properties increase at low temperatures.

10.6. Compressive Strength

The compressive strength of the alloys is an important factor, but varies significantly according to the conditions of testing. It is not often measured as a quality control attribute, tensile strength being ideal. An approximate indication for all alloys is that the stress for 0.2% permanent deformation is comparable to the 0.2% proof stress in tension. The effect of temperature is also not often measured. As a guide, for the copper-tin alloys it has been found that at 250°C there is a 20% decrease in compressive strength.

11. Selection of Casting Process

The selection of the casting process is dependent both on technical considerations and on economics. Technical considerations include the complexity of the component, its size and weight, the alloy chosen and the properties required. Economic considerations relate to the cost of "setting up" the job, i.e. the cost of patterns, core boxes or dies and the number of castings required, but can also include such matters as the dimensional tolerances, machining allowances, and surface finish all of which may contribute to the cost of the final product.

The issues involved are quite complex and this is one area where dialogue between the designer and the foundryman is all important.

The European Standard recognises five types of casting process in its mechanical property data, but the processes really divide into those using bonded refractory particles, usually sand, to make moulds which are destroyed with each cast and those employing permanent moulds of cast iron or steel or, in the case of continuous casting, of graphite. The higher rate of cooling obtaining with these permanent moulds as compared with refractory moulds generally results in castings having enhanced mechanical properties.

11.1. Processes using refractory moulds

11.1.1. Sand casting

The majority of castings are made using one or other of the variants of sand casting. Moulds are made from sand bonded with clays or silicates or various organic mixes, the bond being more or less destroyed by heat during casting. Cores to define the inside shape of hollow castings are also of sand usually bonded with organic mixes or silicates.

The advantages are:-

- Suitable for all casting alloys.
- Can be used for castings of almost any complexity.
- No limitations on the size or weight of the casting other than those imposed by the melting capacity or handling gear of the foundry. An exception is machine moulding when both size and weight are limited by machine capacity with the weight maximum usually 50kg.
- Generally lowest cost for small productions runs.

Main disadvantage is:-

- More vulnerable to occasional variations in the skills of the operatives which can affect surface finish or dimensional accuracy but this is becoming less a problem with modern sand bonding materials which rely less on the operator for consistent results.

For large castings, unless of simple shape, there is no practical alternative to sand casting.

While for large castings or small quantities patterns are mostly constructed from wood, metal patterns and core boxes are usual for longer runs of small to medium sized castings with the patterns fixed to metal plates for machine moulding. This reduces variability as regards dimensional accuracy and surface finish. Pattern costs are higher so that machine moulding is unlikely to be considered for runs of less than 30 castings. However, once patterns have been made machine moulding offers a low cost production route capable of good dimensional accuracy and surface finish. It is often possible to mount replicate patterns on a single plate so increasing output for a comparatively small increase in setting-up cost.

After it has solidified a casting contracts as it cools from the solidification temperature to room temperature. An allowance has to be made for this when constructing the pattern. Average allowances for contraction are about 1.7% for gunmetals and phosphor bronzes and 2.3% for brasses and aluminium bronzes but the contraction is not necessarily uniform and skilled pattern makers can predict how it is likely to vary in different parts of a casting.

11.1.2. Shell moulding

This is a form of sand casting in which the moulding medium, sand, is coated with a thermosetting resin. It requires special equipment. The coated sand is allowed to fall onto heated metal pattern plates. After a short dwell time these are inverted, excess sand falls away leaving a shell of sand adhering to the pattern. Baking to harden the resin results in a strong biscuit, easily handled and stored, from which moulds are assembled. Shell cores made by essentially the same process are frequently used with ordinary sand castings.

Advantages over ordinary sand casting are:-

- Mould making is virtually automatic, requiring low skill levels.
- Moulds are highly reproducible.
- Generally closer tolerances particularly over dimensions coming within a single biscuit.
- Excellent surface finish although it may be matched by good machine moulding.

Disadvantages are:-

- Higher pattern costs and therefore more suited to large productions runs.
- Restricted to small and medium sized castings.
- High projections on the casting can sometimes cause difficulties.
- Relatively costly moulding medium with some environmental objections.

11.1.3. Investment casting

Investment casting by the 'lost wax' process has been used for centuries for casting statues and other art castings and this is still its main outlet in the bronze foundry industry. However, it a process worth considering where complex, high precision components are required as it offers the opportunity to make by a single casting an object that might otherwise entail difficult and expensive machining or a welded or brazed assembly.

The process uses a pattern of wax or other low melting point material which has itself to be 'cast' in a mould, although it may be built up from several parts. The pattern is invested with a refractory slurry several coatings being applied to build up a shell of adequate strength. The pattern is then melted out of this shell which is baked to strengthen the bonding of the refractory and remove moisture. It is then ready for casting.

Advantages are:-

There is no joint line as the pattern is melted out rather than being withdrawn from the mould.

- Little restriction on shape or complexity of the casting.
- Dimensional accuracy is high.
- The surface finish is as fine as that of the pattern.

Disadvantages are:-

- The process is expensive particularly for small quantities.
- There are limitations on the size and weight of the castings.
- Sometimes difficult to remove refractory from enclosed parts of the castings.

11.2. Permanent mould casting processes

11.2.1. Diecasting (gravity)

In this process castings are made in metal moulds - the dies - which are usually of cast iron. The dies are constructed in two parts which open to allow extraction of the casting. Although gravity die casting is most readily applied to solid shapes, many quite complex hollow components are manufactured using either withdrawable metal cores or sand or shell cores. Taps and other plumbing fittings are frequently made in this way.

Advantages are :-

- Good reproducibility of dimensions with generally closer tolerances than for sand casting.
- Good surface finish although there may sometimes be obvious flow lines.
- Higher tensile properties and hardness than sand casting.
- Disadvantages are:-
- Die life considerations limit it to certain brasses including HTB1 and to aluminium bronzes (AB1). Some shapes may also be made in HC copper and CuCr1.
- Usually limited to castings up to 10 kg weight.
- 'Setting -up' costs are higher than for sand casting as dies have to be machined and polished.
- Most suitable for large quantity production from 1000 castings upward.

Another type of diecasting is **Benchcasting.**

In this process dies made of cast iron or beryllium copper are hand held on a bench; molten metal is then poured in to the dies as they are gradually tilted to ensure non-turbulent filling. Products made usually have completed coring which is in the form of sand cores held inside the mould cavity.

Advantages are:

- Low cost tooling
- Good surface finish and closer tolerances achieved compared with that from sand casting.
- Complex internal shapes possible from the use of sand cores.
- Good reproducibility using copper dies.
- Reduced machining requirements when compared with sand casting.

Disadvantages are:

- Size of components restricted because of hand operations
- Production rate relatively slow.

11.2.2. High Pressure diecasting

In this process molten metal is injected in to steel dies under high pressure. Machines with locking forces of up to 500 tonnes are used to create the casting.

Multi-cavity dies are used to give high production which in turn reduces costs. The process can produce complex shapes with very thin sections, thus reducing the need for machining.

Advantages are:-

- Automated production giving consistency of product.
- Thin section of 1.5mm can be cast to close tolerances and excellent surface finish, saving metal costs and weight.
- Near net shape can be achieved needing little machining which reduces costs.
- Multi-cavity production is possible (up to 40 items in one tool), giving production of up to 4,800 components per hour.
- A full range of brasses can be cast, including the high copper alloys
- Disadvantages are:-
- High tool cost for multi-cavity designs makes the process suitable only for long runs.
- Some porosity may occur within components.

Because of these limitations, particularly the high die costs, the process has not so far been used extensively with copper alloys.

11.2.3. Low Pressure diecasting

Dies made from steel, iron, or sometimes beryllium copper, are positioned horizontally on top of a holding vessel in this process. Molten metal in the holding vessel is gently forced up into the dies by compressed air. After a dwell period to allow the metal to solidify, excess is allowed to fall back into the holding vessel by release of the air pressure. The dies are then opened, the castings removed, and the dies prepared for another cycle. Because of the low pressure, the machines are considerably cheaper than high pressure machines and sand cores may be inserted to produce intricate internal cavities in the castings. The process is becoming frequently employed for the manufacture of high quality brass plumbing fittings.

11.2.4. Chill casting

Chill casting is a name given to a gravity diecasting process used for producing simple regular shapes, usually solid or hollow rods or thick walled tubes. It is mainly used for casting phosphor bronzes, lead bronzes and gunmetals, the end products being bearings, valve spindles and the like. To some extent the process has been superseded by continuous casting.

11.2.5. Centrifugal casting.

Centrifugal casting is used extensively for producing discs or rings for the manufacture of gears and worm wheels, for inserts for valve seats and for flanges for pipe fitting. Thick walled cylinders may also be cast and these can be used as pipes, but are often divided into shorter lengths for bearings, valve seats, slip rings and so on. These are the chief applications but the process can be applied to other more or less symmetrical shapes. Lugs or bosses may be included and flanges can be cast on.

The process consists of pouring metal into a mould or die usually of steel rotating at fairly high speed. For unusual shapes or sizes, sand moulds may be used and to improve the mechanical properties chills are often inserted round the periphery. Rings or discs are produced with the die spinning on a vertical axis, while it rotates on a horizontal axis for cylindrical shapes.

Advantages are:-

- It is an economical method for producing a useful range of symmetrical shapes.
- Quality is high as centrifugal forces assist feeding while dross and inclusions are segregated towards the centre and may be removed by machining
- The high rate of solidification in metal dies gives enhanced properties.
- Applicable to almost all the copper alloys, although phosphor bronzes and gunmetals are most frequently cast.

Disadvantages are:-

- Restricted size range. Discs and rings usually from 100mm to 1,500mm OD and cylinders up to 3,000mm long.

11.2.6. Continuous casting

The process is ideal for the production of rods, sections and hollows from which a wide range of bearings, thrust washers and gears may be machined. The bar is also used for valve spindles and similar articles. Although most copper casting alloys can be continuously cast, most of the output is in phosphor bronzes, leaded bronzes and gunmetals.

In the process, metal flows into a graphite die of the required shape which is attached to a holding furnace. The die is sleeved with a water cooled jacket. As the metal passes through the die it solidifies and is withdrawn as a solid product usually by rollers. It is then cut to convenient lengths for handling, typically 3 or 4 metres.

Advantages are :-

- It is capable of producing in a single operation rods, sections and tubes in a range of alloys many of which do not readily lend themselves to manufacture by hot extrusion or rolling.
- Products are to close tolerances and good surface finish providing stock for automatic machines. Machining allowances of less than 1mm on diameter are offered on small rod sizes and 1.5 - 2mm on larger sizes.
- Available generally as rod from 11mm dia. to 150mm and as tube from 20mm OD to 150mm with minimum wall thickness from 4mm for small sizes. Larger sizes are available from some manufacturers.
- Product has high and consistent soundness.
- Mechanical properties are high and very reproducible.
- A wide range of sizes is often available from stock.

12. Pattern Design

Many factors affect the way in which the design of a component is transferred to being a sound cast product economically produced fit for purpose. Significant cost savings can be made if the requirements for optimum foundry practice can be incorporated in to a design at an early stage. At least this gives reproducible production; at best the penalties of failure, rejection, redesign and recasting can be easily avoided. Some knowledge of foundry casting characteristics will be an advantage. Full consultation with experts used to producing similar components will be invaluable.

12.1. Alloy freezing ranges

Alloys for casting may be divided into two main types according to the manner in which they solidify. Some alloys, such as the aluminium bronzes and diecasting and high-tensile brasses, solidify over a very short temperature range so that during solidification they change very rapidly from the all-liquid to the all-solid state. Alloys such as phosphor bronzes and gunmetals solidify over a fairly long (or wide) range of temperature, so that after commencing to solidify they remain for some time in a 'pasty' state as a mixture of solid and liquid metal before they solidify completely. This difference in the rate of solidification affects casting design since the method of feeding is different between the two groups. Optimum shapes for casting are therefore different for shapes intended for the same type of component.

12.1.1. Design for short freezing range alloys

Short freezing ranges mean that feeders need to be attached at frequent intervals in order for sufficient liquid metal to be available before complete solidification. Complete soundness is achieved by using minimum section thickness whenever possible to encourage rapid solidification.

The final shape of all but the smallest castings in alloys with a short freezing range should provide gradual changes in section thickness which will enable the foundryman to apply feeders having maximum efficiency. If this is not done, special techniques will need to be employed to counteract the unfavourable design and this can only lead to a more expensive, and possibly inferior, product.

Table 12.1 Short freezing range alloys

Alloys		**Length of freezing range (°C)**
Sand cast brasses	SCB1	20 - 50
	SCB3	
	SCB6	
	SCB4	
Diecast brasses	DCB1	0 - 20
	DCB3	
	PCB1	
High tensile brasses	HTB1	0 - 20
	HTB3	
Aluminium bronzes	AB1	5 - 15
	AB2	
Manganese aluminium bronzes	CMA1	20 - 50
	CMA2	
High conductivity copper	HCC1	none
Copper chromium	CC1	5 - 15
Beryllium copper	-	80 - 100
Copper-nickels	90/10	40 - 60
	70/30	60 - 80 >

In order to give the soundest casting, the section thickness should be increased progressively from the thin sections towards the heaviest parts which will each be supplied with a feeder. Each feeder should supply metal to the whole of its region, and not just to its heavy section.

If the design cannot be modified in this way, the foundry may be forced to add 'padding' which must subsequently be machined off. It is seldom possible for the design engineer to predict the precise method of feeding the foundry will adopt, so it is of great importance to discuss these aspects with the foundryman as the design evolves.

12.1.2. Design for long freezing range alloys

The temperature range for the long freezing range alloys is of the order of 100-180°C. During solidification, a 'pasty' state is reached which inhibits adequate topping up of shrinkage cavities with liquid metal. Thermal gradients need to be established so that this effect is avoided.

Commercial castings in these alloys may have traces of shrinkage at the centres of medium and heavy sections, the design being such as to prevent it from having a harmful effect on the product in service. The general principle of casting design for long freezing alloys are:

* minimum wall thickness

* avoid changes in section thickness

* minimal machining

Minimum Wall Thickness:

Less than 9.5mm Castings having all their sections less than 9.5mm thick are completely sound provided that the foundry technique is satisfactory.

9.5 to 19mm Sections from 9.5 to 19mm thick can contain some fine porosity at the centre of the section under unfavourable casting conditions.

More than 19mm Feeding becomes progressively more difficult. Unless service conditions are such that the centres of heavy sections can be permitted to contain some porosity, expensive techniques to avoid it must be employed.

Constant Wall Thickness:

A variation in wall thickness is undesirable with castings in these alloys since feeding along the members is largely ineffective. The minimum wall thickness should be used throughout.

12.2. Design of junctions

The mould material removes heat from the molten metal at a constant rate over all flat surfaces, but internal corners and any parts which protrude into the mould cavity are heated from more than one direction and so become hotter than the remainder of the mould wall. This slows down the rate of solidification in these regions and creates 'hot spots' in the castings which can give rise to the formation of local shrinkage cavities, particularly in medium and heavy sections. In the case of diecastings, wear is accelerated in these regions of the die. Design should avoid such features as far as possible.

By avoiding local overheating due to hot spots or sudden increases in section thickness, the design of any junction of two or more members can be improved. Where two members join, it is standard practice to incorporate fillets which help prevent cracking caused by excessive stress concentration, either on solidification or during service. This general engineering design principle accounts for the existence of a greater volume of metal at the junction. In addition, hot spots are always associated with re-entrant corners, and for both these reasons the junction is prevented from cooling rapidly. To counteract this the volume of metal should be reduced, if possible, to that of the individual members as shown in Figure 1.

In the case of the junction of three or four members at right angles, the problem becomes difficult. Ideally, it is desirable to core out those members which are not required to retain a solid face, thus imparting a strengthening effect with no local increase in volume, as shown in Figure 2. The radius of a fillet can be increased to some advantage provided that the outer radius is adjusted accordingly. If this is impossible, the radius desirable for junctions is one half the wall thickness. It should be noted that the severe effect of hot spots increases with section thickness.

Because junctions of thick and thin sections can cause tearing at the shoulder of a solidifying casting due to rapid contraction of the thin member, it is advantageous gradually to increase the thickness of the thinner member as it approaches the thick section. Good design involves enlarging the section until it is at least as heavy as the one to which it is being joined.

Figure 1 – Redesign of a component to avoid hot spots

The core in the centre heavy section was small and unable to dissipate heat evenly. The simple redesign keeps section thicknesses uniform and reduces metal volume, facilitating heat dissipation

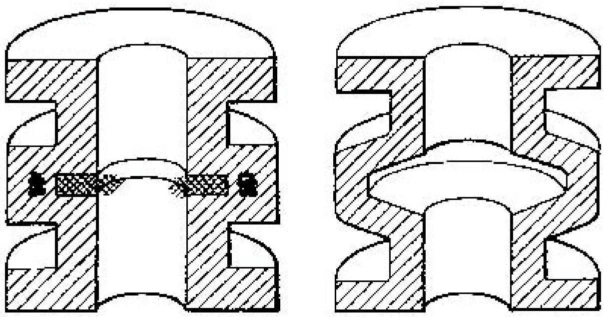
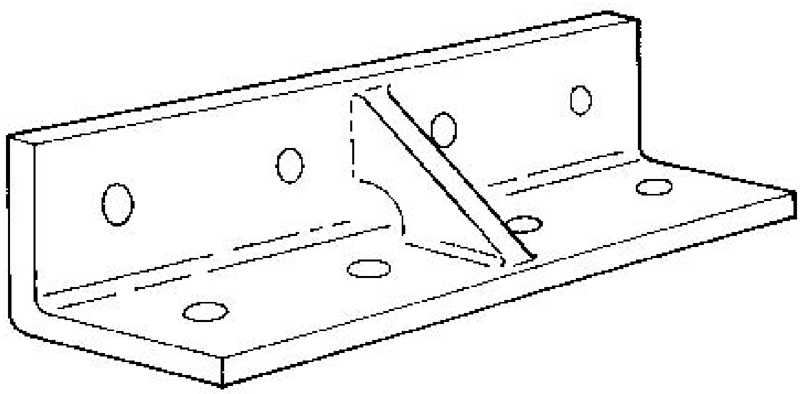


Figure 2 – Avoidance of a local hot spot at the junction of a web by coring out the centre without significant loss of strength

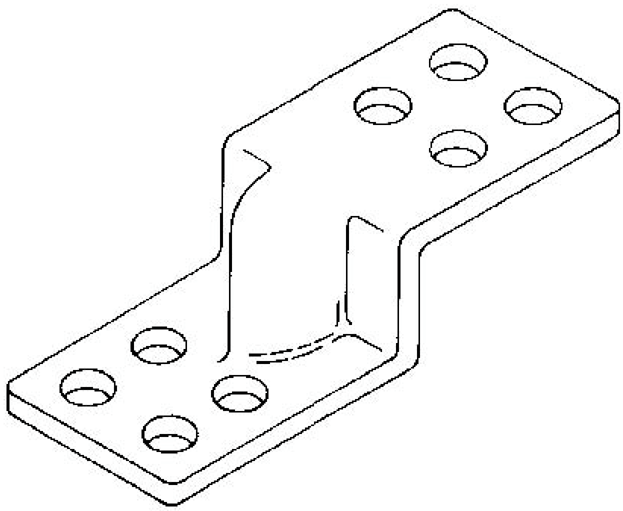


12.3. Ribs

It is common practice in design to add ribs to a component to provide greater rigidity. This does not necessarily result in the best solution for castings since an additional T-junction is introduced. The use of double radiused webs as an alternative to ribs is preferred, see Figure 3.

Where it is necessary to add a rib across a corner there is a marked tendency towards hot spot formation. This should be overcome, wherever possible, by coring out the region of the rib that forms the hot spot, as described in Figure 2.

Figure 3 – Where it is necessary to strength a component by the addition of a rib, the use of double radiused webs in an omega section is preferred since it reduces hot spots and residual stresses.



Castings with thin sections of large surface area are usually not limited in thickness by their mechanical requirements but by the ability to fill the mould before it becomes chilled. Higher pouring temperatures and other techniques may be employed to improve the metal's fluidity but this is not possible in every case, particularly if heavy sections exist in the same casting.

Should the maximum areas shown in the table be exceeded, the flow of metal into thin sections can be assisted by incorporating suitable channels. This method also has the advantage of imparting improved mechanical rigidity.

12.4. Tolerances

The specification of unnecessarily close tolerances can involve greatly increased production costs, and generous allowances should be made wherever possible. If excessively close tolerances are insisted upon, cost and delivery may be adversely affected due to increases both in foundry time and rejection rate.

Table 12.2 Typical tolerances for various casting processes (in mm)

Process	Length of member (mm)				Additional across
	100	100-200	200-300	300-600	joint lines
Sand casting (hand)	±0.7	±0.7	±1.5	±2.5	-0 + 0.7
Sand casting (machine)	±0.7	±0.7	±0.7	±1.2	-0 + 0.7
Shell moulding	±0.4	±0.4	±0.7	±0.7	-0 + 0.7
Gravity diecasting	±0.2	±0.2	±0.4	-	-0 + 0.2
Investment casting	±0.1	±0.2	±0.3	-	-
Continuous casting	±0.1	±0.1	-	-	-
Centrifugal casting	-machined-				

These figures can only be taken as typical and may be subject to discussion according to requirements.

The dimensions of a casting are affected by the solidification rate within its different parts and are therefore dependent upon variations in section thickness, the basic shape of the casting and the method of production employed by the foundry. The standard shrinkage allowances used by pattern makers is correct for simple sections of average thickness, but prediction of variations in contraction in the different parts of a complex casting cannot always be estimated with accuracy.

It is uneconomical to specify very close tolerances in castings which are only required in small numbers, because exact pattern dimensions can only be developed through trial and error.

12.5. Distortion

Poor design can result in distortion of castings. During solidification and cooling, the contraction of various parts of a casting depends upon the relative section thicknesses of the members involved. The thin sections which cool and contract more rapidly are submitted at a later stage to the contraction forces of the heavier members. If the thinner sections do not possess adequate rigidity, they become deformed resulting in permanent distortion of the component. This can be corrected by redesigning the part to give a better balance between thin and heavy members, often by using an arrangement which thins the heavy members.

For certain geometries, tie bars can be used to avoid the distortion of thin members. Often the bars are allowed to remain to prevent distortion during machining.

12.6. Surface Finish

The surface finish on a casting is generally accepted within the capabilities of the process and pattern equipment involved and for most engineering components a shot-blasted finish is suitable, with light machining applied to critical regions.

Faces which are uppermost in the mould may contain slight surface defects caused by floating inclusions. It can therefore be useful to make special mention of any faces which are critical so that they can be placed suitably.

When large numbers are involved, shell moulding frequently offers a superior surface finish to conventional sand casting and is often found to be more economical when closer tolerances and consequent reduction in machining costs are also a consideration. Diecasting gives a smoother surface and offers closer tolerances.

For consistently good high surface finish and control over tolerances in the manufacture of small components, investment casting, although expensive, is unquestionably the preferred process.

The surface finish of sand castings is naturally dependent upon the surface of the pattern as well as the sand quality; when patterns are supplied they should have adequately smooth finish.

12.7. Foundry liaison

Besides the details referred to in other sections, there are many other factors that affect the practicability and economics of the production of cast components. Usually foundries will quote on sight of a drawing of finish-machined components and make their patterns to suit their anticipated foundry practice. If strict conformance to a drawing is essential, foundries will quote on that basis. Alternatively, further discussions may result in useful cost-saving compromises. This can apply equally to the simplest of components as to the most complex.

If likely testing schedules are considered at the design stage, the most economic quality assurance requirements can be established.

12.7.1. Sand Castings

The position of the parting line between the two halves of a mould is significant. Generally it will be in the middle of the component so that the pattern can be easily withdrawn. To facilitate withdrawal, there will be a taper of about 2° on all faces perpendicular to the parting lines. If a centre parting line is not preferred it is possible to move it to an upper or lower edge. Naturally the dimensional tolerances expected across the parting line are not so good as those within one part of the mould. Undercuts should be avoided wherever possible but can be included with the use of loose pieces of pattern that have to be carefully removed separately from the main pattern.

Cores are used in order to provide hollows in most castings. They are moulded and hardened separately and supported within the mould cavity in carefully designed recesses. The size of cores is controlled by the cavity required but can also be vital in maintaining section thickness for good solidification control. Tolerances on the positioning of cores depend on component design and requirements.

Foundries may include metal chills within a mould in order to ensure good solidification and metal properties.

For other refractory mould techniques such as shell moulding, similar considerations apply.

12.7.2. Other Casting Techniques

While sand casting is the most frequently used technique for small, jobbing quantities, similar effective liaison is required for the special requirements of all other casting techniques. Basic considerations of metal flow and solidification apply as modified by the needs of the process and an understanding of these special requirements will be required to achieve cost effective designs. Much expertise is available to optimise modern casting methods such as gravity and pressure die casting, also centrifugal, continuous and precision casting techniques.

13. Machining

Where proof machining of castings is required, it is frequently advantageous to include this in the foundry requirements. Their machine shops have swarf recovery systems that can easily ensure that scrap is economically recycled uncontaminated by other alloys. They can also carry out visual inspection after machining to ensure that the castings are sound.

13.1. Machinability

There are no real problems in machining any of the cast copper alloys although there are differences in machinability relating largely to the hardness of the material. Free-machining materials are available that keep production costs low but even the non-free-machining alloys are generally no more difficult to machine than low alloy steels and infinitely preferable to most stainless steels. The alloys divide into the following groups:-

1) Alloys containing an addition of lead. These give fine chip formation and allow high cutting speeds with low tool wear and good surface finish. They are comparable to free cutting brass bar which is generally recognised as having the best machinability of all metallic materials. Alloys in this group are brasses SCB3, DCB3, DZR1 and DZR2, HTB1(Pb), the gunmetals LG1, LG2, LG4, and CuSn7Pb7Zn3 and the leaded bronzes LB1, LB2, LB4, and LB5.

2) Medium hardness alloys with low lead contents. These produce short turnings with slightly greater tool wear. Alloys in this group are HTB1, Silicon brass, PB1, PB2, PB4 and CuSn12Ni2, aluminium bronze AB1 and copper-chromium CC1-TF.

3) Harder alloys which produce fine swarf but with increased tool wear. In this group are the hard high tensile brass HTB3, aluminium bronzes AB2 and CuAl11Fe5Ni5 and manganese aluminium bronze CMA1, also high strength copper-nickel, CN1. Improved hard tips for tools now mean that machining these materials is not difficult since cutting speeds can be high enough to reduce the effects of work hardening in the metal.

4) High conductivity copper which, because of its softness and ductility, produces long turnings requires the use of tools designed to break the swarf to short chips.

Recommendations for machining practice are contained in CDA publication TN3. (now superseded by TN 44)

Some variations in machining techniques may be needed for castings, especially when taking the first cut from a cast surface. The surface of castings made in refractory moulds may contain inclusions of hard particles as well as the hard oxide found on the more corrosion resistant alloys. To avoid excessive tool wear it is frequent practice to remove the surface with one slow, heavy roughing cut rather than a series of lighter ones. Again, improved hard tips have reduced the need for this practice.

Deep machining should be avoided as far as possible since the temperature gradients during solidification of a casting favour the production of the structure with optimum properties close to the surface. This is particularly important in the case of components made from alloys with a long freezing range which are likely to have sound surfaces but may be liable to interior shrinkage porosity.

13.2. Machining allowances

It is not possible to lay down hard and fast rules about machining allowances as these depend on several factors such as the casting process to be used and the size and shape of the casting. The matter is best settled in consultation with the foundry. As a very general guide, an allowance of about 3mm is fairly typical for medium sized sand castings whereas good quality continuous castings from graphite dies will need less than 1mm cleanup.

14. Joining Processes

CDA publication TN25 (now superseded by Publication No 98) contains recommendations regarding welding practice. The following notes are particularly relevant to castings.

14.1. Arc welding processes

Arc welding using inert gas techniques is used both as a method of assembly of castings into more complex fabrications and for the repair and reclamation of castings.

Aluminium bronzes and manganese aluminium bronze CMA1 are readily welded. High tensile brasses such as HTB1 may also be welded as can cupro-nickel, CN1. With all these alloys a post welding heat treatment is desirable in order to restore the structure of the alloy to its optimum condition if the casting is to be used in a corrosive environment such as sea water and the supplier should be consulted.

Weldability is sometimes affected by minor impurities and it is advisable to inform the supplier if it is intended to weld the castings. For example, it may be necessary to restrict the bismuth and lead contents of copper-nickel and aluminium bronzes to avoid the danger of cracking in the heat affected zone. For minor casting repair, the tin bronzes and the phosphor bronzes can also be arc welded satisfactorily. However, welding of leaded bronzes is not practicable.

14.2. Oxy-acetylene welding

This is usually only employed for joining thin sections. With special attention to fluxing, aluminium bronzes and high tensile brasses may be welded satisfactorily and also thin sections in high conductivity copper.

14.3. Oxy-acetylene bronze welding and brazing

This is satisfactory for tin bronzes, phosphor bronzes and gunmetals. With appropriate fluxes, aluminium bronzes may also be joined. However, it has to be emphasised that such joints have low resistance to corrosion in many types of water and chemical solutions. Leaded bronzes cannot satisfactorily be welded or brazed.

14.4. Silver soldering

This a satisfactory method for making joints of moderate strength in most of the casting alloys including the HC coppers, the brasses, phosphor bronzes and gunmetals. Special fluxes have to be used for those alloys containing aluminium such as the diecasting brasses, high tensile brasses and aluminium bronzes. This is because of the tenacious alumina film that forms on the surface of any alloy containing aluminium.

The heat treatable alloys such as copper-chromium, CuCr1, should be silver soldered after solution treatment but prior to final heat treatment in order to achieve the best possible properties. Care should be taken not to affect too much the heat treatment process.

It is difficult to make satisfactory joints in leaded bronzes.

14.5. Soft soldering

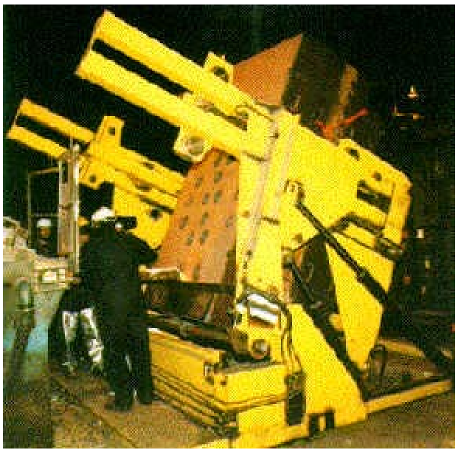
Soft soldering is used mainly for joints in copper and brasses although all copper alloys may be soft soldered. Again the alloys containing aluminium, including the diecasting brasses, require a special flux.

15. Quality Assurance

The majority of good foundries have their quality control techniques for all stages of production and testing approved to BS 5750 or similar externally assessed approvals schemes. This means that they can offer material that is documented to be in accordance with the order. It is of course up to the designer to assure that the design itself is likely to prove fit for purpose and that components have been designed for maximum production economy.

Testing of cast components after manufacture is necessary to ensure conformance to specification but such testing can add significantly to the product cost and should be limited accordingly. Checking conformance to the compositional and mechanical property requirements of BS1400 or similar specifications ensures batch reproducibility but does not ensure fitness for purpose. Other tests may be required such as proof machining, dye penetrant flaw detection, pressure testing and radiography. Each of these can be valuable but should be called for only when and as required. To ensure lowest component costs and eliminate unnecessary rejections, sampling rates and performance criteria need to be suited to the application, with due regard to the consequences of failures.

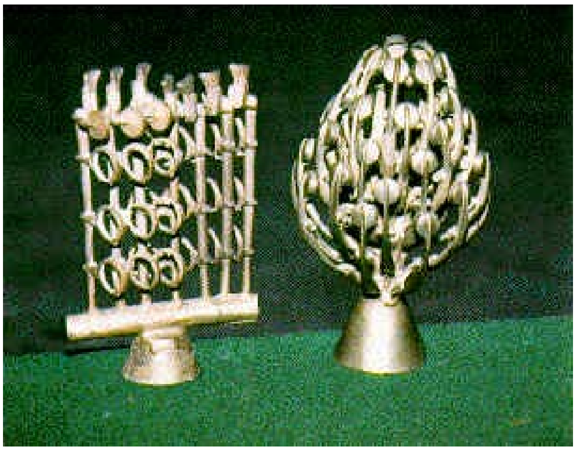
Illustrations



Pouring- aluminium bronze by the Meigh Process

(Meigh Castings Ltd)

The mould is brought to the furnace, tilted through 90% and connected to the furnace by a short launder. The metal flows gently into the mould and, as it fills, the mould is gradually tilted back into a horizontal position The process reduces turbulent flow to a minimum and oxide inclusions are avoided. It ensures that the temperature gradient is always from top to bottom and thereby minimises the likelihood of shrinkage cavities forming.



Precision cast brass keys for a musical instrument

(Boosey & Hawkes Ltd)

Where components must be of a very intricate shape precision casting can be cost-effective. The picture shows sprues of musical instrument keys which were formerly fabricated from a number of pressed and machined items. This production method gives components of good dimensional tolerance close to the required finished shape. Even the hole for the pivot bearing is cored.

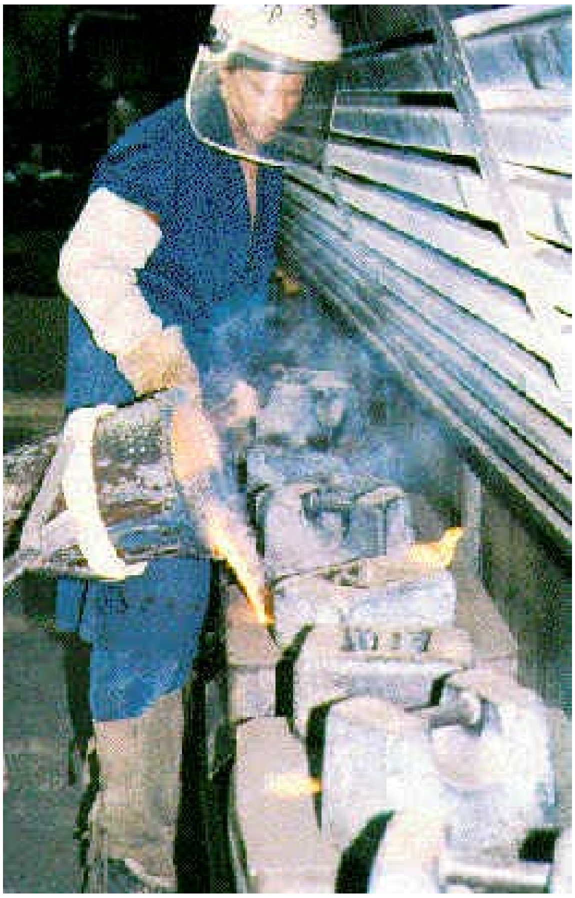
A selection of sandcastings in copper alloys

(Wesley Brothers plc)

A selection of bronze centrifugal castings

(Spunalloys Ltd)

Molten metal is poured into a cylindrical spinning mould. The metal is forced to the outer edge of the casting and the less dense dross and gases remain on the inside diameter and are removed during finish machining. The mechanical properties are excellent because of the uniformity of the casting and the fine grain size



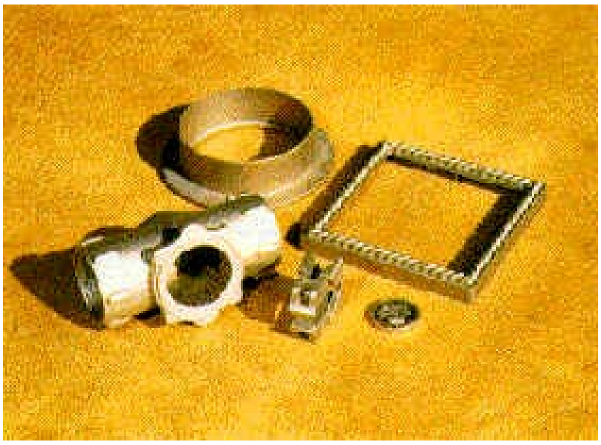
Casting bench in a modern foundry with good fume extraction

(F W Birkett & Sons Ltd)

Valves in copper-nickel-chromium to NES 824

(VSEL)

This alloy requires considerable expertise in casting because it is difficult to ensure its freedom from inclusions.



Pressure die cast brass components

Production rates are considerably higher than in gravity d casting and closer tolerances can be achieved.

(Delta EMS Ltd)

Die cast brass components for a beer pump

(Delta EMS Ltd. Homark Associates Ltd and 'The Coach and Horses', Weatheroak)

The die cast brass components are finish machined and polished to a gleaming surface finish.

Breather valve guard casting

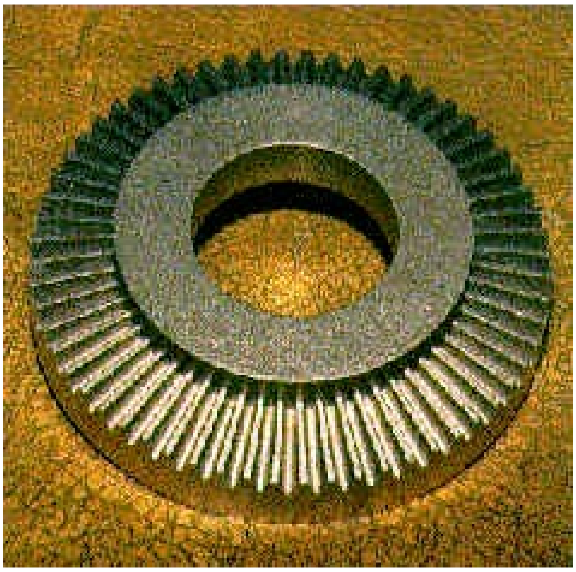
(The Enfield Foundry Co Ltd)

The picture shows the sandcasting complete with the efficient and economical runner and riser system attached. Fettling is simple and there is minimal scrap.

Aluminium bronze pipe with a welded flange

(Birkett Y-Col)

A sea water rising main for the offshore industry, designed to withstand high velocity sea water containing some suspended solids. The flange is centrifugally cast and the tube is made by continuous casting.



Gear for locomotive braking system

(British Rail)

Cast in aluminium bronze to ensure long life in aggressive operating conditions.

A selection of sleeve bearings in phosphor bronzes and leaded bronzes

(J. Roberts (Cleckheaton) Ltd.)

Encon continuously cast section

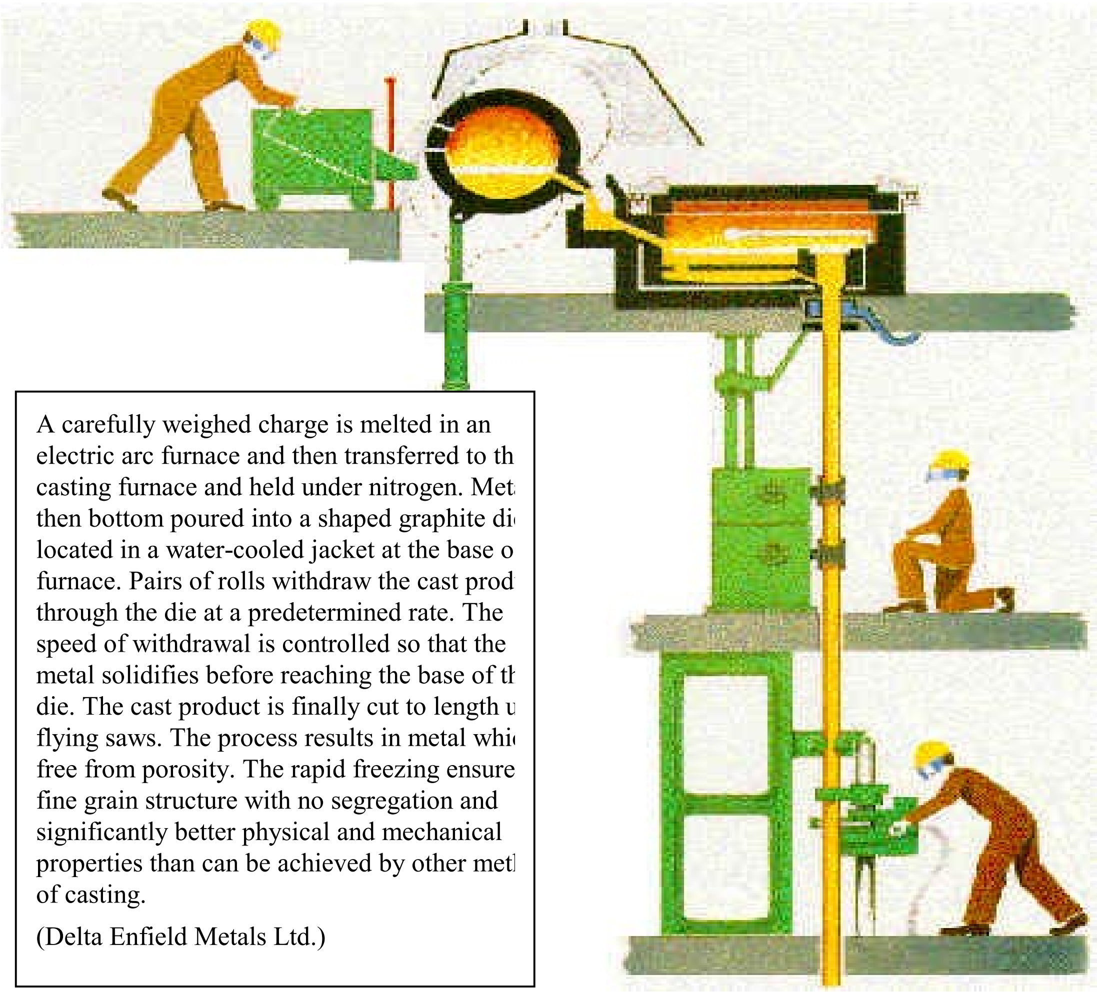
(Delta Enfield Metals Ltd)

A selection of the complex sections which can be cast to very accurate dimensional tolerances.

Self lubricating bearings

(F. W Birkett & Sons Ltd)

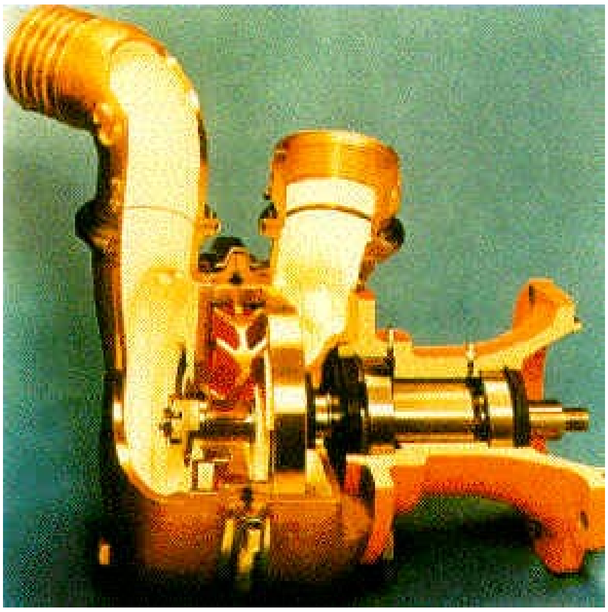
Franberlube bearings are made by machining the casting to final size and then holes are drilled and filled with a lubricating compound. The pattern of these lubricating plug inserts is precisely determined for each application to ensure optimum lubrication and smooth running of the bearing.



A carefully weighed charge is melted in an electric arc furnace and then transferred to th casting furnace and held under nitrogen. Met then bottom poured into a shaped graphite di located in a water-cooled jacket at the base o furnace. Pairs of rolls withdraw the cast prod through the die at a predetermined rate. The speed of withdrawal is controlled so that the metal solidifies before reaching the base of tl die. The cast product is finally cut to length u flying saws. The process results in metal whi free from porosity. The rapid freezing ensure fine grain structure with no segregation and significantly better physical and mechanical properties than can be achieved by other metl of casting.

(Delta Enfield Metals Ltd.)

Continuous casting by the Encon process



Marine self-priming pump

(Gilbert Gilkes & Gordon Ltd.)

These marine pumps are used for a variety of "on board" duties such as bilge pumping, fire fighting, ballast transfer and marine engine sea water cooling. The pumps experience salt water corrosion and electrolytic damage. They are expected to operate on high suction lifts, handling aerated water conditions which always induce varying degrees of cavitation. These pumps have a design life of 20,000 hours and are favoured by navies and merchant shipping for their inherent reliability in such aggressive environments, which is the result of careful attention to detail and exacting choice of materials. The pump casing is made from leaded gunmetal to BS 1400 LG2, chosen for its ability to resist low velocity, silt laden sea water, its castability and relatively economic price. The port plates and distance ring are made from aluminium bronze to BS 1400 AB2 This alloy has good resistance to cavitation, electrolytic corrosion and high velocity erosion, coupled with good machining characteristics. The impeller is made from hardened nickel gunmetal to BS 1400 G3-TF This heat treated alloy offers extra hardness to resist cavitational damage and silt laden seawater erosion, and its mechanical strength and resistance to seizure allow exceptionally close running clearance between the impeller and the port plates.

Aluminium bronze propeller

(Stone Manganese Marine)

This is a fixed pitch propeller and has been cast in one piece using aluminium bronze to BS 1400 AB2

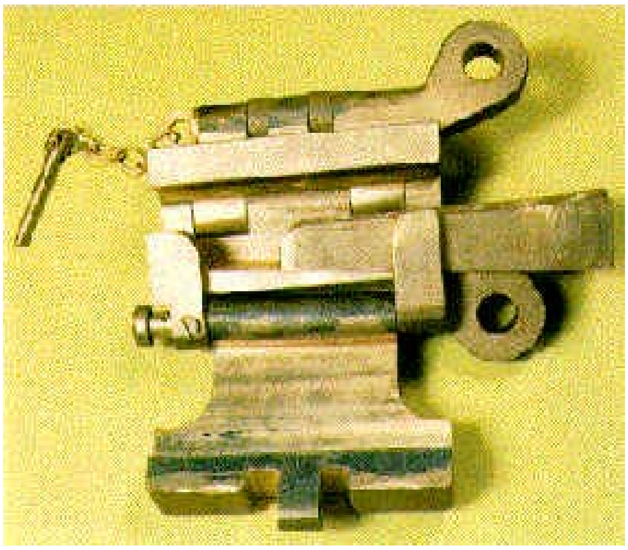
Small aluminium bronze bearing

(Johnson Metall)

Centrifugally cast aluminium bronze inlet outlet header for "Trident"

(A Fryer & Sons Ltd)

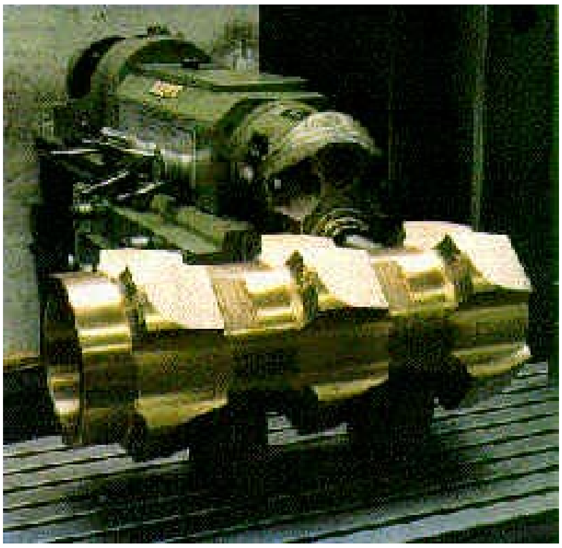
The material for this casting is aluminium bronze to NES 747. The component was made to exacting requirements. Full x-ray inspection and no weld repairs were specified. Six test pieces were taken from various areas and dye penetrant tests were made at four stages of production. The cast weight was 3,500 kg and the final machined weight was 800 kg, emphasising the importance of complete soundness in the initial casting. The photograph shows the casting in the final stages of inspection prior to dispatch.



Silicon aluminium bronze cable clamp

(Birkett Y-Col)

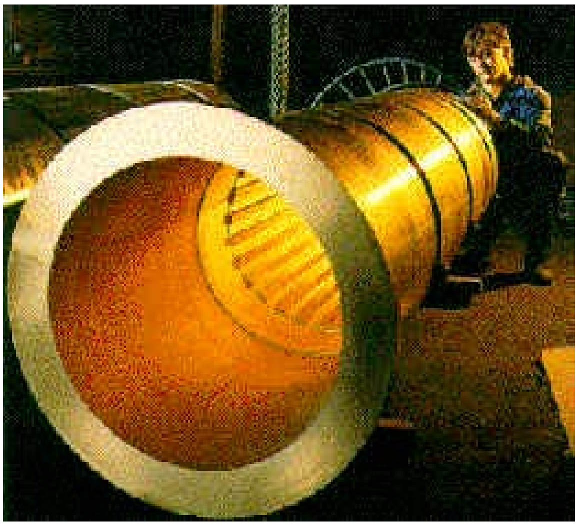
This alloy is used for its strength, ductility and low magnetic permeability.



Spreader for an expanding mandrel for a coiler for a rolling mill or a wire rod mill

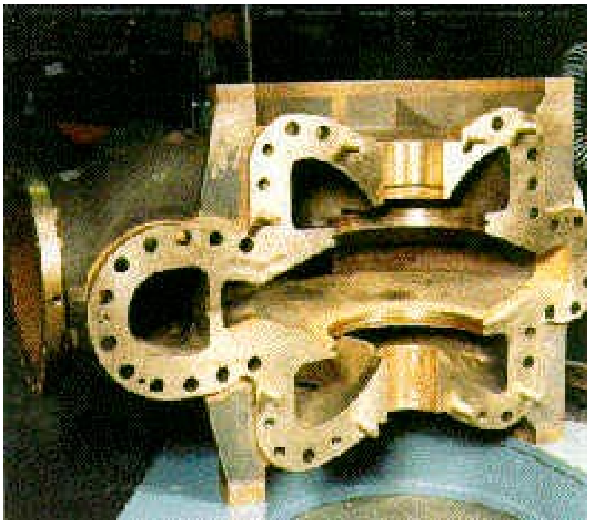
(Westley Brothers plc)

Cast in aluminium bronze to BS 1400 AB2



Propeller shaft bearing in aluminium bronze

(Westley Brothers plc)



Large pump casing in nickel aluminium bronze BS1400 AB2

(Weir Pumps Ltd)

In castings of this complexity selection of the pattern parting lines is very important

Permanent mould for gravity die east pipe fittings

(Conex-Sanbra Ltd)

This process facilitates large volume production of pressure-tight castings at an economical price.

Stages in the manufacture of a gravity die cast brass tap

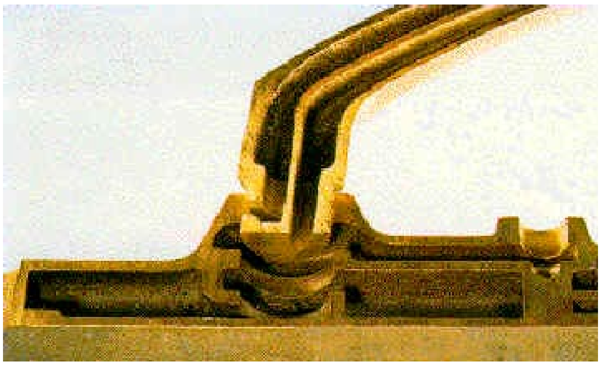
(Armitage Shanks Ltd)

The picture shows the initial core for the casting, the casting itself and, finally, the finished assembled component.

Pickling hook in aluminium bronze

(Westley Brothers plc)

Hooks such as this can be used for, for example, pickling copper rod or wire in sulphuric acid or steel in hydrochloric acid

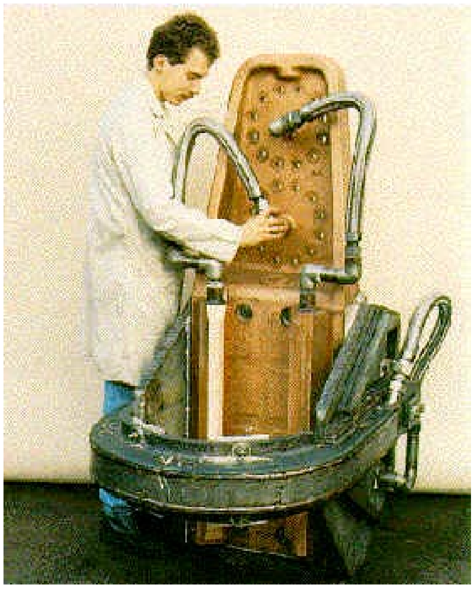


Sectioned gravity die cast brass tap showing structure of hollow core

(Armitage Shanks Ltd)

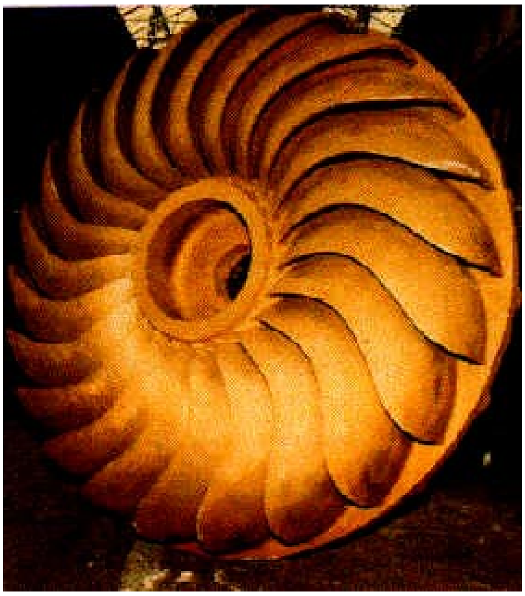
Cast 90/10 copper-nickel pipe fittings and flanges

(David Flanagan Ltd)



High conductivity copper electrode holder for a steel furnace

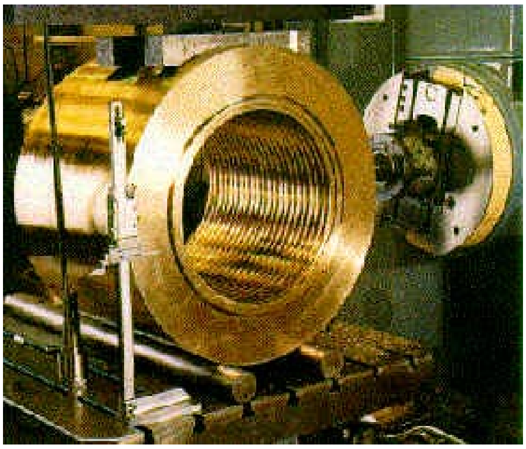
(Westley Brolhers plc)



Turbine runner weighing 2130kg cast in nickel aluminium bronze for a hydro-electric installation

(Meigh Castings Ltd)

These are difficult castings to make involving the careful assembly of many cores (one for each blade). A smooth finish is necessary within the vanes to ensure satisfactory performance.



Adjusting nut for a rolling mill cast in high tensile brass BS1400 HTB3

(Westley Brothers plc)

APPENDIX A

Types of Corrosion

The following notes amplify the comments made on the corrosion resistance of copper alloys in section 3.

1. Selective attack

Most copper alloys used for casting have a heterogeneous metallurgical structure consisting of two or more phases which sometimes exhibit differing rates of attack under corrosive conditions. The most striking examples are the brasses where the common casting alloys consist of a mixture of alpha-phase and beta-phase, the latter conferring plasticity to the material at high temperature enabling it to withstand contraction stresses in the mould without cracks developing.

Under corrosive conditions, in sea water for example or in certain types of domestic supply waters, the beta-phase suffers a form of selective corrosion known as dezincification. In this the copper-zinc alloy forming this phase becomes replaced by a porous mass of copper without change of shape. Obviously this seriously weakens the structure and it can eventually lead to failure of the component.

Brasses have been developed which do not suffer dezincification (DZR brasses). These usually have a single phase alpha structure or contain only small isolated areas of a second phase. Corrosion of the alpha phase can be inhibited by an addition of arsenic or antimony to the alloy although this is ineffective in overcoming dezincification of the beta-phase. Most silicon brasses are also resistant to dezincification.

Less serious selective attack occurs with some aluminium bronzes. AB1 occasionally suffers local dealuminification in alkaline conditions such as boiler feed waters. The nickel-containing alloys such as AB2 have a complex structure which includes narrow bands of alpha-phase adjoining bands of the nickel rich kappa-phase. Under some conditions of corrosion such as in crevices selective attack occurs on the bands of alpha phase but it is on a micro scale and not usually of significance. This accounts for the penetration shown in crevice attack tests in Table 3.1. Where such attack may be expected, heat treatment of the castings will improve corrosion resistance still further.

However, the manganese aluminium bronze CMA1 has an essentially alpha-beta structure and selective corrosion of the beta phase can take place especially under stagnant conditions although it is not as severe as with the alpha-beta brasses.

Tin bronzes, gunmetals and copper-nickels are virtually free from this form of corrosion.

2. Stress corrosion

This takes the form of fine cracks and results from the simultaneous action of tensile forces and specific corrosive conditions. Whereas stainless steels tend to suffer stress corrosion cracking in aggressive chloride conditions, with copper alloys it is usually the presence of ammonia or ammonia compounds which stimulates the attack. Moist sulphur dioxide environments may also promote stress corrosion with some alloys.

The cracks develop in a direction perpendicular to that of the stresses and they can spread quickly with little signs of corrosion leading to early failure of the component. The stresses may be the result of loading the component or they can be internal stresses. A stress relieving heat-treatment after welding reduces the likelihood of stress corrosion.

Brasses are susceptible to stress corrosion and it is recommended that they should be avoided for load bearing structures in polluted atmospheres where ammonia contamination is a possibility. High tensile brass HTB3 is susceptible to intergranular cracking in marine conditions.

Although aluminium bronzes have been shown to suffer stress corrosion cracking when severely stressed in moist ammonia atmosphere, in practice stress corrosion cracking is very rare. Tin bronzes, gunmetals and copper-nickels are practically immune from stress corrosion.

3. Pitting corrosion

This very localised form of corrosion is not often encountered with copper alloy castings. Even in sea water significant pitting does not occur except occasionally when there is sulphide pollution. Under these conditions, which are found chiefly in harbours or polluted in-shore waters, tin bronzes usually perform better than aluminium bronzes. Stainless steels are subject to deep pitting in waters of high chloride content although copper alloys are unaffected.

4. Crevice corrosion

Accelerated local corrosion can often take place in or adjacent to crevices where moisture is present but the access of the oxygen necessary to maintain a protective film is denied so that there is a difference in electro-chemical potential between the shielded area and adjacent freely exposed surfaces. In these circumstances, alloys which depend on a surface oxide film for corrosion resistance tend to suffer corrosion within the crevice. In the case of conventional stainless steels this takes the form of deep pitting and with aluminium bronzes there may be selective phase attack as discussed above. With other copper alloy castings, attack is more likely to occur at the edge of the crevice forming a groove.

Crevices can be found at bolted flanges or at the packing of pump and valve spindles or they may be formed underneath fouling formed by surface deposits.

5. Impingement attack or corrosion/erosion

Impingement attack or corrosion/erosion occurs when a metal is exposed to a high velocity flow of liquid particularly if the flow is very turbulent. It is a problem with sea water handling systems. The effect of the high speed stream is to remove locally the naturally formed protective film from the metal surface and prevent it from reforming. This leads to rapid local attack on the metal sometimes so severe that the metal is penetrated. Design features that increase the liquid velocity locally or cause extra turbulence should be avoided.

The resistance of metals to this form of corrosion is usually assessed by Jet Impingement tests in which a jet usually of sea water carrying entrained air bubbles plays on the surface of the test specimen immersed in sea water. The depth of the pit under the jet after usually a 28 day run indicates the resistance or otherwise of the metal to impingement attack.

Gunmetals, particularly LG4, are reasonably resistant to impingement attack as is high tensile brass, HTB1. Aluminium bronze AB2 is very resistant to attack and copper-nickel, CN1 has probably the highest resistance.

6. Cavitation erosion

Essentially this a more severe form of impingement attack. Metal is removed by the action of collapsing vapour bubbles which form when pressure in a liquid is locally reduced below its vapour pressure as can occur under suction conditions. It is encountered on the suction faces of ships propellers, on pump impellers and casings and in valves. Bearings may also occasionally suffer cavitation erosion caused by local low pressure areas in the lubricant film.

Metal freshly exposed by cavitation is subject to corrosion which aggravates the effect and the combined action can remove small fragments of metal from the surface. Resistance to cavitation is usually assessed by vibrating the specimen in the chosen medium and measuring the depth of metal removed. Table A1 shows results for several metals tested in fresh water.

Table A1 Cavitation erosion rates in fresh water (tests at 20 Hz)

Material		**Cavitation erosion rate mm3/hour**
Aluminium bronze	AB2	0.06
Aluminium bronze	AB1	0.08
Manganese aluminium bronze	CMA1	1.5
High tensile brass	HTB1	4.7
Gunmetal	G1	4.9
Monel(wrought)	K500	2.8
Cast martensitic stainless steel	420	1.7
Cast austenitic stainless steel	347	1.0
Spheroidal graphite cast iron		1.3
Ni-resist cast iron		4.4

I.S. Pearson (Chartered Mechanical Engineer, July 1947)

7. Corrosion fatigue

The effect of cyclic stressing which can result in fatigue failure is sometimes accentuated by a corrosive environment. The relative contributions of cyclic stressing and corrosion depend on the corrosion resistance of the alloy and on the frequency of the cycles of stress. With slow high strain cyclic stressing corrosion plays a larger part than with high frequency low strain cycles of stress. Mostly fatigue conditions are of the latter type. The casting alloys chosen for service in corrosive situations such as sea water are much less affected by corrosion fatigue than are most metals.

Appendix B

Sources of information

The majority of the contents of this book are included in CDA Datadisc 3 'Copper Alloy Casting Design', available in 5 1/4" and 3 1/2" formats.

BS 1400:1985 'Copper alloy ingots and copper alloy and high conductivity copper castings', British Standards Institution.

ISO 1338-1977(E) 'Cast copper alloys - compositions and mechanical properties'.

Deutsche Norm DIN 17655:1981 'Unalloyed and low alloy copper materials for castings'.

DIN 1709:1981 Copper-zinc alloy castings.

DIN 1705:1981 Cast tin bronzes and gunmetals.

DIN 1716:1981 Cast tin-lead bronzes.

DIN 1714:1981 Cast aluminium bronzes.

Norme Francaise NF A53-703 Gravity and pressure cast brasses.

NF A53-707 Bronze and bronze-lead castings.

NF A53-709 Copper-aluminium castings.

ISO 4382/1-1982(E) Cast copper alloys for solid and multi-layer plain bearings.

BS 721:Part 2: 1983 Worm gearing.

BS 4577 & ISO 5182 'Materials for resistance welding electrodes and ancillary equipment.'

'The Machining of Coppers and Copper Alloys', CDA Technical Note TN3. (now superseded by TN 44)

'Joining Coppers and Copper Alloys', CDA Technical Note TN25. (now superseded by Publication 98)

'Aluminium Bronze Alloys - Corrosion Resistance Guide.' CDA Publication No 80

Meigh, H. 'Designing Aluminium Bronze Castings'. CDA Publication No 81

Hudson, F. and Hudson, D.A., 'Gunmetal Castings'. MacDonald and Co. Ltd.

Stolarczyk, J.E., 'The structure and properties of sand cast gunmetals.' British Foundryman, Dec.1960.

Moon, P.D. and Simmons, W.F., 'Creep and rupture properties of five copper base castings alloys'. Proc. ASTM 61, 1961,938-955

Simmons, W.F. and Kura, J.G., 'Creep properties of three low-shrinkage copper base casting alloys'. Proc. ASTM 58,1958,791-804.

Lushey, R.D.S. and Bowers, J.E., 'The creep of cast aluminium bronzes'. Metallurgia 78,1968,59-67.

Rabald, E. 'Corrosion Guide' 2nd Edition, 899pp, Elsevier, 1968.

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