BEARING BRONZES

BOOK SERIES

BEARING BRONZES

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BEARING BRONZES

Introduction

The principal function of a bearing metal is to provide for rotating or sliding contact with another surface, usually steel, with a minimum amount of friction. Consideration of the number of moving parts incorporated in various machines in engineering and other industries emphasises the importance of bearings, but there is still no clear general conception of what constitutes a good bearing material.

Bearing bronzes have been developed from experience in many parts of the world and the information on the subject is not well correlated, and is in some cases conflicting. In the past, the selection of bearing bronzes has been an empirical matter, and a great variety of composition has been specified by different engineers. In recent years tests have been made on different bearing bronzes under controlled laboratory conditions, attempting to reproduce the conditions of practice. It is too early to draw any general conclusions, but there are indications that a smaller number of basis compositions will cover the range of engineering requirements if the effect of varying the percentages of the constituents is understood.

Usually the value of a particular bronze does not depend so much on its exact composition, but rather on the sound manner in which it has been made. It is suggested, therefore, that the co-operation of competent bearing bronze manufacturers should be sought in solving bearing problems.

In this brief summary no attempt is made to deal with American and German bronzes, which sometimes differ from their British equivalents. Instead, attention is confined to British bronzes, which experience, confirmed by more recent scientific tests, has shown to be satisfactory.

REQUIREMENTS OF A BEARING METAL

(1) *Structural Strength, combined with adequate Plasticity to counteract Alignment Errors*

A bearing should have a sufficiently high elastic limit in compression to support its load without collapse at working temperatures. Structural strength is often measured in terms of "resistance to deformation by pounding," which is not necessarily proportional to Brinell hardness, but measures the ability of the bearing to retain its shape if subjected to heavy alternating loads.

By contrast, some plasticity in a bearing is desirable, in order to accommodate errors in fit and alignment, and so to avoid local high pressures. With harder bearing bronzes, it is very necessary that accurate fit and alignment of the bearing and shaft should be secured, as the materials may possess comparatively little plasticity and there would thus be uneven distribution of load. Addition of lead to the bearing bronzes increases plasticity, and this must be balanced against deformation resistance for the particular application (see p. 10).

(2) *Resistance to Wear*

The quality of wear-resistance must be balanced against potential wear on the shaft. For instance, the hard phosphor-bronzes, which are very resistant to wear, should be used only with hardened steels, and an unhardened steel should be run in one of the softer leaded bearing metals. There is no rigid rule which will determine what metals "run" well together, and the development of bearing bronzes has been based on traditional practice.

The copper-tin bronzes have a high resistance to wear and are most suitable for applications where the pressures are high and the speeds comparatively low, that is well under 1,000 ft. per minute.

For high-speed applications it is usually desirable to line the bronze with one of the softer "white metals" (see p. 12). Where space is limited, and the duty is high, the copper-lead bearing alloys may be used with advantage (see p. 18).

(3) *Low Coefficient of Friction*

A low coefficient of friction when run dry is a property sometimes required to avoid excessive heating up and shaft damage due to lubrication failure, or when starting from cold. In this connection, high thermal conductivity of the bearing material is also desirable.

Lead additions to the bronzes reduce the dry friction in a bearing, although this value may be independent of the friction value under lubricated working conditions.

The phosphor-bronzes have low working friction under lubricated conditions, but this is so dependent on design and lubrication that it is seldom possible to forecast definite figures. The coefficient of friction under extreme working conditions may, for instance, vary from 0·0015 to 0·015.

(4) *Toughness, or Freedom from Brittleness*

Toughness is required to avoid cracking the bearing if it has to be driven into its housing or roughly handled, and also for certain designs of bearing which have overhanging flanges.

GENERAL RANGE OF BRITISH BEARING BRONZES

British bearing bronzes are usually *phosphor-bronzes*, which are copper-tin alloys containing 5% to 20% tin, 0% to 20% lead, with a small percentage of phosphorus, and the remainder copper. In some cases 2% to 6% zinc is added in lieu of phosphorus, when the alloys are known as *gun-metals*, and combine satisfactory casting qualities with adequate bearing properties. It is not easy to discriminate between these two classes, but in general the phosphor-bronzes are used where bearing qualities are of paramount importance, and the gun-metals where a complicated casting is involved and foundry considerations take precedence.

In addition, there are special brasses, aluminium-bronzes (90% copper, 10% aluminium approx.), silicon-bronzes (96% copper, 4% silicon approx.), and other copper alloys which are sometimes used as bearing metals.

Finally, there are the copper-lead bearing alloys of approximate composition 70% copper and 30% lead. These are of modern development and show advantages over "white metal" bearings, being particularly suitable for high speeds with comparatively heavy loads (see p. 18).

The composition of bearings is often influenced by manufacturing considerations, particularly ease of casting, machining and also, under certain circumstances, hot and cold working. These features are additional to those necessary for bearing purposes.

PROPERTIES OF COPPER-TIN BEARING BRONZES

Copper-tin bearing bronzes normally range in composition from 5% up to 20% of tin, although the tin content is of the order of 10% to 12% in the customary bearing bronzes. These alloys are usually cast into the desired shapes in sand moulds but they may also be cast into chill moulds, which is a usual method for making phosphor-bronze tubes or rods from which small bushes are machined. For some applications, such as worm wheel blanks, centrifugal casting may be employed with advantage. Certain precautions are necessary in the course of both melting and casting in order to secure the best results. A small amount of phosphorus is usually added in order to secure deoxidation and to improve fluidity (see also p. 9).

While it is possible for the structural features of any particular alloy to be modified by variations of casting conditions, in general there is obtained a duplex structure similar to that illustrated in the photomicrograph on p. 13. The structure consists of a hard tin-copper constituent (delta) in a softer matrix (alpha). A duplex structure of this type is a characteristic feature of most bearing metals.

Effect of varying Tin Content in Bronzes

Cast copper-tin alloys containing more than about 5% of tin show the presence of the harder constituent, the amount of which increases with increase of the tin content and is accompanied by improvement of structural strength and resistance to deformation by pounding.

With more than about 12% of tin the amount of the delta constituent results in the bronzes being very hard and rather brittle. Hence it is only under exceptional circumstances that it is advisable to use alloys of, say, 15% tin content, while with still greater amounts there may be difficulty in machining. Alloys containing 15% tin are used in such special applications as locomotive slide valves, while those of 20% tin content have been used in the construction of movable bridges and railway turntables. When lead or other elements are added to the alloy, the tin-copper ratio is often a better criterion than the actual tin content, because the former determines the proportion of the hard constituent.

On annealing cast bronzes at temperatures of 600° C. and over, there is absorption of the hard delta constituent by the softer alpha matrix, and the alloys are softened. Castings intended for bearing service should not be annealed, owing to the greater wear which occurs upon bearings in the annealed and softened condition.

Copper-tin alloys with tin contents up to approximately 8% or 10% may be obtained in the form of cold-drawn rod or tube. In this form the bronzes have been work-hardened after annealing and are entirely homogeneous in structure, consisting only of the alpha constituent. These products are chiefly applicable for small bearings, such as medium-duty bushes.

ADDITION OF OTHER ELEMENTS TO THE COPPER-TIN BRONZES

It is usual for copper-tin bearing bronzes to contain varying percentages of other elements, of which phosphorus, lead, zinc and nickel are the most important.

Phosphorus in Copper-Tin Bronzes

Phosphorus in small amounts is added to the copper-tin alloys for the purpose of deoxidation, and at the same time to improve the casting properties. Improperly deoxidised bronzes may contain oxides, particularly tin oxide, which is hard and liable to result in subsequent scoring in service. A residual phosphorus content in the bronze of about 0·05% or 0·1% generally indicates the efficient removal of oxygen, with improved crystal structure and wearing qualities.

Further addition of phosphorus in amounts of the order of 0·5% excess after deoxidation results in the formation of a very hard copper phosphide constituent (Cu_3P), which hardens the bearing but may tend to render it brittle.

Upwards of 1% phosphorus is sometimes added to bronzes as an alternative to high tin content, but for bearings, as opposed to gear-wheels, some authorities consider that a high phosphorus content in bronze causes undue shaft wear. High phosphorus may also introduce casting difficulties and produce low melting point constituents. When lead is also present, this may be undesirable because the lead is not "held" in diffused particles while solidifying.

Lead in Copper-Tin Bronzes

The addition of lead to the copper-tin bronzes has been practised for many years, and for some purposes the leaded bronzes have advantages over the lead-free alloys. The solubility of lead in copper is negligible so that it is present as a separate microscopic constituent, and should appear in the form of small globules widely distributed; care must be taken to avoid the formation of "lakes" of lead as the result of a high temperature during casting, and annealing during fabrication should be avoided.

The principal advantage of lead additions to copper-tin bronzes is the increased plasticity afforded by the lead constituent, which can compensate to some extent for want of fit or alignment of bearings. Leaded bronzes are also of advantage when bearings are operated with unhardened steel shafts. In the event of temporary failure of the oil supply, the lead minimises the danger of damage to the shaft, and leaded bronzes should therefore be used where lubrication is indifferent.

Additions of 1% or 2% of lead are made to the copper-tin bronzes with the object of improving machinability. Lead in amounts of 5% and upwards reduces the dry coefficient of friction of a tin bronze. Lead additions up to 12% further improve plasticity, but conversely reduce the toughness and shock resistance of a bearing, and also its resistance to deformation by pounding. Wear tests show that the leaded bronzes may have a higher weight-loss during the initial running-in period, but afterwards the wearing qualities are superior to those of lead-free bronze (French, *Amer. Soc. Test. Mat.*, 1928, 28 (II), p. 298).

Of the group of leaded bronzes, one of the best-known alloys has a composition of 80% copper, 10% tin and 10% lead. Other bronzes containing lead in amounts varying up to about 30% are also in extensive use.

Zinc in Copper-Tin Bronzes

Zinc, like phosphorus, acts as a deoxidiser, and bronzes containing zinc do not usually need phosphorus, or *vice versa*. The presence of zinc in the copper-tin bearing metals is regarded by many authorities as being objectionable, as it is alleged to result in a tendency towards seizing and tearing of the bearing surface (Dews, *The Metallurgy of Bronze*, p. 53). On the other hand, it has been shown that zinc in amounts of 4% does not affect wearing qualities, as measured by means of a laboratory machine (French and Staples, *Amer. Soc. Test Mat.*, 1929, 29 (II), p. 450). It is agreed that the presence of zinc does not appreciably affect mechanical properties such as strength and impact, while it slightly improves the casting properties.

The copper-tin bronzes containing up to 6% zinc, but more generally 2%, and which are known as gun-metals, are often used incidentally for the purpose of bearings. A typical alloy is Admiralty gun-metal (88% copper, 10% tin, 2% zinc: B.S.I. 383), which has been widely used for marine castings. As a general rule, however, zinc is not added as a special constituent to alloys intended for bearing applications, and it is considered that the phosphor-bronzes are superior.

Bearings rich in zinc, which are virtually brasses, tend to have a poor wear value, but are sometimes used where speeds are low (see p. 17).

Nickel in Copper-Tin Bronzes

Within recent years nickel has been added to various bearing bronzes employed in quite a wide range of applications, and nickel may be considered as in the nature of an optional addition but which has certain beneficial effects.

The presence of nickel in the copper-tin bronzes results in a slight increase of strength and toughness, the optimum improvement being obtained with a nickel addition of about 1% or 2%. The crystal structure of castings is also slightly refined, while in the case of leaded bronzes it has been claimed that the segregation of lead is reduced, thus giving a more even distribution of the lead particles.

Further increase of the nickel content gives rise to a group of alloys which have only been applied to a limited extent as bearing materials, but under certain special circumstances, such as at somewhat elevated temperatures or in the presence of corrosive media, they have advantages over the ordinary copper-tin bronzes.

Other Elements in Copper-Tin Bronzes

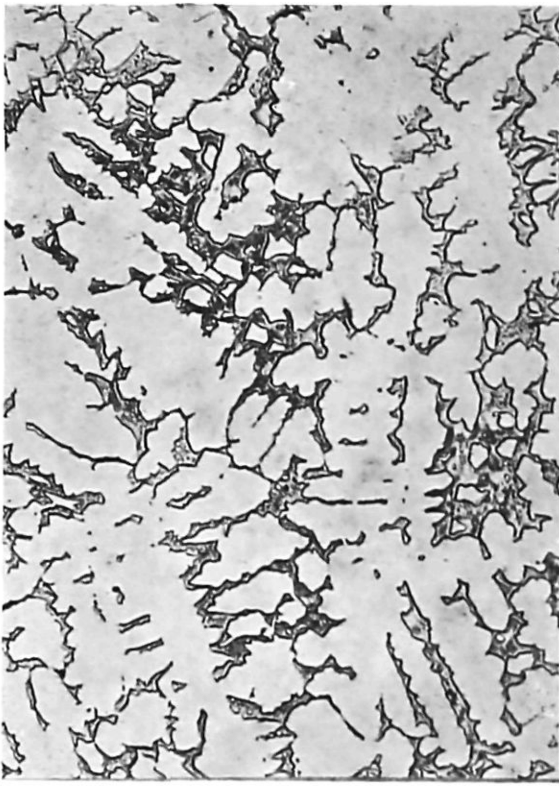
It is doubtful whether any elements other than those mentioned above can be usefully added to the copper-tin bearing bronzes, although numerous other additions have from time to time been suggested. In most cases it is desirable to keep the total impurities present below 0·5% or even below 0·25%.

Typical bearing bronzes, together with average mechanical properties, are given in the table on p. 21.

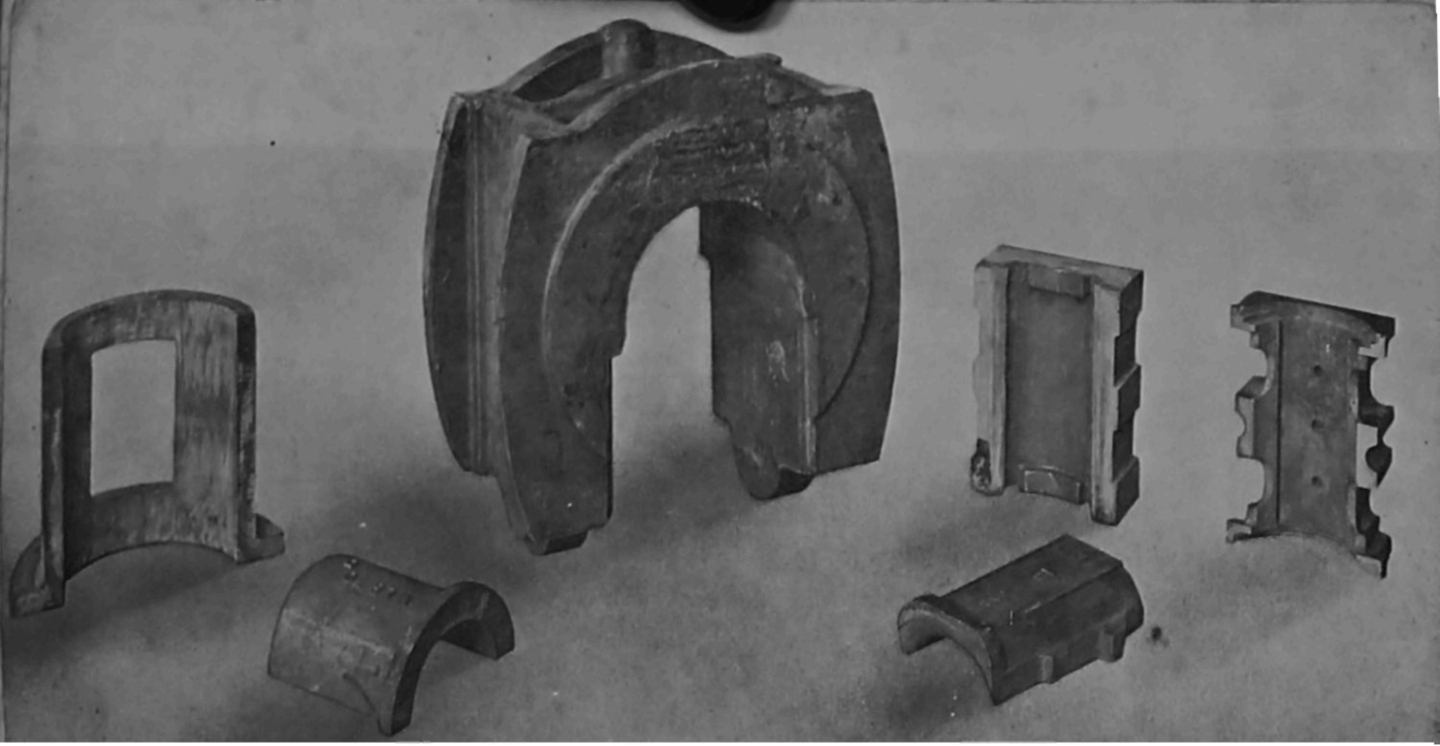
Examples of various forms of bearings are given in the photographs on pp. 14 and 15.

BRONZE BEARING SHELLS

A copper-tin bronze or other similar alloy should be used as the material for bearing shells which carry thin linings of tin, lead or cadmium base "white metals." To avoid spreading under loads, these softer materials can often only be used as a comparatively thin skin or lining, and in the event of failure of this skin, the bronze backing is a safeguard against damage to the shaft. Steel backing does not provide this safeguard and, moreover, the

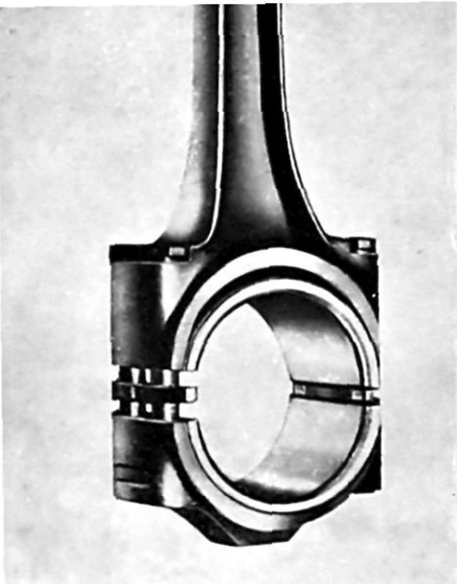


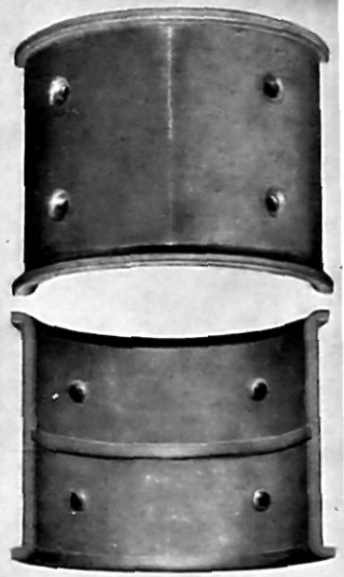
Photomicrograph, magnified about 100 times, of copper-tin bearing-bronze showing duplex structure. The softer alpha areas appear white in this photomicrograph and the hard delta areas dark.



BRONZE CASTINGS for locomotive and wagon axle bearing boxes

5 VARIOUS BRONZE BEARINGS. This group includes floating bushes, shaft bearings, small axle bearings, thrust ring and aero-engine valve guide.



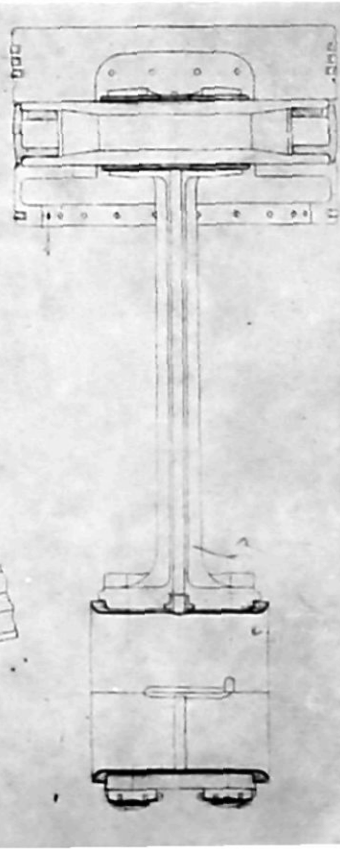


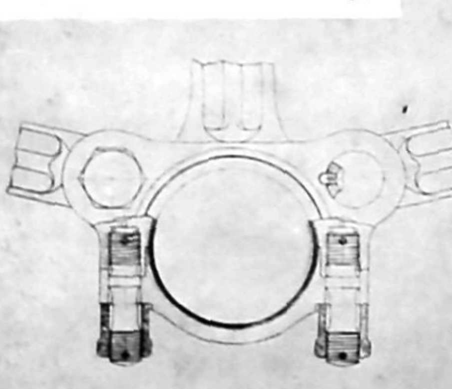
COPPER-LEAD BEARINGS IN HIGH-DUTY ENGINES

Top left. A.E.C. commercial vehicle Diesel engine connecting-rod bearing. Top half is lined with copper-lead bearing alloy. (*By courtesy of Associated Equipment Co. Ltd.*)

Top right. Ford V.8 automobile engine split floating bush for con.-rod big-end. Lined inside and outside with copper-lead alloy. (*By courtesy of Ford Motor Co. Ltd.*)

Below. Napier aero-engine con.-rod bearing assembly. Master rod is fitted with a copper-lead bearing shell. (*By courtesy of D. Napier & Son Ltd.*)





bonding strength of the bearing metal with a bronze shell is much superior (E. G. Soash, *Metals and Alloys*, 1934, 5, p. 268). Bronze also has the further advantage of good thermal conductivity, which avoids local hot spots. If the design calls for flanged bearings, these can be made easily and cheaply in bronze owing to its good machining qualities.

BEARING BRASSES

Although the copper-zinc alloys or brasses, containing approximately 60% copper or less, possess a duplex structure which is a characteristic feature of most bearing metals, these alloys are not suitable for bearings subject to heavy loads at high speeds since they possess relatively poor wearing properties and tend to lose structural strength at temperatures of the order of 300° C. Brasses are, however, used for certain applications, because they are considerably cheaper than the copper-tin bearing bronzes. Quite frequently additions of iron, manganese and aluminium are made for further hardening and strengthening purposes, and a typical alloy has an approximate composition of copper 60%, aluminium 1·5%, manganese 1%, iron 1%, zinc 36·5%.

In some forms of bearings it is convenient to make the general body of the casting of brass and to insert cast phosphor-bronze strips to form the working surface. Such assembled bearings, which have been limited to certain axle boxes and rolling mills, are cheaper than bearings made entirely of copper-tin bronze, but the heat dissipation and performance may be impaired unless there is particularly good contact between the bronze strips and the body of the casting.

COPPER-LEAD BEARING ALLOYS

Also known as "Lead Bronzes"

The possibilities of a 70% copper, 30% lead mixture as a material for lining bearings have been known for many years, but the technique for diffusing the lead evenly through the metal has only recently been perfected and is still a matter for specialists. Such alloys are unsuitable for casting in the normal manner, but with correct treatment, highly successful results may be obtained in lining bearing shells with copper-lead alloys, which have advantages in many applications.

In some cases the mixing of the lead with the copper is achieved by casting the metal into the bearing shell centrifugally. When circumstances do not permit centrifugal casting, lead segregation can be somewhat lessened by additions of tin or zinc of the order of 1%, but these additions reduce the otherwise excellent thermal conductivity, which reduction is a disadvantage if much heat has to be removed from the bearing. A typical copper-lead bearing alloy which is widely used contains 25% to 30% lead, 0 to 1% tin, remainder copper.

Melting the copper and adding the lead, followed by solidification of the alloy and re-melting under a special flux to avoid excessive gas absorption, has been found to reduce lead segregation on casting. The addition of traces of silicon, zirconium and sulphur has also been suggested for overcoming lead segregation (H. K. Herschmann and J. L. Basil, *Bureau of Standards Research Journal*, X, May, 1933).

A further process which is used for the production of copper-lead alloy steel bushes involves passing mild steel strip, about $\frac{1}{16}$ in. thick, through a bath of the molten copper-lead alloy at 1,150° C. and subsequently through a graphite die to wipe off excess and secure a smooth surface. The coated strip is then subjected to various finishing operations and formed into semicircular half-bushes.

Copper-lead bearing alloys permit about 20% higher loading than lead or tin base white metals, and have high resistance to wear, so that they are being used extensively for bearing purposes, including high-duty aeroplane, automobile and Diesel engine crankshaft bearings as illustrated in the photographs on p. 16. Average bearing loads for copper-lead automobile big-ends are about 1,200 lb./sq. in. with instantaneous loads exceeding 2,000 lb./sq. in.

Further advantages are associated with the high thermal conductivity, which permits the rapid removal of heat from the bearings, and the low coefficient of friction of about 0·002.

Although the Brinell hardness is only about 30, copper-lead alloys have relatively high load-carrying capacity, but to avoid the possibility of spreading under load only a thin layer of 0·060 in. to 0·020 in. thickness is usually employed. With correct preparation excellent adhesion with the bearing shell is secured. The extremely good "welded" bond between the copper and the steel of the shell is indeed thought to contribute considerably to the excellent performance of these alloys. As copper-lead bearing alloys are cast at temperatures exceeding 1,100° C., mild steel (*e.g.* 0·20% carbon steel) is generally used as a shell, since tempered steels would tend to become softened by the molten metal.

It is important that the lubricating oils employed in conjunction with copper-lead bearing alloys should not contain much free fatty acid and that the oil should be filtered carefully to avoid gritty particles.

TABLE OF SOME TYPICAL BEARING BRONZES

As already indicated the number of bearing bronzes which are in actual use is extremely large, due to the number of combinations which are possible with the component elements, and a comprehensive list would be almost impossible. The table on p. 21 gives, in order of the resistance to "pounding," a representative list of bearing bronzes which may be regarded as typical and which will form a satisfactory basis to cover most requirements. The effects of variation of composition, by modifying the tin, lead or phosphorus contents, and by adding other elements such as nickel, may be deduced from the information given on pp. 8 to 12.

The mechanical properties quoted should only be regarded as approximate, for they are affected to a very great extent by the casting conditions, such as temperature of metal, gas content, size and form of test piece and rate of cooling. Neither mechanical properties alone, nor chemical composition alone, form a satisfactory basis for specifications.

Density of Bronzes

The density of the bronzes is largely influenced by casting conditions and it would therefore be misleading to quote specific values for individual alloys. The densities may be assumed to range from about 8·3 to about 8·9, alloys containing large quantities of lead having of course the higher density values.

SOME
TYPICAL
BEARING
BRONZES

SOME TYPICAL BEARING BRONZES

Nominal Percentage Composition by weight					Average Mechanical Properties			Description and Applications	Equivalent British Standards Institution or Air Ministry Specifications
Copper	**Tin**	**Lead**	**Zinc**	Phosphorus*	Tensile Strength tons/ sq. in.	Elongation % on 2 in.	Brinell Hardness		
85	15			(0·1)	14	2	100	Hard wearing bronze suitable for heavy compressive loads. Employed for locomotive slide valves, bearings for turntables, etc.	
89	10 min.			(0·5 min.)	18	4	100	PHOSPHOR-BRONZE, suitable for heavy loading, and very widely employed.	2B8
88	10		2		17	20	65	ADMIRALTY GUN-METAL. A bronze for general casting purposes, especially to resist marine corrosion. Suitable for bearings when lubrication is good.	383
80	10	10		(0·05)	15	15	65	Possesses good anti-friction properties combined with plasticity. May be applied where lubrication is doubtful.	
77	8	15		(0·05)	14	15	60	Suitable for use where lubrication or alignment is still less satisfactory than for the above.	
85	5	5	5		13	16	55	An alloy suitable for general castings, such as hydraulic fittings not requiring high strength. Only occasionally used for bearings but suitable for bearing shells.	
74	1·2 max.	25			8	15	30	This alloy has high thermal conductivity and is capable of carrying higher loads at high speeds than "white metals" and is therefore used for high-duty aeroplane and other engine crankshaft bearings, etc. Special technique in casting is required (see p 18).	D.T.D. 229

*Phosphorus content varies widely and values given are typical only.

Conductivity Values

The thermal and electrical conductivity of most bearing bronzes may be accepted as being of the order of 10% to 20% of the corresponding H.C. copper values, depending upon the actual composition and other factors. In the case of the copper-lead bearing alloys, free from addition of such elements as tin and phosphorus, much higher conductivities may be obtained, of the order of 50%.

BUSHES FOR LIGHT-DUTY APPLICATIONS

Under many conditions, frictional contact between two steel surfaces causes scoring, undue wear or seizure. It is therefore usually an advantage to insulate a steel shaft pin, or flange, with a non-ferrous bush so that it does not rub directly in contact with another steel member. The bushes in such fittings may be obtained conveniently from bronze tubes, which may be drawn to specified dimensions and afterwards parted off to the required lengths.

For light duty where much wear is not anticipated, bushes may be produced from various brasses, some of which are hardened by aluminium, iron and manganese. Although these materials are not bearing metals in the usual sense, they are employed where low cost is of special importance (see p. 17).

In other instances, bearings for light duty may be obtained from bronze strip of about $\frac{1}{16}$ in. thickness, which is folded up into cylindrical form and given a final reaming operation.

For some applications it is often convenient, and even more economical, to make parts, such as levers or brackets, from hot brass stampings or other fabricated copper alloy products instead of using steel and resorting to the use of bushes. Typical examples of one-piece brass levers are those used for automobile carburetters (see p. 25).

BEARINGS MOULDED FROM COPPER POWDER MIXTURES

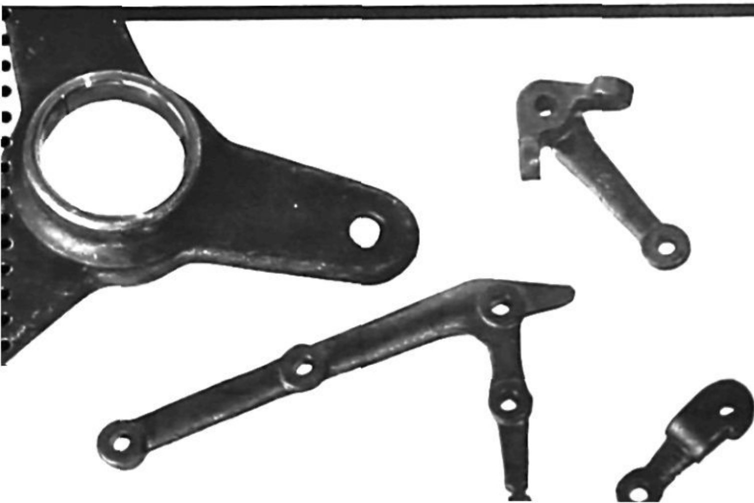
Advances in the technique of moulding metallic powders permit the production of bearing bushes for medium loads with the minimum of manufacturing operations and with consequent saving in cost. With controlled manufacturing conditions, the moulded bushes possess good mechanical properties, although they may not withstand very severe loading.

A typical mixture consists of 90% copper powder with 10% tin powder, and graphite is also sometimes added. The powder used for moulding is sharp grained and is graded to give direct control of grain size, while freedom from inter-crystalline oxide is also ensured.

The powders are moulded in self-ejecting presses under pressures of about 40,000 lb./sq. in. and the moulded pellets afterwards sintered, that is furnace heated, in a reducing atmosphere at a temperature below the melting-point of the constituents.

By controlling moulding pressures it is possible to produce bearings having a density from 70% upwards of the equivalent solid metal density, and the bearings can thus be made slightly porous to hold oil if necessary. This property of self-lubrication has been exploited for many bearings difficult to lubricate on automobiles—such as brake camshaft bushes—and on aeroplanes, electric machines and agricultural machinery, in heavy plant such as conveyors and in small apparatus such as typewriters.

Above. Moulded bearings produced from copper powder mixtures.
Below. Left: Steel component with bush formed from bronze strip.
Right: Hot brass stampings for carburetter levers.



Porous moulded bronze bushes are also used in machinery for textile and other trades where oil splashing is objectionable.

The photographs at the top of p. 25 show the wide variety of bearing types which can be manufactured by moulding; the sizes are as large as 3½ in. diameter.

The moulded dimensions may be controlled to within limits of 0·001 in., but a final sizing operation is usually given by drifting. As the satisfactory performance of moulded bearings is usually to a large extent associated with the openness of the structure, it is important that machining or grinding operations, which would partly ruin this feature, should be avoided.

Moulded bearings should be inserted into their housings with a special supporting mandrel so as to preserve accurately the size and condition of the bearing and hence avoid necessity for further machining or fitting. For automobile work the recommended housing fits for these bearings have been standardised under Institution of Automobile Engineers Data Sheet Number 186.

GENERAL NOTES ON THE INSTALLATION OF BRONZE BEARINGS

Machining and Fitting Bushes

Modern machining methods permit very accurate finishing of bronze bearings by reaming, drifting, diamond turning, broaching or other methods, so that hand fitting is superseded for many applications. Care should, however, be taken, in broaching bronzes of high lead content, to avoid deformation.

A bearing bush should preferably be a press fit in its housing, say about 0·002 in. interference fit on a bush for a 1 in. diameter shaft, 0·004 in. for a 2½ in. shaft, and *pro rata;* these fits will close the bore of the bush about as much as the amount of interference, although this is, of course, influenced by the thickness of bush and the stiffness of the housing. If design permits, pegging or keying the bush is an added precaution to prevent rotation. Cast bronze bearings usually have a wall thickness of ⅛ in. upwards per inch of diameter, but drawn tubular bushes may be thinner.

Bushes may be line-reamed in position with advantage, and about 0·003-in. should be left on for this purpose. The tool should penetrate the skin of the metal to give a clean cut, although the final cut should otherwise be as light as possible to give minimum crystal disturbance on the bearing surface. If considerable misalignment is anticipated, extra stock should, of course, be left on for reaming.

Clearances

For general purposes it is usual to give about 0·001 in. bearing clearance per inch of shaft diameter to compensate for thermal expansion and to permit an oil film, but clearances should be the subject of trial and error.

For a bearing whose resultant load acts always in the same angular direction, the arc of contact is sometimes reduced to 90° or less to secure the most favourable lubrication conditions.

Oil Feed

Oil should be fed into a bearing on the side of lowest pressure, and part of the bearing is sometimes relieved to form an oil reservoir. Oil grooves, if employed, are usually parallel or at an acute angle to the axis of the shaft, and do not break through to the ends of the bearing.

It is now realised that the PV factor (P = load or pressure, V = velocity) is not always a good indication of loading if the bearing is designed on sound hydro-dynamic principles, because viscous drag on the oil film builds up oil pressure and so will carry high loads at high speeds. In fact, there are sometimes lubrication and bearing difficulties with heavy machines operating at very low speeds as it is not possible to build up an oil film between the bearing and the shaft.

Oil Temperature

For some applications it is necessary to find a satisfactory compromise between oil deterioration at high temperatures and viscous drag and friction loss due to cold oil. In automobile engine practice, a usual operating oil temperature is 70° C.

Design Proportions and Pressures

To reduce rubbing speeds, the diameter of a bearing should not be designed excessively large, but the required loading per square inch of the projected area must of course be maintained by correspondingly increasing the length of bearing. The relative merits of different ratios of bearing length to diameter are very controversial, and dependent on the given application. However, length/diameter ratios of 1½, 1, and even ¾ to 1 are becoming increasingly usual, in order to avoid microscopic shaft deflections which may destroy valuable oil film conditions. If rigidity of the housing can be ensured, longer bearings can be used with advantage when the shaft is not subjected to severe bending moments. When both loads and speeds are high, and space is limited, a floating bush is often an advantage, as it tends to divide the duty.

It is difficult to give useful information about permissible loading, as this varies so much with the lubrication and other conditions. For instance, with large machinery and heavy rotors, it may be necessary to take care of starting-up conditions with an incomplete oil film, and 175 lb./sq. in. is a usual working pressure for bronzes supporting a heavy rotor from rest. If maximum pressures are not attained until considerable speed is reached, a loading of 400 lb./sq. in. is frequently permissible.

Instantaneous pressures on phosphor-bronze bushes for engine gudgeon-pins may exceed 4,000 lb./sq. in., although here the rubbing speed is only of the order of 100 to 200 ft./min.

For high-speed applications with high-pressure oil feed, such as petrol-engine crankshaft bearings, where space is limited, mean pressures of 1,200 lb./sq. in. and instantaneous pressures exceeding 2,000 lb./sq. in. are not infrequent with copper-lead bearing alloys. Here the rubbing speeds are of the order of 2,000 ft./min.

WHERE TO SPECIFY BRONZE OR BRONZE-BACKED PLAIN BEARINGS

In specifying a bearing, it may be recalled that plain bearings, which are still by far the most important for engineering work, offer advantages over ball or roller bearings for applications coming within the following categories:

For dynamic applications, the housings for bronze bearings are of small diameter and the resultant space saving may be a particular advantage. Any possible centrifugal problems connected with component balls or rollers are eliminated.

If assembly is difficult, a bronze bearing may be designed in two halves bolted together, to permit insertion of the shaft.

To withstand shock loads and give silent operation, bronze bearings have a resilient oil film so that they are not sensitive to wide clearances, are not prone to "bump," and are silent in operation.

For heavy duty, bronze bearings have high thermal conductivity and permit controlled distribution of oil under pressure for lubrication and cooling.

Where long life free from risk of breakdown is required, bronze bearings are not sensitive to corrosion by damp, or to fatigue and breakage of balls or rollers by local high pressures due to the entry of grit.

Where low cost is important, bronze bearings show a considerable all-round saving. Their first cost is low, they have a long life and finally a high scrap value.

The Copper Development Association will be glad to give further information if desired. The Association is a non-commercial body which has been established by the Copper Industry to collect and distribute information, and to develop applications and processes connected with copper and its alloys.

LIST OF C.D.A. PUBLICATIONS

No. 1. *Introductory Leaflet.* (The nature, organisation, activities and services of the C.D.A.)
No. 2. *Copper Tubing.* (Semi-technical, for architects, illustrated.)
No. 3. *Copper through the Ages.* (Historical and general, illustrated.)
No. 4. *Copper-Steels to Resist Corrosion.* (Engineering data.)
No. 5. *Sheet Copper-work for Building.* (Practical handbook, for architects, builders and plumbers, illustrated.)
No. 6. *Brasses* (1). (Engineering and metallurgical data.)
No. 7. *Behaviour of Copper on Exposure to the Elements.* (Reprinted from the *R.I.B.A. Journal.*)
No. 8. *The Use of Copper for Domestic Water Services.* (Technical, for architects, water authorities, etc., illustrated.)
No. 9. *Copper Sheet.* (Semi-technical, for architects, illustrated.)
No. 10. *Steel-cored Copper Conductors.* (Technical data for electrical engineers, etc.)
No. 11. *Cadmium-Copper Conductors.* (Technical data for electrical engineers, etc.)
No. 12. *Copper Data.* (Mechanical and other data for engineers, etc.)
No. 13. *Copper for Gas and Water Installations.* (Reprinted from *Gas Times.*)
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No. 18. *Copper for Architecture in Sweden and Denmark.*
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