

SELECTION OF ALLOYS FOR HYDRODYNAMIC BEARINGS

1. INTRODUCTION

In plain bearings, where the load is transmitted between two opposing surfaces in relative sliding motion, one of the surfaces is generally of a material such as carbon steel, low alloy steel or cast iron, chosen primarily for its structural properties, while the other surface is of a “bearing material” chosen to operate satisfactorily against the structural member. Wear of these surfaces is minimal in bearings designed to operate in the hydrodynamic regime where surfaces are nominally separated. However, much of the technology of selection of the bearing material is related to the need for the bearing to operate with imperfect separation of the opposing surfaces, a condition which will occur, at least momentarily, in virtually any operating machine. Accordingly, a relatively soft bearing material is generally used so that any damage is confined to the bearing surface which is usually easier to repair or replace than the counterface. Traditional bearing alloys based on tin and lead are outstanding and are probably still the most widely used materials. However, with continuing advances in machine performance, alternative alloys, able to operate at higher temperatures or to provide better fatigue strength, are often required.

With the usual mineral oil lubrication, bearing temperatures rarely exceed about 130°C. Higher temperatures are sometimes generated and temperatures as high as 260°C can be contemplated with synthetic lubricants. Alternatives to the traditional tin- and lead-based alloys would certainly be required at such high operating temperatures. Alternative materials, offering better fatigue strength, might also be required in applications involving dynamic loads such as industrial diesels and reciprocating compressors. This Item is intended primarily to provide guidance on the selection of bearing alloys for industrial machinery, examples of which are listed in Table 1.1. Automotive applications are not considered.

TABLE 1.1 EXAMPLES OF INDUSTRIAL MACHINERY

Turbines and turbogenerators
Electric motors and alternators
Ship propeller shaft bearings
Marine gearboxes
Rolling mills
Gear pumps
Hydraulic motors and pumps
Slow and medium speed diesel engines
Reciprocating compressors and pumps

Bearing costs are, of course, important especially in mass produced equipment. Considerations of the overall performance of a bearing material, however, generally far outweigh initial-cost considerations since the time lost through machine shutdown for repair is usually very expensive. In any case, bearing costs are usually more effectively reduced by close attention to the mechanical design of the bearing system and to production methods. Accordingly, this Item concentrates on the properties of the bearing alloys as they affect performance and the utilisation of these alloys in the various mechanical designs of bearings. The scope, assumptions and limitations of the Item are summarised in Table 1.2.

TABLE 1.2 SCOPE, ASSUMPTIONS AND LIMITATIONS

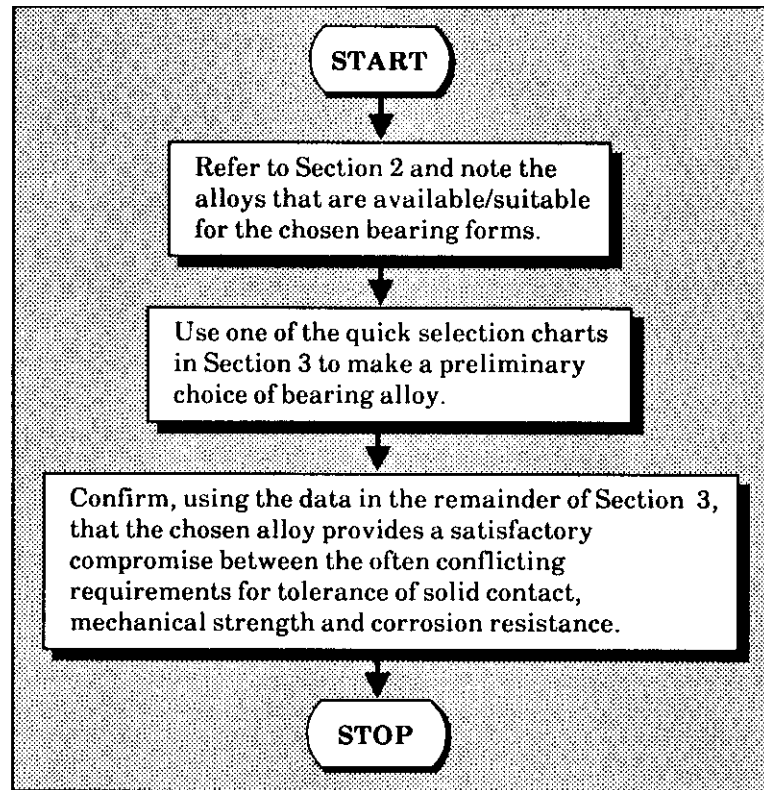
Scope and assumptions:	Limitations:
Selection of bearing alloys for industrial machinery.	Automotive applications are not considered although other applications involving dynamic loads, such as industrial diesels and reciprocating compressors, are considered.
Metallic bearing alloys that are appreciably softer than the counterface which is assumed to be carbon steel, low alloy steel or cast iron unless otherwise stated.	Porous lubricant retaining materials, polymers and ceramics are excluded.
Bearings designed to operate in the hydrodynamic lubrication regime and only experiencing boundary lubrication at start-up and run-down or in unusual circumstances.	Bearing failures arising from inadequacies in design, manufacture or assembly are not discussed.
Provision of a continuous supply of nominally clean lubricant which is assumed to be mineral oil unless otherwise stated.	

1.1 Guide to the Use of This Item

In order to use this Data Item to select a bearing alloy you should have available the following information.

- (i) A preliminary bearing design with an estimate of operating parameters such as the maximum bearing temperature (see Reference 1, 2 or 3) and, where dynamically loaded, the peak loads. Ideally an estimate of the minimum film thickness will also be available.
- (ii) A preliminary choice of bearing form or construction. That is a choice between a direct lined bearing, a solid insert or replaceable thick or thin-walled components.
- (iii) A summary of operational factors such as the frequency of stop/starts, the likelihood of contamination by dirt particles or by potentially corrosive substances, the expected misalignment and the consequences of damage occurring to the mating surface.

Having collected this information, a bearing alloy may be selected by following the procedure of Sketch 1.1.

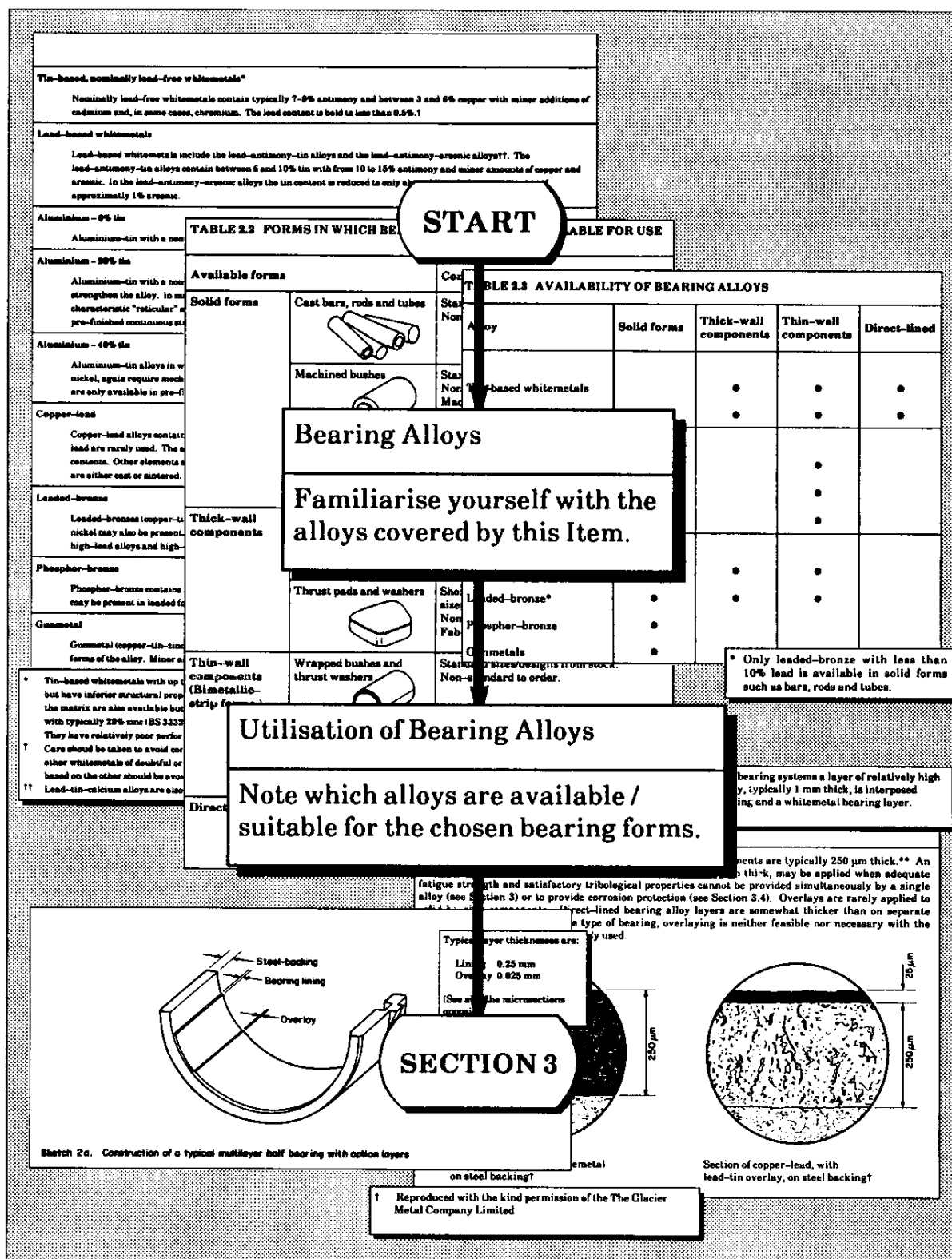


Sketch 1.1

In some cases, revision of the mechanical design of the bearing or relaxation of an operational factor may prove advantageous. For example, a change from a solid bearing to a wrapped bush might provide economies and, at the same time, allow a softer, tribologically more favourable, alloy to be used with benefit to bearing reliability. In other cases a reduction in bearing operating temperature, and enhanced reliability, may be obtained by, for example, attention to the running clearance of the bearing.

2. AVAILABILITY OF BEARING ALLOYS

This section classifies the bearing alloys, identifies the forms in which these bearing alloys may be obtained and summarises their availability. Brief constructional details of the various bearing types are given but their relative merits are not discussed. Sketch 2.1 illustrates the procedure of this section.



Sketch 2.1

2.1 Bearing Alloys

There are three major categories of bearing alloys. They are based:

- (i) on tin or lead,
- (ii) on aluminium, and
- (iii) on copper.

All incorporate various alloying elements to produce a structure consisting of a mixture of relatively hard, strong phases with softer, weaker ones[†]. Table 2.1 lists those considered in this Item.

2.1.1 Whitemetals

Whitemetals are based on either tin or lead with strengthening additions of antimony and, usually, copper. Some tin is always present in the lead-based alloys. However, even small amounts of lead can impair the high temperature performance of the tin-based alloys and for this reason nominally lead-free specifications are preferred. The structure of all whitemetals is essentially one of a soft matrix reinforced by a dispersion of hard particles or needles. Whitemetals are probably the most important type of bearing alloy for industrial plant where the direct lining (see Section 2.2) of the bearing housing is common practice.

2.1.2 Aluminium-base alloys

The alloying constituents of aluminium-base alloys include both high melting point elements such as silicon and nickel and low melting point elements such as tin and cadmium. Well known alloy types are aluminium–tin, aluminium–cadmium, aluminium–silicon and aluminium–cadmium–silicon[‡]. In general aluminium-base alloys have high coefficients of expansion and consequently generous clearances may be required with solid bearing components. More usually, thin-wall steel-backed bearings would be employed.

2.1.3 Copper-base alloys

The major alloying constituents of copper-base bearing alloys include tin, zinc and phosphorus which form intermetallic compounds within the copper based solid solution. Other elements such as nickel may be present to refine the structure of the alloy. Lead, which forms a separate dispersed phase, is often incorporated to improve the tribological properties of the alloy. Copper-base alloys include copper–lead, containing little or no tin, and the phosphor and leaded bronzes containing at least 3% tin. Gunmetals, which contain at least 2% zinc, are also included in their leaded forms. Copper-base alloy bearings are either machined from cast forms (see Section 2.3) or are supplied as thin-wall steel-backed bearings.

[†] The microstructure and the properties of an alloy can depend on manufacturing method (see Section 3.2.1).

[‡] Alloys of aluminium with silicon and/or cadmium (ISO 4383) are mainly confined to automotive applications. Aluminium–zinc alloys are also possible but are not widely used.

TABLE 2.1 BEARING ALLOYS**Tin-based, nominally lead-free whitemetals[†]**

Nominally lead-free whitemetals contain typically 7–9% antimony and between 3 and 6% copper with minor additions of cadmium and, in some cases, chromium. The lead content is held to less than 0.5%[‡].

Lead-based whitemetals

Lead-based whitemetals include the lead–antimony–tin alloys and the lead–antimony–arsenic alloys^{††}. The lead–antimony–tin alloys contain between 6 and 10% tin with from 10 to 15% antimony and minor amounts of copper and arsenic. In the lead–antimony–arsenic alloys the tin content is reduced to only about 1% with the incorporation of approximately 1% arsenic.

Aluminium – 6% tin

Aluminium–tin with a nominal tin content of 6% may also contain small amounts of copper, nickel and silicon.

Aluminium – 20% tin

Aluminium–tin with a nominal tin content of 20% may also contain small amounts of copper and nickel which serve to strengthen the alloy. In manufacture, the alloy requires mechanical working and heat treatment in order to obtain the characteristic “reticular” structure of an interlocking network of tin in an aluminium matrix and is only available in pre-finished continuous strip forms (see Section 2.3).

Aluminium – 40% tin

Aluminium–tin alloys in which the tin content has been increased from 20% to 40%, usually with the exclusion of copper or nickel, again require mechanical working and heat treatment in order to obtain the characteristic “reticular” structure and are only available in pre-finished continuous strip forms (see Section 2.3).

Copper–lead

Copper–lead alloys contain at least 20% lead. The lead content may be as high as 50% but alloys with more than about 35% lead are rarely used. The alloys are usually nominally tin-free although up to 3% tin may be present with the higher lead contents. Other elements such as nickel and silver may be present in small amounts. In manufacture, copper–lead alloys are either cast or sintered.

Leaded-bronze

Leaded-bronzes (copper–tin–lead alloys) contain from 8 to 25% lead and from 3 to 10% tin. Minor amounts of zinc and nickel may also be present. The higher lead contents are associated with the lower tin contents so that there are low-tin, high-lead alloys and high-tin, low-lead alloys.

Phosphor-bronze

Phosphor-bronze contains from 7 to 12% tin with small (up to 1%) but significant amounts of phosphorus. Up to 8% lead may be present in leaded forms of the alloy. Minor quantities of zinc and nickel may also be present.

Gunmetal

Gunmetal (copper–tin–zinc) alloys contain from 2 to 6% zinc and from 4 to 8% tin. Up to 8% lead may be present in leaded forms of the alloy. Minor amounts of nickel may also be present.

[†] Tin-based whitemetals with up to 5% lead (ISO 4381) and, usually, increased antimony contents of about 12% are available but have inferior structural properties at high temperatures. Intermediate alloys in which both tin and lead are present in the matrix are also available but, again, they have inferior high temperature properties. So called “marine” whitemetals with typically 28% zinc (BS 3332/D) are intended to be anodic to steel and so protect journals from corrosion by sea-water. They have relatively poor performance as a bearing alloy and are seldom used.

[‡] Care should be taken to avoid contamination of tin-based whitemetals by lead. Certainly, they should never be mixed with other whitemetals of doubtful origin. Also, the practice of using a lead-based whitemetal on one half of a bearing and a tin-based on the other should be avoided.

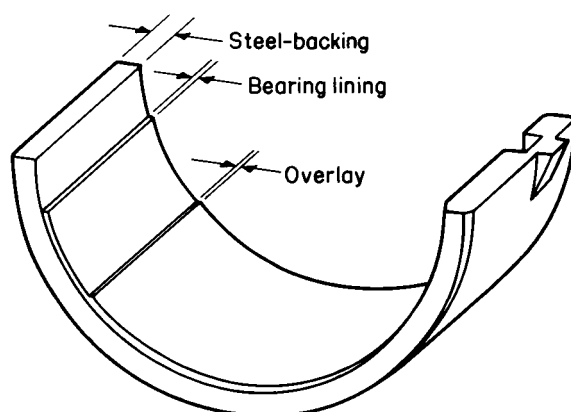
^{††} Lead–tin–calcium alloys are also possible but they have poor corrosion resistance and are rarely used.

2.2 Utilisation of Bearing Alloys

Bearing alloys are utilised either in their solid form or as a relatively thin layer metallurgically bonded to a steel or occasionally bronze structural backing. This structural backing may be a separate bearing component, for end assembly into a housing, or may be the housing itself, where the bearing alloy has been cast directly into the housing ("direct lined"). Separate bearing components may be classified as thick-wall or thin-wall depending on the rigidity provided by the structural backing.[†]

Traditionally, solid bearing inserts have been used extensively but they are usually only feasible in the stronger alloys. They may be machined from cast bar, rod or tube. Stock bushes are available in certain materials. The bearing surface may be pre-finished or machined in situ.

In the majority of applications, thick- or thin-wall bearing components are used. Thin-wall components (see Sketch 2.2) are manufactured from continuous strip material and are obtained pre-finished from the manufacturers. Thick-wall components may also be obtained pre-finished or may be fabricated by normal machine-shop methods and then surfaced with a bearing material. Some standard size thrust pads are available.



Typical layer thicknesses are:

Lining 0.25 mm
Overlay 0.025 mm

(See also Table 2.4)

Sketch 2.2 Construction of a typical multilayer half bearing with option layers

Direct-lining with bearing alloys such as whitemetals is usually only contemplated in ferrous housings although some copper alloy housings may also be lined. The bearing surface is then finished to size.

2.3 Availability of Bearing Alloys

The various forms in which bearing alloys are available for use, both finished or semi-finished bearing components and forms from which bearings can be manufactured, are summarised in Table 2.2 under the four broad headings of "Solid forms", "Thick-wall components", "Thin-wall components" and "Direct-lined". Particular alloys are generally not available in all of these forms as indicated in Table 2.3.

[†] Thick-wall components are sufficiently rigid for the geometrical truth of the bearing surface to be independent of irregularities in the housing. Thin-wall components, on the other hand, are relatively flexible and the geometrical truth of the bearing surface depends on the accuracy of the housing. Components with a wall thickness between thin-wall and thick-wall (medium-wall components) may sometimes be specified as a replacement for existing bearings or to perpetuate a tradition but they lack the economic advantages of thin-wall bearings while failing to provide enough rigidity for the geometric truth of the bearing surface to be independent of housing irregularities.

TABLE 2.2 FORMS IN WHICH BEARING ALLOYS ARE AVAILABLE FOR USE

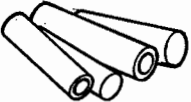
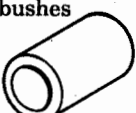
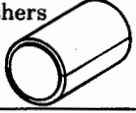
Available forms		Comments
Solid forms	Cast bars, rods and tubes 	Standard sizes from stock. Non-standard sizes to order.
	Machined bushes 	Standard sizes from stock. Non-standard sizes to order. Machine from bar, rod or tube. Machine from casting.
	Special castings 	To order. Cast from ingot
Thick-wall components (see also Table 2.4)	Half bearings 	Short lead-time manufacture to standard sizes/designs. Special designs to order. Fabricate.
	Thrust pads and washers 	Short lead-time manufacture to standard sizes/designs. Non-standard to order. Fabricate.
Thin-wall components (Bimetallic-strip forms.) (see also Table 2.4)	Wrapped bushes and thrust washers 	Standard sizes/designs from stock. Non-standard to order.
	Half bearings 	Short lead-time manufacture to standard sizes/designs. Special designs to order.
Direct-lined	—	Specialised services. Cast from ingot.

TABLE 2.3 AVAILABILITY OF BEARING ALLOYS

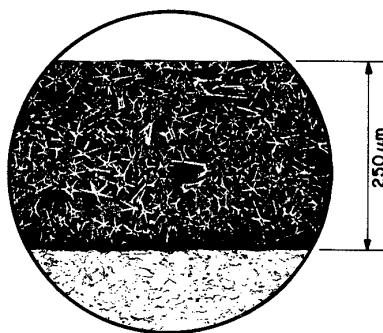
Alloy	Solid forms	Thick-wall components	Thin-wall components	Direct-lined
Tin-based whitemetals		•	•	•
Lead-based whitemetals		•	•	•
Aluminium-6% tin	•		•	
Aluminium-20% tin			•	
Aluminium-40% tin			•	
Copper-lead		•	•	
Leaded-bronze*	•	•	•	
Phosphor-bronze	•			
Gunmetals	•			

* Only leaded-bronze with less than 10% lead is available in solid forms such as bars, rods and tubes.

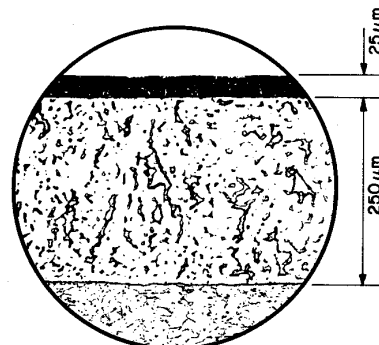
TABLE 2.4 BEARING ALLOY LAYERS

** In so called trimetal bearing systems a layer of relatively high fatigue strength alloy, typically 1 mm thick, is interposed between a steel backing and a whitmetal bearing layer.

Bearing alloy layers on both thick- and thin-wall bearing components are typically 250 μm thick.** An electroplated overlay of lead-tin or lead-indium, typically 25 μm thick, may be applied when adequate fatigue strength and satisfactory tribological properties cannot be provided simultaneously by a single alloy (see Section 3) or to provide corrosion protection (see Section 3.4). Overlays are rarely applied to solid bearing components. Direct-lined bearing alloy layers are somewhat thicker than on separate bearing components. With this type of bearing, overlaying is neither feasible nor necessary with the whitmetal alloys almost exclusively used.



Section of tin-based whitmetal on steel backing†



Section of copper-lead, with lead-tin overlay, on steel backing†

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