NONFERROUS METALS AND PLAIN BEARINGS[①]

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ABSTRACT

The definition of a plain bearing is given. The requirements for bearing materials are proposed. The historical perspective and recent development of the bearing materials are introduced, and the performances of current bearing materials are compared

Key words: nonferrous metals plain bearing performance recent development

1 INTRODUCTION

I have chosen this subject because, as I will explain later, I am not a metallurgist but I do know something about plain bearings. The variety of nonferrous metals such as Cu, Sn, Sb, Pb, As, Ni, Al, Zn, Ag, Bi, Cd, In, that have been and are being used in the manufacture of plain bearing is quite extensive. For example, in the 1950's, when I was a manufacturing engineer in the Glacier Metals Company, we alone purchased ten tons of tin per week, purely for the manufacture of plain bearings.

2 PROVENANCE

At this stage I would like briefly to outline to you the extent of my own experience in the field from which you will see that I am not a materials engineer. In my mid-twenties I went to work as a mechanical engineer, mainly involved in manufacturing, for the Glacier Metal Company. This company was, and still is one of the best known manufacturers of plain berings across the world. In one capacity or another I remained interested in that company for over thirty years, eventually becoming chairman of AE PLC, which owned Glacier amongst other companies, but whose principal engineering interest was the manufacture of highly stressed components for engines. In addition to bearings, they manufacture pistons, piston rings, camshafts, valves, turbine and compressor blades.

Being involved as an engineer in this type of business inevitably lead to great interest in materials, since one of the principal sources of product development lies in the field of manufacture and use of improved materials and processes. So, as you can see, it is as a user and producer of these products that my interest in materials originates.

3 PLAIN BEARINGS

For completeness, it is probably best for me to define what I mean by a plain bearing. A bearing is a device for transmitting forces between two parts which are mov-

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ing relative to one another with minimum power loss. This definition of course includes rolling contact bearing, but apart from this reference to them, I shall exclude them from the subject of this paper, since my interest has been almost wholly in the field of sliding contact bearings in which nonferrous materials play such an important part.

It is worth reflecting that dynamic seals are not too dissimilar from bearings in many aspects of their manufacture and design. A dynamic seal is a device allowing movement to take place between parts of a system with minimum pressure or fluid loss.

Bearings can of course be required in many applications. They can be rotational straight sliding and they can be straight sliding. There can be journal loads and there can be thrust loads. The movement can be continuous in one direction or reciprocating. Of course one of the biggest applications for plain bearings is in the crankshafts of reciprocating engines.

4 THE HISTORICAL PERSPECTIVE

The Egyptians used wooden rollers or lubricaled planks and the Romans a wooden taper roller bearing but no doubt friction and wear were high. In the early 1800's however special attention began to focus on the development of special materials for use in plain bearings. Bronze, a material which has been in use for five thousand years in one form or another, began to be specially developed in the 1800's, partly as a result of the development of gun metals, but the properties of bronze — particularly when it was fluxed with phosphorus — were valued for purposes in which a hard strong metal was required, such as pump plungers, valves and the bushes of bearings.

In 1839 Babbitt, Isaac developed and patented a suitable bearing material for steam engines. Babbitt's patent covered only the principle of using a soft conformable alloy supported by a stronger shell. The alloy mentioned in the patent contained 89 parts of tin, 9 of antimony, and 2 of copper. Babbitt's metal had a two-phase structure, consisting of hard particles in a soft matrix. At the time it was theorized that the hard particles formed a sort of "pavement" that supported the load, while the soft matrix was worn down to a level slightly below that of the hard pavement, thus providing a series of channels for the support of lubricant. The antimony strengthens the matrix by dissolving into the tin and by forming hard cubic particles of tin-antimony. Copper additions form hard needle-shaped particles of copper-tin (Cu_6Sn_5) which entrain the tin-antimony cuboids and ensure uniform distribution. However, many of these theories are now regarded with suspicion.

The term "Babbitt" is widely used to include three groups of bearing alloys: those with high tin, which are substantially lead-free, containing 90% or more tin; high lead alloys, containing 70% or more lead; and intermediate alloys, containing tin and lead in the matrix.

The evolution of engineering through and since the industrial revolution has required the study of the engineering science of bearing materials as the demand for higher loads, higher temperatures, greater corrosion resistance and lower friction have forced the pace of development.

5 PROPERTIES REQUIRED FOR PLAIN BEARING MATERIALS

In the majority of application the reduction of friction and wear between sliding sur faces is achieved primarily by the creation of a fluid lubricant film, most commonly of oil, between the surfaces. Thus, the use of a special bearing material as one or other of the surfaces only makes a contribution when this oil film is not present or is discontinuous. If indeed a satisfctory oil film were continuously present, then there would be no need for special bearing materials at the surface, and one would choose a material that was adequate for the strength of the force transmission required. In practice, however, few if any bearing operate under ideal conditions. When a machine starts from rest, no pressure will normally exist in the lubricant unless provided independently, so hydrodynamic conditions will not obtain. Moreover, a journal bearing may develop no hydrodynamic pressure when the direction of the load is rotating at half the speed of the shaft, a condition that can obtain for short periods in engine bearings. Lubricant films can, moreover, be interrupted by particles of dirt which are frequently embedded in one or other of the surfaces. For these and other reasons continuous hydrodynamic lubrication is the exception rather than the rule, even in bearing supplied with oil under pressure. In bearings lubricated by more hit and miss methods, departures from hydrodynamic lubrication are correspondingly greater. The result is that part of the load between the two components is carried by direct sliding contact between solid surfaces, modified by the presence of extremly thin films of lubricant, a regime generally referred to as "boundary" lubrication. If these films also break down dry friction between the solid surfaces results. Solid friction occurs when two surfaces are in real contact at high points over an area that increases as the normal load increases. Over the area of real contact elastic and usually plastic deformation occurs and the surfaces adhere to an extent that depends on the materials involved, and the presence of surface contaminants, such as oxides. Energy is absorbed in plastic deformation and in rupturing the bonds that form between the surfaces. Wear occurs with the particles being torn from one or other of the surfaces. These particles, which are frequently oxides, may themselves act as abrasives giving rise to further wear. Breakdown of the surfaces due to continued plastic deformation may also contribute to wear. Lubricants can and do degenerate with corrosive results and thus resistance to corrosion is another desirable feature.

Therefore, the requirements of a lubricated bearing are broadly a low rate of wear and an ability to carry the required load without seizure, significant distortion, mechanical breakdown or appreciable corrosion, and of course these properties interact.

So what are the properties required in a plain bearing material? Clearly, there must first be sufficient strength to carry the load, and not only the load in simple terms but in fatigue terms. The load may include vibration forces. Secondly, the material needs to have some degree of conformability to allow a certain amount of distortion to take place to allow for the misalignment between shaft and bearing or between the sliding surfaces. Clearly, if distortion/misalignment does exist, then the load will be transmitted over a smaller than intended area, and if conformation can take place then this area can be increased and the stresses reduced.

The next, and very important property is "seizure resistance" of the material. Seizure resistance can be described as that property of a bearing material which, when running against a specified surface, makes it less prone to form chemical bonds which cause local welding or fusion of the two surfaces. There are a number of subjective words used to describe these properties, such as lubricity. The melting point of the bearing alloy, or at least some of its phases, is an extremely important aspect of this property, as it is theorized that in certain instances of complete metal to metal contact, with the temperature rise that rapidly occurs, local melting of the bearing material may provide a type of lubrication which can see the bearing through its peroid of non-oil lubrication, which of course may be only a few microseconds. The next property required is the ability of the bearing material to absorb dirt. It is important that dirt particles, which are often extremely abrasive are not embedded in the bearing materials so as to remain projecting into the clearance, thus wearing the shaft. The bearing material ideally should be able to absorb particles of dirt so that they do not project above the bearing surface. Bearings must be able to conduct heat as all power losses result in heat generation, and particularly when partial discontinuities in the lubrication occur, the ability to conduct heat from the bearing surface is extremely important. Finally, the material should be resistant to corrosion and of course not excessively expensive.

A basic difficulty is that the running properties of a lubricated bearing depend on a number of factors beside the bearing material. The lubrication system, the chemical. and physical properties of the lubricant, the presence of abrasive particles, the loading characteristic, the clearance, the finish of the surfaces, all are of major importance. A material that is perfectly satisfactory under one set of conditions may be quite useless if the conditions are changed. Furthermore, there is no single criterion of good performance; in some cases the minimum rate of wear is the principal interest; in others it is the maximum load that can be carried without seizure or overheating. The time during which a bearing will function according to "good" bearing qualities helps to explain the diversity of conclusions that have been reached on the relative merits of different materials.

6 BEARING MATERIALS

Babbitt or white metals were the principal special bearing material for about a hundred years following Babbitt's patent. Various improvements took place with differing alloys and methods of construction and manufacture. The compositions of white metals are varied. Thin- based materials usually contain about 14% antimony and up to 10% copper, the most generally used alloys being in the range of 7%～10% antimony and 3% ～ 5% copper. The main constituents are β-phase(Sb Sn) and a γ-phase (Cu_6Sn_5) and, the metallurgists tell me, a ternary peritectic complex. Lead in these alloys is generally regarded as detrimental as it causes a sharp reduction of the solidus and in high duty alloys is limited to about 0.35%, although some researchers have claimed that lead improves the running properties. Cadmium increases hardness, tensile strength and fatigue strength, while nickel and tellurium have been added with the same objective. The tensile properties and hardness of tin-based alloys are affected only to a moderate extent by changes in composition over the normal range in which they are employed. Thus, the softest alloy in normal use which is 7% antimony, 3.5% copper, has a hardeness at 100 C of about Hv 11; whilst the hardest alloy normally used- 10% antimony, 10% copper has a hardness at 100 C of Hv16. The fatigue strength is somewhat affected by composition.

It has been claimed that the fatigue strength of low tin lead-base alloys becomes superior to tin-base alloys at higher temperatures. This would be expected from the higher solidus temperature of the lead-base alloys.

What has been found and generally agreed upon is that the finer the grain structure of the white metal the better its bearing properties. This requires a rapid solidification of the alloy and has been one of the reasons why the actual thickness of the bearing material has been reduced to a minimum, thus making more rapid solidification of the bearing alloy possible. This requirement, plus the fact that most of the white metals are quite expensive materials, has led to the development of techniques for the bonding of the bearing material to another material (usually steel but sometimes bronze). This route requires a satisfactory bond between the bearing material and the backing material and is vitally important, both for structural rigidity and for heat transfer. A numtages. The next major step forward was the development of copper lead alloys, and although there was no sharp dividing line between the leaded bronzes and the copper lead alloys, these latter generally imply between 20% and 50% lead, and not more than 5% tin, nickel or silver. These alloys have been used since the 1930's and have been used very extensively for aircraft and diesel engine bearings. They were then developed intensively during the Second World War for aircraft, fighting vehicles and ships, and of course as their own strength is normally insufficient to maintain fit and absorb the forces they are invariably used in a steel-backed form. At the present time, for engine bearings, an alloy containing 25% ~ 30% lead with little or no tin is most commonly used. But for higher loads, a stronger alloy with 20% ~ 25% lead and 2% ~ 4% tin is common. The achievement of a bond between the copper-lead and the steel backing — and at the same time achieving the proper metallurgical structure of the acting as a bearing material.

Later a process was developed, again very successfully, for creating the bi-metallic strip by producing the copper lead as powder and sintering this onto the steel strip in a continuous process. This sintering route took a long time to develop but has proved extremely successful and is most convenient in that it enables the composition of the various alloys to be varied whilst retaining the same basic sintering process.

Like all developments in bearing materials, improving the strength almost always brings with it a deterioration in one or other of the desirable properties. The extra hardness reduces conformability and embedability and it has been commonplace to provide a softer bearing material on the surface (only 12 micrometers thick) by electroplating the bearings after manufacture with a coating of lead-tin. This in itself yields problems as very often the tin migrates at elevated temperatures into the copper-lead alloy. To prevent this it has been commonplace to use a nickel barrier between the bearing metal and the overlay plate. Other manufacturers have used indium instead of tin, since this then e-

The choice of aluminum for such development work derived from its position as the next most readily available metal in the melting point scale afer tin, lead and zinc.

Three distinctly different lines of approach were followed, and all to some extent met with a degree of success, at least in certain fields.

The first approach, which was exploited in Germany, was an attempt to produce an alloy with a structure analogous to those of tin-base and lead-base white metals; in other words a hard phase and a relatively soft matrix. This approach was based on an hypothesis of bearing behaviour which is probably now considered to be fallacious, but nevertheless developed some serviceable alloys. Some of them contained 2%~15% copper and others small amounts of lead, antimony, copper, manganese and iron.

The second approach, which was pursued in both the United States and Great Britain, was to seek an alloy just strong enough to serve as a non-backed bearing, but containing a proportion of low melting point constituent to improve its bearing properties. The resistance of aluminum tin alloys to um and steel. When aluminium is cast onto steel the two react to form an aluminium iron compound layer. This layer very rapidly attains considerable thickness, rendering the bond very brittle. The formation of a thick, brittle compound layer can be avoided by adopting a solid phase welding method and several rolling processes have been developed into commercial operations. The process developed by the Glacier Metal Company, which was also the subject of work by the Tin Research Institute and Fulmer, involved scratch brushing the steel surface, applying a scratched brush aluminium foil by cold-rolling onto the prepared aluminium alloy strip, and then bonding the two by rolling, and finally, by heat treatment, consolidating the bond and annealing the aluminium alloy. With proper heat treatment the structure can be much improved to recrystallize the aluminium and to produce a reticular structure. The percentage of tin is 20% in aluminium with 1% copper. These bearings can run well without an overlay.

tively low melting point and hardness and their low cost and ready availability. They are used to some extent in lightly loaded bushes but their suitability for more arduous applications is doubtful.

Silver is another material which for a time aroused great interest but has largely died away. At one period the pure metal was widely used for aircraft engine bearings. but owing to its tendency to sudden seizure it became usual to plate it with lead and then to protect the lead from corrosion with a flash of indium. Silver-lead alloys with 3%～5% lead have been used. but the decline of the interest in silver has probably been due to the fact that other types of bearings such as overlay copper-lead. leaded bronze and aluminium alloys appear to serve at least equally well in practice and of course are very much cheaper.

In summary the most widely used materials for engine bearing at the present time are steel backed copper-lead alloys and steel-backed aluminium alloys.

7 RECENT DEVELOPMENTS

As has been stated, steel-backed aluminium bearings have been used in automotive applications for many years since the successful introduction by Glacier of AS15, that is the 20% tin and 1% copper in aluminium. It is able to operate without an electro-plated overlay, against forged steel and nodular cast iron counterfaces, and has excellent corrosion resistance in acidic engine oils. However, with increasing specific loads on bearings in smaller engines Glacier has identified the need for a competitively priced bearing material with a load carrying capacity without an electro-plated overlay. To meet this need Glacier has developed AS124 which is 12% tin, 4% silicon and 2% copper in aluminium, and this has been successful following a seven—years development and test programme.

Where overlays are required, techniques have been developed to replace elecroplating, using sputtering which enable alloys to be deposited in thin layers which are highly compatible with the base bearing material. Sputtering is done under vacuum and is essentially the ejection of atoms from the surface of a target resulting from atom and ion bombardment. In its simplest form a plasma is maintained in which argon ions are accelerated to a target by a negative potential. Suitably placed work-pieces or substrates will become covered with these atoms and receive a solid surface coating.

Interesting developments for the future may be significantly influenced by 3-D surface mapping, by which it is possible to relocate and follow the process of bedding and asperity polishing. In addition, the distribution of bearing area, with height of asperities to be quantified, and studies on the limiting minimum oil film thickness can be carried on. Work is continuing on the effect of a comomiation of materials with different hardness and material specifications, both of which control the development of optimum topography after bedding of the bearing materials. The controlled polishing action of AS124 is readily illustrated using the 3-D surface mapping technique.

I hope this very brief overview of the significance of nonferrous metals in the development of plain bearings will have been interesting, and it is clear that nonferrous metals play the dominant role as far as material velopment is concerned.