PROPERTIES OF THE BEARING ALLOYS USED FOR SLIDE BEARINGS OF CRANK MECHANISM

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Abstract

The paper deals with requirements set for materials most commonly used for slide bearings of IC engine crank mechanism. Particular prerequisites for selection of these materials from the point of variable conditions of bearing operation are presented as well. Finally, the paper contains a comparison of utility and operational properties of the applied bearing alloys.

1. Introduction

Any slide bearing is a machine subassembly consisting of three basic elements: journal, bush and lubricant. Since the latter divides the cooperating surfaces carrying the actual load, its proper selection (viscosity, lubricating ability) decides to the large extent about the bearing correct operation. Other two elements should demonstrate proper mechanical and thermal strength and good sliding properties. These properties could be neglected if the surfaces of journal and bush were smooth and rigid, and always separated with a layer of lubricant of appropriate viscosity, not containing any deposits or corrosives. Such case is strictly theoretical and practically impossible because of deflections of journal and bush resulting from acting loads, and because of lubricant deteriorating viscosity as a result of its oxidation and contamination with fuel and water.

Slide bearings, widespread in crank mechanisms carry the dynamical loads through the oil film layer as thin as 1 μm. This implies the need for mutual conformation of cooperating surfaces. As to achieve this one surface should be rigid enough to impose the position of working surface, while the other should be soft in order to conform. The rigid surface has to be at least five times more rigid than the soft one. This is why the journal surface is usually four to five fold harder than the bush, and it is always made of steel while the cooperating surface in made of bearing alloy. In a case of sudden loss of fluid film lubrication (e.g. engine start and stop) the conditions of bearing operation change radically which makes the selection of proper bearing alloy of extreme importance.

The most important requirements for engine crank mechanism bearing material are:

- high mechanical strength (especially fatigue one), corresponding to the load and temperature of running bearing,
- good sliding properties (at mixed lubrication, for example),
- high corrosion resistance (including cavitation erosion),
- scuff resistance,
- ability to absorb hard particles,
- appropriate flexibility and conformability,
- good heat conductibility and moderate thermal expansion.

Since the presented requirements are often opposite one to another, selection of suitable bearing material is always a compromise. Another problem are technological requirements as to metallurgy, machining or availability of bearing alloy components.

2. Low friction materials for bearing bush

Generally, following materials are used for engine crank mechanism bearings:

- white metals (high tin, low tin and cadmium alloys),
- copper matrix alloys,
- aluminum matrix alloys,
- zinc alloys,
- silver alloys (often pure silver with Pb, Sn or In overlay).

The world leading manufacturers [1], [8], [9] most frequently use bronzes (cast or sintered), aluminum alloys and white metals (tin or lead) for crank mechanism bearings of various type engines. Due to that, the further part of this paper will be devoted to these low friction materials.

To the bearing alloys of copper matrix one can assign copper and tin alloys (tin, tin - phosphorus or tin-lead bronzes), mixtures of copper and lead (lead bronzes with or without addition of tin, nickel, silver – preventing the lead segregation) and so called special bronzes, i. e. multicomponent no-tin alloys of Cu-Si-Fe type (silicon bronzes) and of Cu-Al-Fe type (aluminum bronzes).

Bearing alloys of aluminum matrix are first of all those made of aluminum and tin (with or without additives), aluminum and silicon, aluminum and zinc (with additives). White metals of tin matrix belong to the oldest bearing alloys. Those used to day merely differ from the original Babbit alloy and they contain on average 80÷93% of Sn, 3÷8% of Cu and 4÷14% of Sb. On the other hand, the white metals of lead matrix contain on average 2÷20% of Sn, 10÷16% of Sb, up to 3% of Cu, and Cd, Ni, or As as well.

3. Comparison of bearing material properties

Comparing low friction properties of materials used for slide bearings one should realize that to day main and crank bearings are made almost exclusively as multilayer ones. This is so, because the thinner layers of bearing material put on steel backing reveal far higher load capacity than thicker ones (fig.1) [3]. Advantageous slide and strength properties of shells made of hard material covered with thin layer of soft material result from the Bowden's theory [7].

The load capacity, which depends on hardness, should not deteriorate along with the temperature rise. For example, a drop in hardness of tin based white metal with the temperature rise from 20 to 150 ^{o}C amounts to about 70%, when for lead bronze it is only about 5% for the same temperature rise [3].

The load on both crankpin and main bearing varies in magnitude and direction with time. In case of such loads the bearing material should be characterized with appropriate fatigue strength (unfortunately, high fatigue strength comes along with low conformability).

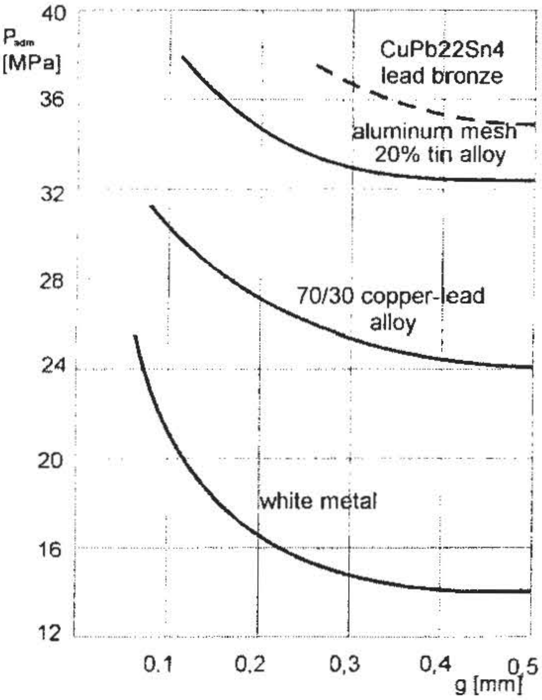

Fig. 1. Admissible specific load vs. bearing layer thickness

A number of new bearing materials that reveal better fatigue properties of the overlay have been introduced recently. As the example, certain aluminum alloys in which matrix has been enforced through a limitation in content of such components as silicon, manganese or copper with a concurrent reduction of tin to 10÷14% could be presented. This happens in case of bimetal bearings. Application of an additional overlay could also increase the fatigue strength. A comparison of fatigue strength of various bearing materials has been presented in Fig. 2.

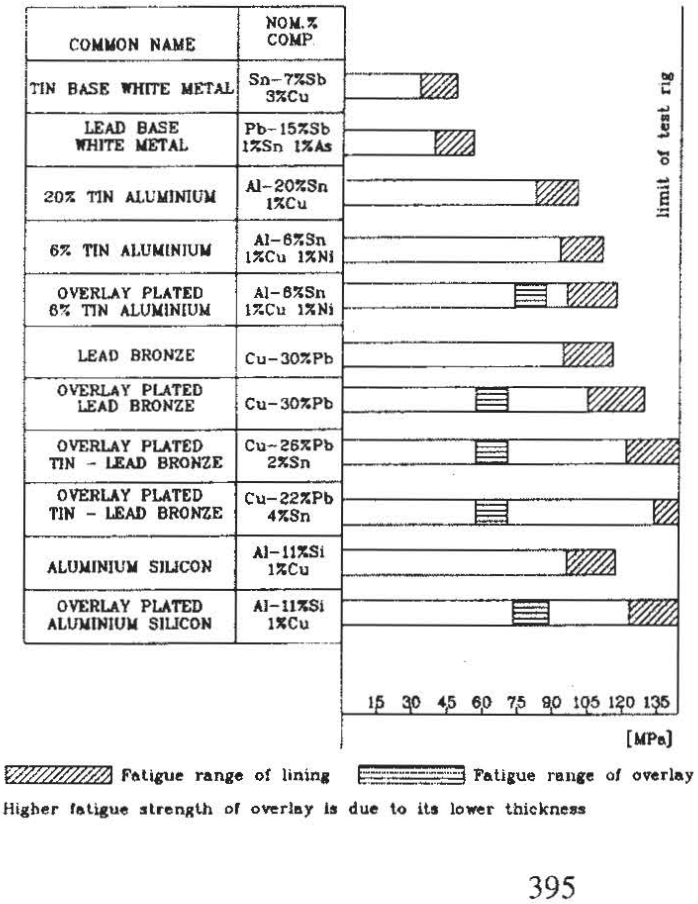

Fig. 2. A comparison of fatigue strength of various low friction bearing materials [3]

Bearing alloys of aluminum matrix most often are overplated on a steel backing. The Al-Sn bearing material with a content of tin up to 20% reveals the highest scuff resistance but the strain resistance, yield point and plasticity limit deteriorate when the tin content exceeds 10%. An increased strength has been achieved by the cold rolling and heat treatment (annealing). Thanks to that tin expands along the aluminum grain not on its surface.

In comparison to AlZn4SiPb other bearing materials, as for example AlZn4.5Mg which can be plated over a steel backing and moreover can be coated with an electroplated overlay, is characterized by far higher fatigue strength at elevated temperatures (up to 15%). This outcomes from the delicate grain achieved during recrystallization. A tendency to scuffing for bearings made of aluminum matrix material at different oil temperatures as well as sensitivity to dirt for the same materials have been presented in Figs. 3 and 4, respectively.

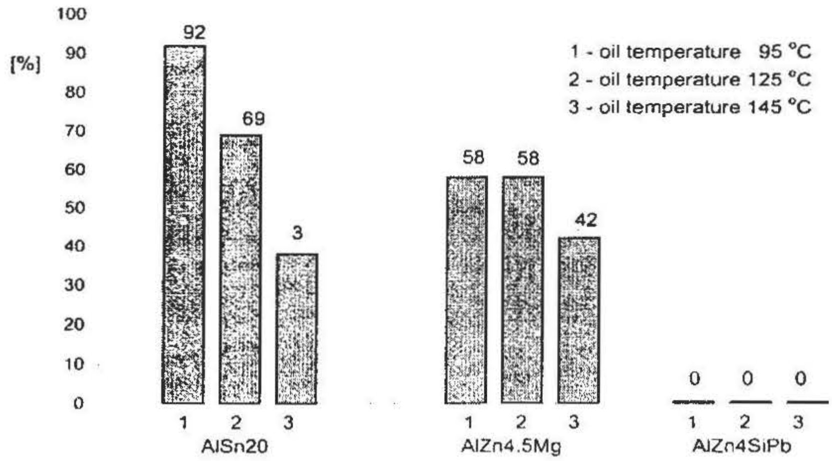

Fig. 3. Tendency to scuffing of AlZn4.5Mg and AlZn4SiPb aluminum alloys in comparison to AlSn20 [2]

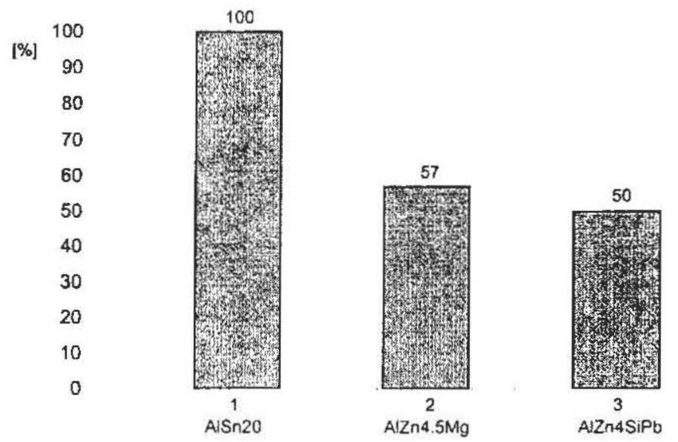

Fig. 4. Sensitivity to contamination of different bearing alloys: AlZn4.5, AlZn4SiPb and AlSn20 [2]

Another type of bearing material used for crank mechanism bearings of heavy duty automotive engines is the AlSi4CuMg alloy. It consists of aluminum matrix with intrusions of silicon, copper and magnesium. This material is characterized by excellent corrosion resistance and sometimes is covered with additional overlay of lead-tin-copper or lead-tin-aluminum alloy that improves the properties of the soft phase [9].

Most frequently bearing alloys of copper matrix are cast, sintered or rolled over the steel backing developing a sliding surface. Sometimes an extra overlay of 5 to 40 μm (e.g. PbSn18Cu2) in thickness is used, separated from the backing with a boundary layer of, for example nickel, in order to prevent the migration of overlay's components into sliding surface.

Another concept of composition of sliding surface has been proposed by the MIBA company of Austria. It is a so called Rillenlager (striped bearing) where a hard bearing alloy has been used (e.g. CuPb22Sn) as a rigid backing with grooves filled with a soft alloy (e.g. PbSn18Cu), that secures advantageous sliding properties in case of oil film rupture. The same company manufactures bearings with a sliding cover made of sputtered AlSn20 (see Fig. 5). These bearings are very expensive and are applied only when the highest load capacity is required [8]. The high cost results mainly from process of production, carried out under conditions of high vacuum.

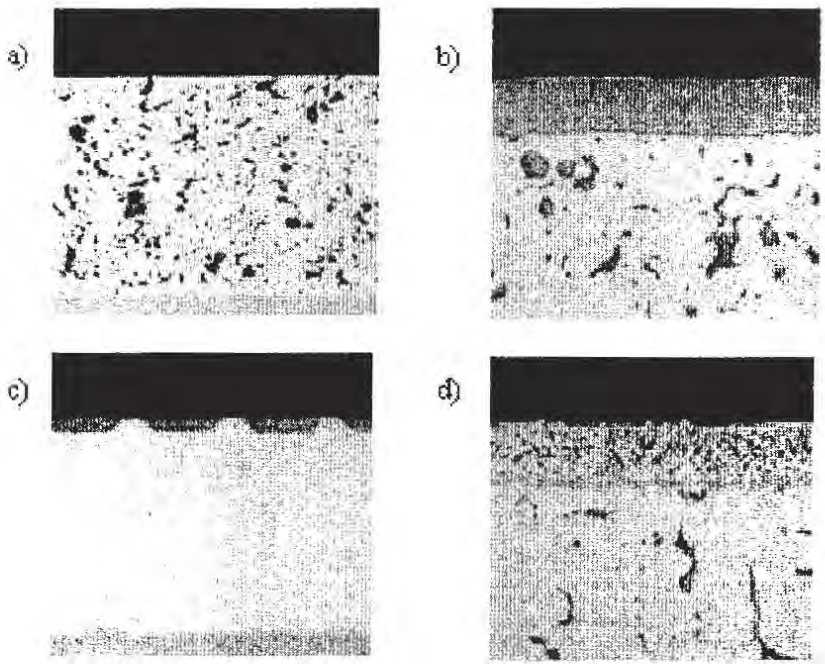

Fig. 5. Shell cross-sections: a) bimetal bearing: steel + lead bronze alloy (CuPb10Sn10), b) tri-metal bearing: steel + lead bronze (CuPb22Sn2)+ Ni + PbSn18Cu2, c) striped bearing (Rillenlager): steel + AlZn4SiPb + Ni + PbSn18Cu2, d) sputtered bearing: steel + CuPb20Sn4 + Ni + sputtered [8]

Tests on the wear of materials used for crank mechanism bearings are carried out on specialized test rigs and during operation of specific types of bearing in engines as well. Fig. 6 presents the results of wear tests of three types of bearings: tri-metal, striped and sputtered ones. These results are clearly different with respect to run time and volume of wear as well. The lowest wear and the longest life time are characteristic for the sputtered bearing. In this case the wear is merely 5 μm (which corresponds to the height of journal and shell asperities). The striped and tri-metal bearings revealed the wear up to 16 μm, but it was achieved in different period of operation. The run time of the striped bearing was triple that of the tri-metal bearing. The conclusion is that not only the kind of bearing material but also type and technology of the overlay are vital for the increase in durability and operational reliability of engine bearing assemblies.

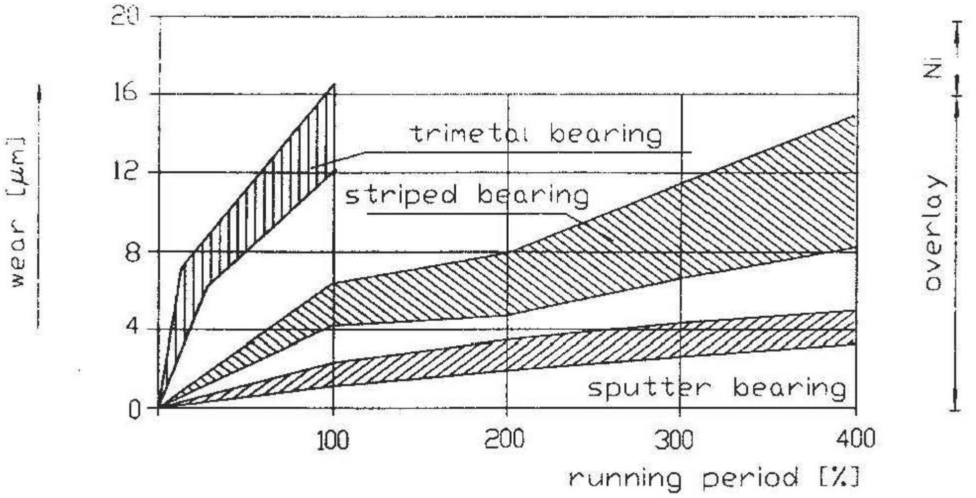

Fig. 6. The wear of highly loaded crank mechanism bearings in a research test [5]

4. Conclusions

Properties of the low friction material suitable for engine crank mechanism bearings should assure their longest possible life time. An increased wear of the bearing sliding surface is observed during engine start and stop as well as for the sudden rise in load or velocity. However, it is not enough to select a suitable bearing alloy in order to diminish the bearing wear but also considering appropriate design and technology of lining and overlay is of vital importance. Bearing producers are conducting continuous efforts on the application of new overlays (like lead, tin or ceramics) that should achieve a considerable increase in wear resistance not reducing the bearing load capacity.

Because of opposite requirements for bearing materials contemporary designs are made of inhomogeneous materials of extremely fine matrix that can meet the highest demands. A common feature of all materials produced is an appropriate bond with the steel backing. This has to ensure bearing required rigidity and a proper interference fit, that prevents relative movement of shell in direction of crank shaft rotation.

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