Recent Developments in Cast Non Ferrous Bearing Materials

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A bearing is interposed between two surfaces in relative motion to minimize the wear by one surface of the other and/or to reduce the friction between them. Hundreds of bearing materials have been developed in the recent time which offers promising individual properties to meet particular service requirements. There is no single best bearing material. Selection of a specific bearing alloy requires very careful consideration of the application and the material characteristic themselves. This paper explains recent developments in cast non ferrous bearing materials such as bronzes, brasses, heat treated copper alloys, aluminium base, and zinc base alloys, their characteristics and application areas. Comparison also has been made between different non ferrous bearing materials available, which will help the designer in the selection of the right alloy and also in determining the necessary wall thickness, diameter and length ratio of the bearings. This paper also explains selection procedure and considerations for a given application.

The problem of transporting heavy loads was significantly reduced by the invention of the wheel. The invention of the wheel was significant, but the bearing surface that supported the wheel must be regarded with equal importance. When any two surfaces move relative to each other, effectively a bearing is being used. A prime essential of bearing is to maintain a lubricant film to prevent metal to metal contact and hence local welding of the two surfaces. Based on the fundamental difference of motion, the bearings can be divided into two broad classes, rolling element bearings and sliding surface bearings. These are further divided according to different forms of surface geometry and different types of interactions. The classification is shown in Figure 1. The term bearing material is generally used to describe the special materials used in plain bearings, that is bearing in which a load is transmitted between relatively moving parts by sliding contact and without the use of balls or rollers. Many metallic, non metallic and compound materials are available to designers. Metallic materials are designed for higher loads and lower speeds and vice versa for non metallic materials. Many metallic materials are available nowadays with promising individual properties to meet particular service requirements. Casting, out of all fabricating processes, has always been one of the best methods for fabricating intricate shapes. Cast bearings share in this advantage of castings process, can be obtained with complicated and irregular outlines. This paper is concerned with cast non ferrous bearing materials such as copper base, aluminium base and zinc base alloys and does not cover ferrous materials which have their own peculiar property requirements. How and when the bearing was invented is not known, but it may be assumed that once invented, its use spread fairly rapidly. Eventhough the use of a tin alloy for
the bearing properties was described by Leonardo da Vinci in about 1500AD, but was patented only in 1839 by Isaac Babbit. From then gradual improvements undoubtedly were made all the time to these bearing systems. Copper base bearing materials have been used for heavy load support in machinery since the first steam engine. How and why bearings worked, and why the introduction of lubricants in them lowered the friction remained much of a mystery until the late 18th and into the 19th century. But the real breakthrough in experimental work, leading directly to the developments of hydrodynamic theory, should be credited to Beauchamp Tower. These experiments stimulated Osborne Reynolds to develop the “Physical Wedge Concept” for hydrodynamic lubrication in 1888. Around the beginning of the 20th century, Strubeck and Sommerfield in Germany advanced the hydrodynamic lubrication theory toward engineering application. From then on, a lot of bearing materials came into picture for using under various operating conditions. Interest in special aluminium alloys as bearing materials dates from about 1935, when expensive research was started in Great Britain, U.S.A and Germany. The introduction of Al-20%Sn alloy bearing has been one of the most significant developments in bearing technology since the Second World War. ZA (Zinc-Aluminium) family of alloys, namely ZA-8, ZA-12 and ZA-27 were developed as general foundry alloys during the 1960’s and 1970’s. ZA-8 and ZA-27 alloys were developed by Noranda Research Centre during the 1970’s while ZA-12 was developed by the New Jersey Zinc Co. Ltd. During the period of 1980’s lot of research has been done by these firms to improve the performance of these bearings materials.

Requirements of bearing materials

Under ideal conditions, a fluid lubricant film separates the journal from the bearing. This condition is called hydrodynamic lubrication. In this situation, the bearing material has only a secondary role to play i.e., one of carrying the load of the journal. Hence adequate compressive strength would be only consideration. In practice, however, this ideal condition rarely achieved. Starting and stopping, distortion of bearing, difficulty in achieving perfectly smooth surfaces on the journal and the bearing, rupture of oil film by surface roughness, lubrication starvation etc., lead to contact taking place between the journal and the bearing, resulting in wear and reduced bearing life. In fact, the behaviour of materials under nonideal conditions determines their performance.

Therefore, besides compressive strength, bearing materials need to

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possess other properties listed below in order to fulfill their functions effectively.

1. Strength at operating temperature and pressure
2. Resistance to corrosion by lubricant and atmosphere
3. Satisfactory sliding behaviour
4. Embeddability
5. Deformability
6. Cost, ease of fabrication and availability
7. Dimensional stability
8. Matching thermal expansion

Indeed, the above requirements are so varied from each other that the characteristics expected are somewhat contradictory to each other.

Cast nonferrous bearing materials

Insight of the versatility of the casting process, probably the great majority of cast bearings are made in simple shapes. Close tolerances and more complicated shapes are readily obtained but at an increase in cost.

The category of cast bearings includes many types of bearings ranging from cast babbitt bearing lining to iron castings which have bearing surfaces. However, the term usually refers to bearings cast in bronze, although in recent years aluminium base and zinc base alloys have received much attention. Bronze is popular material because of its high strength, good bearing properties and high heat conduction. The following are the materials of different non ferrous materials used as material for bearings.

1. Babbitts: Tin and lead based babbitts
2. Copper base alloys: Bronzes and copper lead alloys
3. Aluminium based alloys: Al-Sn alloys
4. Zinc based alloys: Zn-Al alloys
5. Cadmium alloys and silver alloys

Bronze, Al-Sn alloy, and Zn-Al alloy bearing materials were explained in detail because of their raising importance in recent decades. The softest metallic bearing materials are babbitts. Both tin and lead based babbitts have been widely used as bearing materials for years. They are much softer than bronze and are able to embed foreign particles, which helps prevent shaft scoring or wearing. Babbit bearings offer excellent resistance to shaft scoring and seizing in boundary lubrication conditions. Because they are so soft, these materials usually serve as linings, with stronger material for support. Copper lead is also soft, though it approaches some of the softer bronzes in hardness. Because of high cost, other materials such as cadmium and silver are in only limited use. Cadmium can serve in high temperatures where no other material is satisfactory. Suspected toxicity of cadmium in some uses should be considered. Silver has food resistance to seizing and scoring and is usually electroplated onto a steel backing. Almost any metal can be cast into the shape of a bearing.

Cast bronze bearing materials

Bronzes are unquestionably the most versatile class of bearing materials, offering a broad range of properties from a wide selection of alloys and compositions. The widespread use of cast bronzes is a good example of the empiricism of bearing practice, and are particularly suitable for high compressive loads combined with low or moderate speeds. It is not at all unusual to come across a bronze bearing that has been performing satisfactorily for decades, even under severe operating conditions. Technically, bronze is an alloy of copper and tin. However, bronzes used for bearing purpose generally have other metals, usually lead, added in order to improve going from high lead bronze to high tin bronze. At the same time, compatibility, conformability and embeddability properties decrease as the amount of lead decreases. Other alloying agents, such as Al, Fe, Mn, Zn, or Ni are often added in varying percentages. These materials are sometimes used in applications requiring high strength and fatigue resistance, but compatibility characteristics are not as good as the high lead bronze materials. The bearing bronzes are listed in Table 1 by their UNS alloy designation with chemical composition and mechanical properties. Table 2 gives the comparative bearing properties of different cast non ferrous bearing materials available.

1) Tin Bronzes: C90300, C90500, C90700

Tin’s principal function in these bronzes is to strengthen the alloys (Zn also adds strength, but more than about 4% Zn reduces the antifrictional
properties of the bearing alloy. The tin bronzes are strong and hard and have very high ductility. This combination of properties gives them a high load carrying capacity, good wear resistance and the ability to withstand pounding. The alloys are noted for their corrosion resistance in sea water and brines. The tin bronzes hardness inhibits them from conforming easily to rough or misaligned shafts. Similarly, they do not embed dirt particles well and therefore must be used with clean, reliable lubrication systems. They require a shaft hardness between 300-400 BHN. Tin bronzes operate better with grease lubrication than other bronzes; they are also well suited to boundary film operation because of their ability to form polar compounds with small traces of lubricant. Differences in mechanical properties among the tin bronzes are not great. Some contain Zn as a strengthener in partial replacement for more expensive tin.

2) Lead-Tin Bronzes: C92200, C92300, C92700

Some tin bronzes contain small amounts of lead, and its main function is to improve machinability. Also, the leaded bronzes also contain zinc, which strengthens the alloys at a lower cost than tin. Otherwise these have similar properties as the tin bronzes.

3) High Lead-Tin Bronzes: C93200, C93400, C93500, C93700

The family of high-lead tin bronzes include the workhorses of the bearing bronze alloys. These high-lead tin bronzes are used for general utility applications under medium loads and speeds, i.e., those conditions which constitute the bulk of bearing uses. Strengths and hardnesses are somewhat lower than those of the tin bronzes but these materials have excellent antifriction and machining properties. Alloy C93200 has a wider range of applicability, and is more often specified, than all other bearing materials. C93700 is known for its corrosion resistance to mildly acidic mine waters and mineral waters. Alloy C93800 and C94300 embed dirt particles very well and conform easily to irregular shaft surfaces and permit use with unhardened shafts. The lead addition to these alloys prevents welding and seizing and these alloys should not be specified for use under high loads or in applications where impacts can be anticipated.

4) Aluminium Bronzes: C95300, C95300HT, C95400, C95400HT, C95500, C95500HT, C95510

The aluminium bronzes are the strongest and most complex of the copper based bearing alloys. The aluminium content provides most of their high strength and makes them the only bearing bronzes capable of being heat treated. Their high strength, up to 120 ksi permits them to be used at unit loads up to 50% higher than leaded tin bronzes. They consequently require shafts hardened to 550-600 BHN. Careful attention should be given to lubricant cleanliness and reliability, the latter because these alloys do not have the anti-seizing properties typical of the leaded and tin bearing bronzes. These bronzes have excellent corrosion resistance. These are the only bronzes able to operate at temperatures exceeding 500 °F.

5) Manganese Bronzes (High Strength Brasses): C86300, C86400

These are modifications of the Muntz metal type alloys containing small additions of Mn, Fe and Al plus lead for lubricity, anti-seizing and embeddability. These bearings can operate at high speeds under heavy loads, but require high shaft hardnesses and nonabrasive operating conditions.

6) Copper Beryllium Alloys: C82400, C82600, C82800

Copper beryllium alloys can be heat treated to attain higher strengths than any other copper alloy. Copper beryllium alloys have good bearing properties. When fully hardened, they withstand extremely high stresses. Heat treatment can be adjusted to produce a range of mechanical properties. These alloys, however, quite expensive and their use is therefore reserved for applications in which their strength can be fully exploited. These bearings require reliable lubrication. Dirt embedding properties are poor.

7) Silicon Brasses: C87600, C87900

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therefore reserved for applications in which their strength can be fully exploited. These bearings require reliable lubrication. Dirt embedding properties are poor. Silicon imparts good castability to brasses, and also adds significantly to the alloys' strength. These alloys are not among the most common bearing alloys, but they do have good bearing characteristics at moderately high speeds.

**Zinc based bearing materials (ZA bearing materials)**

Zinc-Aluminium (ZA) alloys have emerged in recent years as a cost effective alternative to bronze alloys. In addition, ZA cast alloys possess a number of other shop floor advantages (such as lower melting and casting temperatures, lower energy requirement for melting, absence of fumes, excellent casting characteristics and superior machinability) over conventional copper base alloys. However, successful application of ZA alloys is restricted primarily to high load, low speed applications. This family alloys namely ZA-8, ZA-12 and ZA-27 were developed as general foundry alloys during eighties. Fig. 2 shows the maximum load speed curves for two Zn-Al alloys plotted against C93200 bronze. Though the graph clearly shows higher load capacity of the ZA alloys (which could also be interpreted as longer life under equal load), it should be pointed out that even though ZA alloys cost much less than bronze, they are more limited by temperature than bronze having maximum operating temperature below 300°F. Maximum bearing loads for the ZA alloys in clean or contaminated oils were found to lie between those for Al-10%Sn and bearing bronze. ZA alloys should therefore be limited to low speed, low temperature applications. Table 2 gives the composition and properties of the most important ZA alloys i.e. ZA-12 and ZA-27.

**Cast Aluminium Bearing Alloys**

Aluminium bearing alloys are relatively new. These alloys usually have excellent resistance to corrosion, good load carrying capacity and good fatigue resistance. These alloys are the result of an intensive research and development program carried out by Hunsicker and others. Aluminium-tin alloys are the main alloys in this category. Pure Al-Sn alloys do not possess the strength needed in highly stressed bearings. The addition of Si forms a hard constituent which increases strength markedly. Antiscuffing qualities are improved also, although ductility is reduced. Al-Sn-Si-Cu alloy is the most successful Al bearing alloy. Manufacturing costs are low because of good machining characteristics and high speed with which the material can be cut and finished. In this family, Al-10%Sn, Al-20%Sn, Al-30%Sn and Al-40%Sn are the most important alloys. 20%Sn alloys have high fatigue strength along with embeddability and conformability. Corrosion resistance is also good for this alloy. 30%Sn alloy, for service in especially dusty conditions, has been known for its greater embeddability and conformability than 20%Sn alloy. For 40%Sn, the compatibility and conformability is more than 30%Sn.
Selection procedure for bearing materials

The selection of a suitable bearing material for a given application is a rather difficult task because, unlike the theoretical calculations used for film thickness determinations, a large number of variables are involved. In practice, though, we seldom design a completely new bearing system. Often there is a similar design or an extension of a given design that we can glean some information from for the start of material selection. To know what has been used for a specific application is a very powerful way to start with a given material selection. Even if the application is not quite the same as what you are working on, it will most likely form a good starting point. The material must be strong enough to withstand the peak applied bearing stresses, and it must have sufficient temperature capacity.

Conclusion

Nowadays number of non-ferrous bearing materials are available for using for specific application. The choice can be made by comparing all the required properties for the particular application, design aspects of the bearing. There is no single best bearing material, every material promising individual properties to meet particular service requirements.

References