A STUDY ON THE HYDROUDYNAMIC BEARING MATERIALS & PROPERTIES

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ABSTRACT

The continuously growing demands on standard components of machine elements with respect to power density, efficiency and durability while operating can reach the borders of load bearing capacity and lead to premature failure. Especially in engineering applications with insufficiently predictable operating conditions, bearings can usually meet these requirements. Possible correctives are the use of new materials with modified properties or changes in the design. Bearing materials constitute an import part of any journal bearing. Bearings provide either a sliding or a rolling contact whenever relative motion exists between parts of a machine. Sliding contact bearings are referred to as plain bearings and rolling contact bearings are often called antifriction bearings. Journal bearings can be classified into two types: hydrodynamic bearings and hydrostatic bearings. Hydrodynamic bearings attained lift between the mating surfaces by wedging lubricant into the contact area with a relatively high rotational speed. Good bearing design involves three fundamental elements: understanding the service environment, designing for proper lubrication and selecting the best bearing material for the job.

Keywords: *Operating condition, Plain bearing, Environment, Lubrication, Bearing material.*

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1. INTRODUCTION

1.1 Sliding Contact Bearings:

Bearings are machine elements which are used to support a rotating member viz., a shaft. They transmit the load from a rotating member to a stationary member known as frame or housing. They permit relative motion of two members in one or two directions with minimum friction, and also prevent the motion in the direction of the applied load. The bearings are classified broadly into two categories based on the type of contact they have between the rotating and the stationary member

a. Sliding contact
b. Rolling contact

The sliding contact bearings having surface contact and are coming under lower kinematic pair.

1.2 Sliding Contact Bearings - Advantages And Disadvantages:

These bearings have certain advantages over the rolling contact bearings. They are:
1. The design of the bearing and housing is simple.
2. They occupy less radial space and are more compact.
3. They cost less.
4. The design of shaft is simple.
5. They operate more silently.
6. They have good shock load capacity.
7. They are ideally suited for medium and high speed operation.

The disadvantages are:
1. The frictional power loss is more.
2. They required good attention to lubrication.
3. They are normally designed to carry radial load or axial load only.

1.3 Sliding Contact Bearings – Classification:

Sliding contact bearings are classified in three ways.

1. Based on type of load carried
2. Based on type of lubrication
3. Based on lubrication mechanism.

1.3.1 Bearing classification based on type of load carried

a. Radial bearings
b. Thrust bearings or axial bearings
c. Radial – thrust bearings.

1.3.2. Bearing classification based on type of lubrication

The type of lubrication means the extent to which the contacting surfaces are separated in a shaft bearing combination. This classification includes:

a. Thick film lubrication.
b. Thin film lubrication.
c. Boundary lubrication.

1.3.3 Bearing classification based on lubrication mechanism

a. Hydrodynamic lubricated bearings
b. Hydrostatic lubricated bearings
c. Elastohydrodynamic lubricated bearings
d. Boundary lubricated bearings
e. Solid film lubricated bearings.

2. BEARING MATERIALS

Bearing materials constitute an import part of any journal bearing. Their significance is at the start of the hydro-dynamic lubrication when metal to metal contact occurs or during mixed and boundary lubrication period. Many millions of bearings operate successfully in the boundary and mixed-film modes for their entire service lives. The only penalty this entails is an increase in friction compared to hydrodynamically lubricated bearings and a consequently higher energy expenditure. Bearing life, however, will depend very heavily on the choice of bearing material. Even hydrodynamic bearings pass through boundary and mixed-film modes during start-up, and shut down, or when faced with transient upset conditions. This means that material selection is an important design consideration for all sleeve bearings, no matter what their operating mode.

2.1 Desirable Properties Of A Good Bearing Material:

1. Load capacity: The allowable compressive strength the material can withstand without any appreciable change in shape is the primary deciding factor in deciding a bearing material. Plain bearings are expected to have the following characteristics for the ease of functioning and satisfying the design criteria. Strength to take care of load-speed combinations
2. Fatigue strength: where bearing materials are subjected to stress cycle as in internal combustion engines. The retention of strength characteristics of softer bearing materials at temperature of operation which may rise within the design limit. The material must easily conform to shape of the journal and should be soft enough to allow the particulate contaminants to get embedded
3. Conformability: Conformability (low elastic modulus) and deformability (plastic flow) to relieve local high pressures caused by misalignment and shaft deflection. It helps to accommodate misalignment and increase the pressure bearing area (reduce the localized forces). Relatively softer bearing alloys are better in this respect.
4. Embeddability: Embeddability or indentation softness, to permit small foreign particles to become safely embedded in the material, thus protecting the journal against wear. It is the ability of a material to embed dirt and foreign particles to prevent scoring and wear (decrease 3rd. Body abrasion). Materials with high hardness values have poor embeddability characteristics.
5. Shear Strength: Low shear strength for easy smoothing of surface asperities.
6. Bondability: Many high capacity bearings are made by bonding one or more thin layers of a bearing material to a high strength steel shell. Thus, the strength of the bond i.e. bondability is an important consideration in selecting bearing material.

7. Strength: Adequate compressive strength and fatigue strength for supporting the load and for enduring the cyclic loading as with engine bearings under all operating conditions.
8. Coefficient of friction: Low coefficient of friction the material combinations of sliding surfaces, along with the lubricant should provide a low friction coefficient for reducing damage and lower running costs
9. Thermal conductivity: The bearing material should be of high thermal conductivity so as to permit the rapid removal of the heat generated by friction.
10. Thermal expansion: Bearing material should be of low coefficient of thermal expansion, so that when the bearing operates over a wide range of temperature, there is no undue change in the clearance.
11. Compatibility: The shaft and bearing materials in rubbing condition should not produce localized welds leading to scoring or seizure. A good bearing-shaft metal combination is necessary. It should be compatible with journal material to resist scoring, welding and seizing.
12. Corrosion resistance: The oxidized products of oils corrode many bearing alloys. Some protection can be provided by forming a thin layer of anti-corrosion materials on the bearing alloy surface should have good corrosion resistance against the lubricant and combustion products.
13. Wettability: An affinity for lubricants so that they adhere and spread to form a protective film over the bearing surface.
14. Relative hardness: The bearing material should usually be softer than that of the journal to prevent shaft wear but hard enough to resist adhesive and abrasive wear of its own surface. Bearings are more easy to replace than shafts (that require dismantling of the whole engine). If one bearing is worn out only that bearing needs replacement instead of the whole shaft.
15. Elasticity: should be elastic enough to allow the bearing to return to original shape upon relief of stresses that may cause temporary distortion, such as misalignment and overloading.
16. Availability: The material should be readily and sufficiently available, not only for initial installation but also to facilitate replacement in the event of bearing failure.
17. Cost: The economic consideration is the ultimate deciding factor in selecting a bearing material.

Table 2.1 Properties of metallic bearing material:

Bearing material	Fatigue strength	Conformability	Embeddability	Antiscoring	Corrosion resistance	Thermal cond.
Tin base babbit	Poor	Good	Excellent	Excellent	Excellent	Poor
Lead base babbit	Poor to fair	Good	Good	Good to excellent	Fair to good	Poor
Lead bronze	Fair	Poor	Poor	Poor	Good	Fair
Copper lead	Fair	Poor	Poor to fair	Poor to fair	Poor to fair	Fair to good
Aluminium	Good	Poor to fair	Poor	Good	Excellent	Fair
Silver	Good	Almost none	Poor	Poor	Excellent	Excellent
Silver lead deposited	Excellent	Excellent	poor	Fair to good	Excellent	Excellent

2.2 Materials Used For Sliding Contact Bearings:

The materials commonly used for sliding contact bearings are discussed below :

2.2.1 Babbit metal:

Babbitts are the most commonly used bearing materials. Babbitts have excellent conformability and embeddability, but have relatively low compressive and fatigue strength, particularly above 77°C. Babbitts can seldom be used above about 121°C. Other materials such as tin bronze, leaded bronze, copper lead alloy, aluminium bronze, aluminium alloys and cast iron are also used in many applications. Widely used bearing material compositions are given below:

a. Tin base babbits : Tin 90% ; Copper 4.5% ; Antimony 5% ; Lead 0.5%.
b. Lead base babbits : Lead 84% ; Tin 6% ; Antimony 9.5% ; Copper 0.5%.

c. Copper alloys such as Cu- 10% to 15% Pb.

The tin base and lead base babbits are widely used as a bearing material, because they satisfy most requirements for general applications. The babbits are recommended where the maximum bearing pressure (on projected area) is not over 7 to 14 N/mm2. When applied in Marine bearings automobiles, the babbit is generally used as a thin layer, 0.05 mm to 0.15 mm thick, bonded to an insert or steel shell.

In industry today, tin-based Babbitt alloys are physically far superior to lead-based Babbitt alloys. Tin-based Babbitt can withstand surface speeds of 1000 to 2400 ft/min and loads of 100-2000 lbs/sq. in., easily surpassing the lead-based Babbitt limits of 100-1000 ft/min and 100-500 lbs/sq. in. Tin-based Babbitt alloys are also structurally stronger as they exhibit greater tensile strength and elongation than lead-based Babbitt. These numbers are laid out in Tables 2.2 and 2.3 for two of Behr Iron & Metal most commonly requested products, Grade 2 and Grade 7 Babbitt. Additionally, although not clearly compared in the tables below, at 100 ºC (212 ºF), lead-based Alloy grade 7 shows a hardness of 10.5 HB while the hardness of tin-based Alloy grade 2 is 22 HB.

Table 2.2 Tin Babbitt Alloy Grade 2 (89 Sn – 7.5 Sb – 3.5 Cu):

Temperature		Tensile Strength		Elongation	Reduction
ºC	ºF	MPa	Ksi	% (a)	In Area, %
20	168	77	11.2	18	25
49	120	63	9.2	24	27
100	212	45	6.5	23	28
149	300	28	4.0	32	38

Table 2.3 Lead Babbitt Alloy 7 (75 Pb – 15 Sb – 10 Sn):

Temperature		Tensile Strength		Elongation	Hardness,
ºC	ºF	MPa	Ksi	% (a)	HB
25	77	72	10.5	4	22
100	212	38	5.5	25	10.5
150	302	21	3.0	52	8

Even with the significant advantage tin-based Babbitt holds over lead-based Babbitt, there is no lack of demand for lead-based Babbitt today. Not every application requires the full capabilities of tin-based Babbitt and, in those cases, lead-based Babbitt may suffice. Needing only 10% tin to obtain maximum strength at room temperature, lead based Babbitt is a much more economical choice when work is being done at a slower speed and/or with a less heavy load.

2.2.2 Copper:

Copper is one of the earliest metals discovered by man. The boilers on early steamboats were made from copper. The copper tubing used in water plumbing in Pyramids was found in serviceable condition after more than 5,000 years. Cu is a ductile metal. Pure Cu is soft and malleable, difficult to machine. Very high electrical conductivity second only to silver. Copper is refined to high purity for many electrical applications. Excellent thermal conductivity – Copper cookware most highly regarded–fast and uniform heating. Electrical and construction industries are the largest users of Cu.

2.2.3 Copper Alloys:

Brasses and Bronzes are most commonly used alloys of Cu. Brass is an alloy with Zn. Bronzes contain tin, aluminum, silicon or beryllium. Other copper alloy families include copper-nickels and nickel silvers. More than 400 copper-base alloys are recognized.

Table 2.4 Copper Alloys:

Family of Cu Alloys		
Alloy	Alloying Element	UNS Numbers
Brass	Zinc (ZN)	C1xxxx-C4xxxx, C66400-C69800
Phosphor bronze	Tin (Sn)	C5xxxx
Aluminium bronzes	Aluminium (Al)	C60600-C64200
Silicon bronzes	Silicon (Si)	C64700-C66100
Copper nickel, nickel silvers	Nickel (Ni)	C7xxxx

a) Brass:

Brass is the most common alloy of Cu – It's an alloy with Zn. Brass has higher ductility than copper or zinc. Easy to cast-relatively low melting point and high fluidity. Properties can be tailored by varying Zn content. Some of the common brasses are yellow, naval and cartridge. Brass is frequently used to make musical instruments (good ductility and acoustic properties). The proportions of the copper and zinc are varied to yield many different kinds of brass. Basic modern brass is 67% copper and 33% zinc. Lead commonly is added to brass at a concentration of around 2%. The lead addition improves the machinability of brass.

Brass Properties:

- Bright gold appearance.
- Higher malleability than bronze or zinc.
- Acoustic properties appropriate for use in musical instruments.
- Low friction.
- Soft - may be used where low chance of sparking is necessary.
- Relatively low melting point.
- Easy to cast.

Table 2.6 Alloys of Brass and application:

Alloy	**Composition**	**Use**
Admiralty brass	30% zinc and 1% tin.	Inhibit dezincification
Aich's alloy	60.66% copper, 36.58% zinc, 1.02% tin, and 1.74% iron.	Marine applications
Alpha brass	Less than 35% zinc.	Pressing, forging, or similar applications
Prince's metal or Prince Rupert's metal	Alpha brass containing 75% copper and 25% zinc.	Imitate gold.
Alpha-beta brass or duplex brass	35–45% zinc.	For hot working.
Aluminium brass	Contains aluminium.	Seawater service and in Euro coins (Nordic gold).
Arsenical brass	Contains an addition of arsenic and frequently aluminium.	Boiler fireboxes.

Beta brass	45–50% zinc content.	For casting.
Cartridge brass	30% zinc brass with good cold working properties.	Ammunition cases.
Common brass, or rivet brass	37% zinc brass.	Cold working.
Gilding metal	95% copper and 5% zinc.	Ammunition jackets
High brass	65% copper and 35% zinc, has a high tensile strength.	Springs, rivets, screws.
Red brass	Red brass usually contains 85% copper, 5% tin, 5% lead, and 5% zinc.	Gun Metal.
White brass	Brittle metal containing more than 50% zinc.	
Yellow brass	American term for 33% zinc brass	Bearings.

b) Bronze:

Copper alloys containing tin, lead, aluminum, silicon and nickel are classified as bronzes. Cu-Sn Bronze is one of the earliest alloy to be discovered as Cu ores invariably contain Sn. Stronger than brasses with good corrosion and tensile properties; can be cast, hot worked and cold worked. Wide range of applications: ancient Chinese cast artifacts, skateboard ball bearings, surgical and dental instruments. The bronzes (alloys of copper, tin and zinc) are generally used in the form of machined bushes pressed into the shell. The bush may be in one or two pieces. The bronzes commonly used for bearing material are gun metal and phosphor bronzes.

The gun metal (Copper 88% ; Tin 10% ; Zinc 2%) is used for high grade bearings subjected to high pressures (not more than 10 N/mm2 of projected area) and high speeds.

The phosphor bronze (Copper 80% ; Tin 10% ; Lead 9% ; Phosphorus 1%) is used for bearings subjected to very high pressures (not more than 14 N/mm2 of projected area) and speeds.

c) Beryllium copper:

Cu-Be alloys are heat treatable. Max solubility of Be in Cu is 2.7% at 866 C. Decreasing solubility at lower temp. Imparts precipitation hardening ability. Cast alloys - higher Be. Wrought alloys – lower Be and some Co. Cu-Be is ductile, weldable and machinable. Also resistant to non-oxidizing acids (HCl or H_2CO_3), abrasive wear and galling. Thermal conductivity is between steels and aluminum. Applications -Used in springs, load cells and other parts subjected to repeated loading. Low-current contacts for batteries and electrical connectors. Cast alloys are used in injection molds. Other applications include jet aircraft landing gear bearings and bushings and percussion instruments.

2.2.4 Cast iron:

The cast iron bearings are usually used with steel journals. Such type of bearings are fairly successful where lubrication is adequate and the pressure is limited to 3.5 N/mm2 and speed to 40 meters per minute.

2.2.5 Silver:

The silver and silver lead bearings are mostly used in aircraft engines where the fatigue strength is the most important consideration.

2.2.6 Non-metallic bearings:

The various non-metallic bearings are made of carbon-graphite, rubber, wood and plastics. The carbon-graphite bearings are self-lubricating, dimensionally stable over a wide range of operating conditions, chemically inert and can operate at higher temperatures than other bearings. Such type of bearings are used in food processing and other equipment where contamination by oil or grease must be prohibited. These bearings are also used in applications where the shaft speed is too low to maintain a hydrodynamic oil film. The soft rubber bearings are used with water or other low viscosity lubricants, particularly where sand or other large particles are present. In addition to the high degree of embeddability and conformability, the rubber bearings are excellent for absorbing shock loads and vibrations. The rubber bearings are used mainly on marine propeller shafts, hydraulic turbines and pumps. The wood bearings are used in many applications where low cost, cleanliness, inattention to lubrication and anti-seizing are important.

The commonly used plastic material for bearings is Nylon and Teflon. These materials have many characteristics desirable in bearing materials and both can be used dry i.e. as a zero film bearing. The Nylon is stronger, harder and more resistant to abrasive wear. It is used for applications in which these properties are important e.g. elevator bearings, cams in telephone dials etc. The Teflon is rapidly replacing Nylon as a wear surface or liner for journal and other sliding bearings because of the following properties:

1. It has lower coefficient of friction, about 0.04 (dry) as compared to 0.15 for Nylon.
2. It can be used at higher temperatures up to about 315°C as compared to 120°C for Nylon.
3. It is dimensionally stable because it does not absorb moisture, and
4. It is practically chemically inert.

3. CONCLUSION

1. Based on the above discussion, suitable brass alloy could be chosen with optimal tribological and mechanical properties for high demanding bearing applications. To select a high performance brass alloy for future applications, in addition to the determination of basic mechanical properties of brass, different tribotests, model tests and component tests, should be perform. At harder conditions, shock loads, it is important to provide materials with increased strength and wear resistance at consistent toughness level. In addition to this material property, improvement of the tribological behaviour is very important to reduce wear and friction.
2. The bearing material selected must suit both the service environment and the operating mode. The wide array of properties offered by the bearing bronzes simplifies material selection process and helps insure that the alloy chosen will provide optimum bearing performance.
3. A bearing material should be cost-effective and available on short notice. No single bearing material excels in all these properties and that is one of the reasons bearing design always involves a compromise.

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