Comparative Study of Bearing Materials and Failure of Plain Bearings

S. B. Chikalthankar[1], V. M. Nandedkar[2], P. V. Jawale[3]
[1,3] Department of Mechanical Engineering, Government Engineering College, Aurangabad, India.
[2] Department of Production Engineering, SGGS Institute of Engineering and Technology, Nanded,India

***Abstract*— The first part of this paper highlights the general requirements of bearing materials and bearing material properties. The different causes of failure of plain bearings along with remedies to avoid them are discussed. The research work related to failure of bearings is presented.**

Keywords*— Hydrodynamic Lubrication, Score Resistance, Deformability, Fatigue, Wear

I. INTRODUCTION

An actual bearing is much more than some bearing material wrapped around a shaft or held against a moving bearing. A bearing is a machine element that must be properly designed. Practical design considerations of bearings include deformation of the bearing shell, length to diameter ratio, misalignment, heat transfer and heat dissipation capacity, clearances, allowable pressures and various mechanical and thermal construction details. The bearing material is only one component of an overall integrated design. A bearing may still fail even when employing the best bearing material if the design of the unit is faulty [1].

II. THE PLAIN-BEARING ENVIRONMENT

To determine the choice of a bearing material it is useful to recognize four main types of bearing applications:

(i) Reciprocating engine bearings operating with hydrodynamic lubrication, a dynamic load being applied to the bearing surface through the oil film. The best-known examples are the big-end and main bearings of the automotive engine. This bearing application is of particular importance, not only because of the sheer volume of internal combustion engines now produced, but because the high oil-film pressures generated over the bearing surface have provided an important impetus in bearing materials development.

(ii) Rotating plant bearings operating with hydrodynamic lubrication, the load applied to the bearing surface through the oil film being steady. Examples are turbine journal bearings, rolling-mill bearings, marine stern tubes, tilting-pad thrust bearings.

(iii) Lubricated bearing applications operating under conditions that do not create full hydrodynamic lubrication. This category covers the common copper-based alloys, used-oil- or grease-lubricated in general engineering applications, as well as graphited bronze, wick-lubricated whitemetal, and the important classes of oil-impregnated porous bronze bearing and prelubricated plastic or plastic-lined bearings.

(iv) Non-lubricated bearing applications, i.e. bearings operating dry or in non-lubricating media. For such applications the most commonly used bearing materials are those based on the polymer polytetrafluoroethylene (or ptfe) [2].

III. GENERAL REQUIREMENTS OF BEARING MATERIALS

a) Score resistance
b) Mutual Solid Solubility
c) Compressive strength
d) Fatigue strength
e) Deformability
f) Corrosion resistance
g) Structure

Bearing materials are selected on the basis of applications and which properties are of prime importance in that application.

a) Score Resistance:- The anti-weld or anti-seizure characteristic of a bearing material is referred as score resistance. White metals are used where score resistance is of prime importance. Improved score resistance is obtained at the expense of loss of hardness or strength. Table I shows the relative order of common bearing metals with regard to score resistant tendencies.

TABLE I.

Bearing Materials	**Order of Score Resistance**	**Order of Inherent hardness or strength**	**Application**
Aluminium Alloys	3	1	For heavily loaded moderate speed bearings
Copper Leads	2	2	For heavily loaded high speed bearings
White Metal alloys	1	3	Low to moderately loaded, low to high speed bearings where dirt and deflection are present

b) *Mutual Solid Solubility:* Early work by Ernst and Merchant showed that the mutual solid solubility between metal pairs was a very significant parameter in predicting friction and wear. Table 2 lists scoring resistance of elements against stee

TABLE II.

Good	**Fair**	**Poor**	**Very Poor**
Germanium	Carbon	Magnesium	Beryllium
Silver	Copper	Aluminium	Silicon
Cadmium	Selenium	Copper	Calcium
Indium	Cadmium	Zinc	Titanium
Tin	Tellurium	Barium	Chromium
Antimony		Tungsten	Iron
Thallium			Cobalt
Lead			Nickel

c) *Compressive Strength:* - It is the ability of the material to carry imposed load without extrusion or disintegration.

d) *Fatigue Strength:* Engine bearings such as main and connecting rod bearings of crankshafts must carry high alternating loads. Automotive connecting rod bearings sometimes reach pressures of 27.6 MPa based on projected area. Actual peak pressure in the oil film may exceed the average pressures by a factor of 5 or 6 and hence magnitude of alternating stresses is severely high. Bronze has high fatigue strength but has low deformability. Table 3 shows fatigue strength and deformability of typical bearing materials

Sr. No.	**Bearing Material**	**Order of Fatigue Strength**	**Order of deformability**
1	Bronzes	1	7
2	Copper Lead with tin or silver	2	6
3	Thin-Babbit overlays	3	5
4	Aluminium alloys	4	4
5	Copper-Lead	5	3
6	Cadmium alloys	6	2
7	Lead and Tin based babbits	7	1

e) Deformability: The ability of a bearing material to yield to deformation while operating without causing failure is highly important. When loads are applied to the structure the bearings and journals deflect often leading to edge contact. Tin base babbitt is able to wipe out locally relieve any high spots or areas of metallic contact and then reform its contour to re-establish fluid film contact.

f) Corrosion resistance: The corrosive aspects of Bearing materials are important especially in engine bearings when high automobile sump temperatures caused an epidemic of oil oxidation and deterioration and the formation of acid. This acid proceed to attack vigorously and effectively on new bearing materials resulting in disastrous results [1]. Table III List the Corrosion Resistance of Bearing materials:

TABLE III.

Non-corrodible	**Intermediate**	**Corrodible**
Aluminium alloys	Bronzes (High Lead)	Cadmium Alloys
Tin-base Babbitt	Copper-Lead	
Lead base Babbitt	Alkali hardened lead	
Cadmium Indium alloys	Silver	
Bronzes (low lead)		

IV. MATERIALS FOR THE CRANKSHAFT BEARINGS OF THE HIGH SPEED INTERNAL COMBUSTION ENGINE

The selection of bearing material in High Speed Internal Combustion Engine depends upon:

h) The Engine Bearing Environment an oil film, thickness of the film, pressure generated in the film and temperature attained in the film.
ii) Maximum Oil Pressure of the order of 140-210 N/mm^2
iii) Minimum oil film thickness in the region of 5 μm
iv) Maximum oil film temperature 100-170^{o}C
v) Cavitation

A. *WhitemetaI Engine Bearing Alloys:*

Tin- and lead-based whitemetals, Le. Tin antimonycopper or lead-antimony-tin alloys, have excellent compatibility, and being soft (20-30 HV) have good conformability and ability to embed dirt. Their corrosionresistance is in general very good. Unfortunately, their resistance to fatigue is, by the standards of present-day engines, poor. In UK a tin-based alloy (89 Sn, 7·5 Sb, 3·5 Cu) is used for high speed engines. In USA lead-based whitemetal to SAE15 (83 Pb, 15 Sb, 1 Sn, 1 As) is still used fairly widely in automobile engines.

B. *Copper-Lead and Lead-Bronze Engine Bearing Alloys*

High-lead, copper-lead alloys, with lead contents in the range 25-50%, were introduced in the US in the 1930's, and are still used in that country under the broad classification of intermediate' bearing alloys [2].

V. ENGINE BEARING FAILURES

A. Bearing failures due to metal-to-metal contact

Mixed lubrication is one of the main causes of engine bearing failures. Metal-to-metal contact may appear in the following forms of bearing wear:

- **Accelerated wear**: is when the bearing is not overheated and only a shiny appearance of the bearing surface is observed.
- **Wiping or heavy wear:** this appears in the form of overheating and partial melting of the overlay (the left part of the Fig.1).
- **Severe wear or Hot Short:** it results in torn surfaces, severe overheating, melted overlay and lining material (right part of the Fig.1).

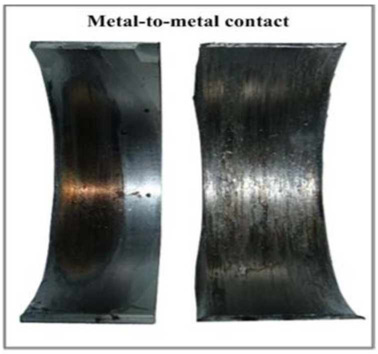

Fig 1: Metal To Metal Contact

Causes of mixed lubrication and the methods of solving the problem are presented in the table below:

TABLE IV.

Bearing failures due to metal-to-metal contact	
Cause	**Solution**
Insufficient oil supply (oil starvation)	Check oil supply system (e.g. clean clogged oil passages ,insufficient clearance, etc)
Breaking the oil film (due to oil contamination or bearing material fatigue)	Change bearing material (tri-metal instead of bi-metal) or solve overloading problem
Misalignment (e.g. out-of-shape grinding, distorted connecting rod)	Correct deficient machining, fix/replace distorted parts
Poor journal surface finish	Verify proper grinding/polishing procedures
Foreign particles embedded in the bearing surface	Determine origin of particles, improve cleaning procedures prior to assembly. Clean parts with hot soapy water. Do not clean with solvents
Low viscosity oil (diluted with fuel or coolant)	Identify/address source of oil dilution, use higher viscosity oil
Grinding chatter marks (waviness) and lobing	

B. Engine bearing failures due to fatigue

Bearing material fatigue is the second cause of bearing failure. **Fatigue of an aluminum lining**. The fatigue cracks form on the surface and propagate inside the lining reaching the steel back. The cracks then progress along the bond line between the lining and the steel. Pieces of the lining flake out from the steel back resulting in oil contamination and eventual bearing failure. Fatigue of aluminum alloys may also cause extrusion of the lining material past the length of the bearing edges.

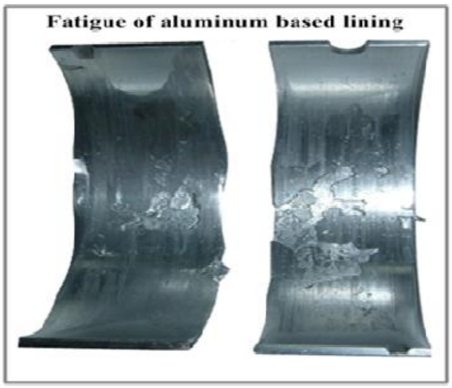

Fig 2: Fatigue of aluminium lining of bi-metal bearings

Fatigue of a tri-metal overlay. Spider web-like cracks are seen on the surface (Fig.4). Fatigue limit of an overlay is determined by the strength of the material and the thickness of the overlay. The thinner the overlay, the higher its fatigue strength. Overlay fatigue itself does not cause the bearing to fail. However, running the bearing with fatigued overlay may cause partial flaking of the overlay, lowering the oil film thickness and eventual seizure of the exposed intermediate layer.

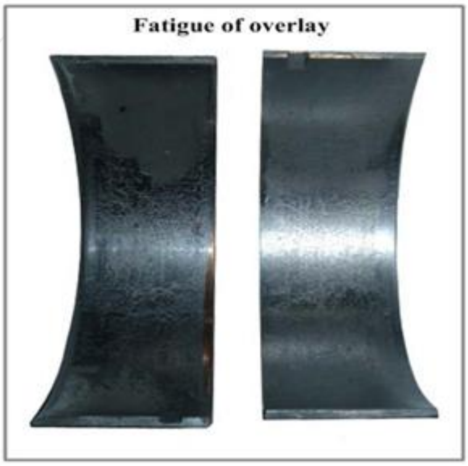

Fig 3: Fatigue of Trimetal Bearings

Fatigue of a copper based intermediate layer. Fatigue of a copper based lining (Fig.4) starts from a fatigue of the overlay. The overlay flakes out from the copper lining resulting in an interruption of the oil film, breaking the hydrodynamic lubrication regime. The load localizes at the contact area causing formation of small cracks on the lining surface. The cracks then propagate throughout the lining thickness, meeting the steel back surface and continuing to advance along the steel-copper boundary. As a result, parts of the intermediate layer detach from the steel surface.

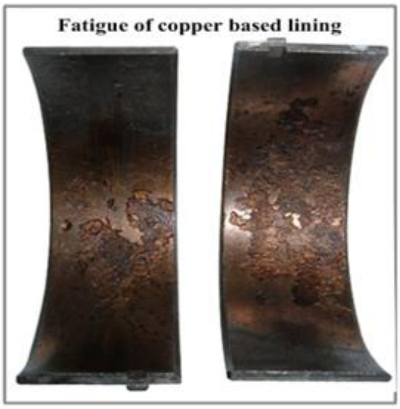

Fig 4: Fatigue of the copper based intermediate layer of tri-metal Bearings

The table below shows factors that cause fatigue and methods of preventing bearing failures due to fatigue.

Engine bearing failures due to fatigue	
Cause	**Solution**
Wrong selection of engine bearing material	Change to a bearing material with higher load capacity (e.g.tri-metal instead of bi-metal)
Fuel detonation / advanced ignition	Retard ignition or use a fuel with higher octane number
Running engine at high torque and low RPM for a long time (climbing)	Change to bearing material with higher load capacity (e.g. tri-metal instead of bi-metal)
Poor conforming of the bearing back with the housing surface	1. Check the bearing crush height 2. Properly re-size the housing
Oil starvation causing localization of load at particular bearing areas	Check oil supply system for clogged oil passages, check clearances, component geometry, oil pressure + volume
Geometry misalignments causing localization of bearing loading	Fix/replace distorted parts or use more conformable material (bi-metal instead of tri-metal)
Corrosive action of contaminated oil enhancing Fatigue	Eliminate/diminish oil dilution or use oil with corrosion inhibiting additives

C. Geometric irregularities

Fig. 5 and 6 show examples of the effect of geometric irregularities. Both problems are seen in the picture: local wear with shiny appearance and the overlay fatigue in form of spider web like cracks on the areas of metal-to-metal contact.

Distorted (bent or twisted connecting rod) is one of the causes of localized loading of engine bearings (Fig.5). Overloading of an internal combustion engine due to detonation or running under high torque at low rotation speed may cause distortion of the connecting rods. The distortion results in non-parallel orientation of the bearing and journal surfaces. The non-parallelism causes localized excessive wear of the bearing surface due to metal-to-metal contact (boundary or mixed lubrication) occurring near the bearing edge. Localized metal-to-metal contact may also cause fatigue cracking of the bearing material in the locations of the contact.

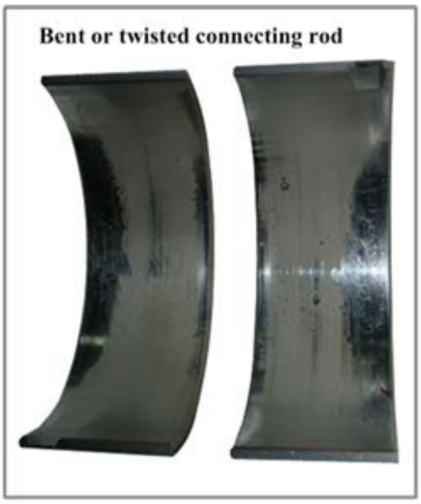

Fig 5: Bent or twisted connecting rod

Imperfect journal geometry is another cause of localized loading of engine bearings (Fig. 6). Use of a worn stone in grinding a crankshaft results in obtaining an imperfect (out-of-shape) journal surface: taper shape, hour glass shape or barrel shape. The parts of the journal surface having higher diameter (central part of the barrel shape journal, edge parts of hour glass shape journal) come to metal-to metal contact (boundary lubrication) with the bearing surface. The metal-to-metal contact causes excessive wear. Fatigue cracking of the bearing materials may occur in the contact areas.

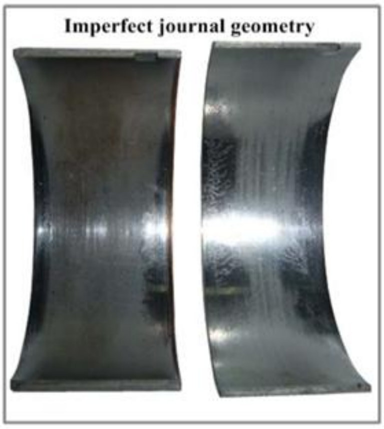

Fig 6: Imperfect journal geometry

D. Cavitation erosion of the overlay

Cavitation erosion is another type of engine bearing failure differing from both fatigue and metal-to-metal contact. Cavitation is a phenomenon related to hydrodynamics. Cavitation occurs when the load applied to the bearing fluctuates at high frequency (high RPM). The oil pressure instantly falls causing formation of bubbles (cavities) due to fast evaporation. When the pressure rises the cavitation bubbles collapse at high velocity. Such collapse results in impact pressure, which can erode the bearing material (Fig.7). Soft lead based overlays of tri-metal bearings are prone to the cavitation erosion. Therefore replacement of tri-metal bearings with babbitt overlay with bi-metal material or with high strength tri-metal bearings (e.g. GP) will prevent the failures due to cavitation [3].

Fig.7 Cavitation erosion of soft lead based overlay

VI. CONCLUSION:

The failure of bearing materials not only depends on the bearing materials, their proper selection it is greatly affected by the working conditions of the bearings. The common causes of engine bearing failure and their remedies are discussed in this study. A judicious attempt has to be made while selecting the bearing materials and compromising between the properties of the bearings while selecting the material for a particular bearing application.

REFERENCES

1. Dudely D. Fuller ‘Theory and Practice of Lubrication for Engineers’, 2nd Edition April 1984 p. 619-628
2. G.C. Pratt. Materials for Plain Bearings, International Metallurgical Reviews 1973, Vol 18
3. Dr. Dmitri Kolpelivioch ‘Engine Bearings Failures and How to avoid them’, King Engine Bearings Inc.
4. King Engine Bearings Inc. ‘Engine Bearing Materials’
5. Dr. Dmitri Kolpelivioch ‘Engine Bearings and How they work’, King Engine Bearings Inc.