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MECHANISM OF THE FATIGUE CRACKS DEVELOPMENT IN BEARING SLIDE LAYER

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Abstract

In the paper some problems concerning relations between slide bearings fatigue resistance and the bearing material and structure characteristics of the slide layer have been considered on the basis of bibliographic descriptions. In particular the mechanisms of the nucleation and development of cracks were discussed as dependent not only on the bearing dynamic loading pattern and number of loading cycles but also on the slide layer geometry and its structure design. Two basic types of the possible fatigue cracks were distinguished: structural and "magistral" ones. The process of the fatigue rapture formation and development were analyzed from the viewpoint of fracture mechanics according to the Nemec's model.

In particular types of fatigue cracks, structural cracks (cross-section of the bearing surface layer) and mechanism of fatigue crack development from the viewpoint of fracture mechanics, as well as fracture of magistral type (on the surface of the bearing) almost perpendicular to the circular direction of the bush, fatigue durability for various types of fracture developments, Fractures on the boundary of Si particle in AlSn12 Si4 alloy and Sn particle in AlSn20 alloy, fractures on the boundary of the intermetallic compound grain CuAl2 in AlSn20 alloy are presented in the paper.

Keywords: *bearings, bearing slide layer, fatigue cracks, fracture mechanics, lubrication, fractography*

1. Introduction

Fatigue failures of the bearing slide layer are occurring as the development of cracks and spalling in the bearing material, observed as a result of bearing variable loading, providing that the stresses exceeds the values that are critical for the slide layer material at the operating temperature.

The failure can occur on the whole sliding surface or only locally. The mechanisms of these phenomena are very complex and not fully explained yet despite the fact that the recent development of the theoretical and experimental investigations in mechanics of materials, hydro and elastohydrodynamics theory of lubrication, fractography and computer technique brought a substantial improvement in understanding of these processes.

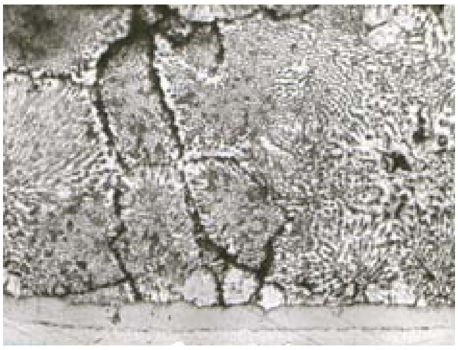
2. Types of fatigue cracks

In case of the slide bearings two basic types of fatigue cracks can be distinguished: *structural* and *magistral* (or arterial)[1] one.

For the structural cracks (Fig. 1) the generation of the microscopic fracture is associated with forming the connections of the weak joining of the layer structure (eg. soft big cells of the bearing layer, voids and heterogeneity in bearing material). The net of the structural cracks is rather randomly distributed (as to the density and directions).

The magistral type of fatigue cracks can be observed as development of single thin sections that are usually starting at the surface (Fig. 2) and propagate perpendicularly to the slide surface (Fig. 3). Nucleation of these cracks is taking place at the area of slide surface defects, concentration of the

[1] In this paper the name of *magistral* crack is used.

a) 

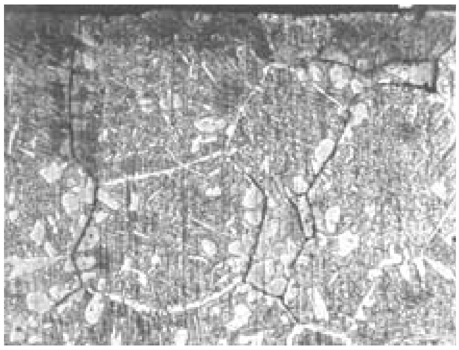
b) 

Fig. 1. Structural cracks (cross-section of the bearing surface layer): a) in bearing alloy of CdZn X4 (magnified 200x), b) in bearing of CuZnX20 brass (magnified 300x)

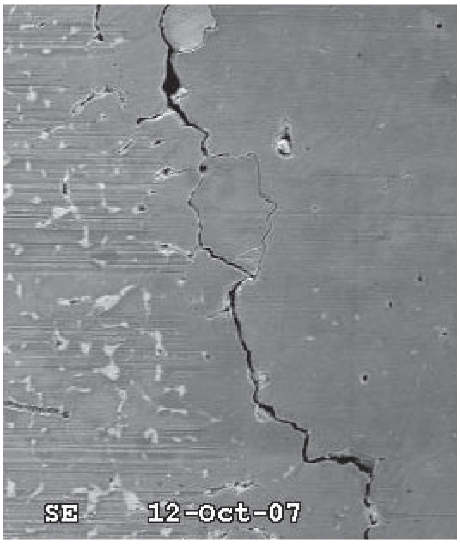


Fig. 2. Fracture of magistral type (on the surface of the bearing) almost perpendicular to the circular direction of the bush for the lining made of CuPb22Sn4 alloy (magnified 100x)

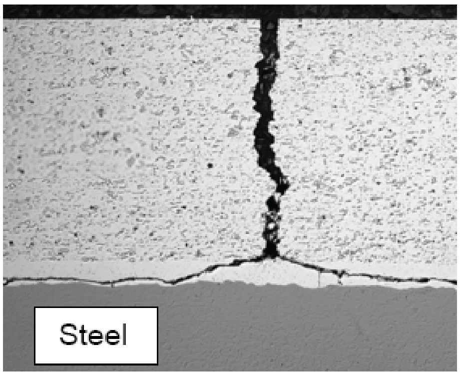


Fig. 3. Fracture of magistral type (in cross-section of the bearing surface layer) for the lining made of AlSn20 alloy (magnified 100x)

soft material components or microvoids at the connection with bearing material, where the cracks are finally developing in parallel to the slide surface (Fig. 4) after reaching the interface between lining and backing of the bearing shell. Connecting two or more such sections is leading to spalling off the quite big particles from the wearing material.

Researches are trying to explain the reason for differentiation of these two patterns for cracks type. They have come to the conclusion that it is due to the resultant stresses values and their distribution in the slide layer.

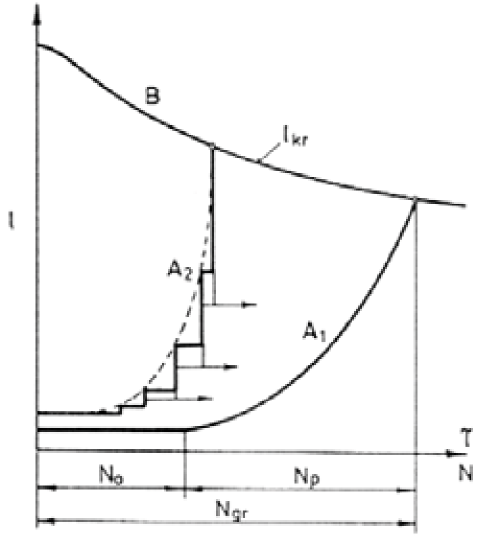


Fig. 4. Fatigue durability for various types of fracture developments [1]

In general the slide layer is subject to the action of the stresses that are dependent on the initial assembly loading stresses, heat stresses and the hydrodynamic dynamic pressure. All of these components have been of compression nature so it could be justified if the cracks are visible at the 45 angle degree to the slide surface as effect of compression stresses action. Since in practice cracks are rather (especially in case of magistral cracks) generated perpendicularly to the slide surface (Fig. 2) one can expect existence of the tensional stresses in this region.

It should be noticed that because of the complexity of the bearing material structure (depended on the complexity of the production process and the working condition of the bearing assembly), the fatigue process is always stochastic, not determinate and one should always expect only some approximation of the specific values of tested parameters.

3. Mechanism of fatigue crack development from the viewpoint of fracture mechanics

In the Fig. 4 the relative fatigue damage versus the time of the bearing operation is presented. Fatigue process in material, in classical model, is always related to the number of loading cycles while in case of Nemec's bearing model [1], elaborated in 70-ties of XX century, one should consider not only effects of variable mechanical loading but also the effects of creep, ageing, wear, corrosion and microcavitation of the bearing alloy. In this fatigue development model the relative measure of failure D is the ratio of crack length "l" to the critical length of crack "l_{cr}" ($D = l/l_{cr}$). Critical length (l_{cr}) of the cracks is understood as a value, which is sufficient to start spontaneous increase in the fracture length. In case if the critical crack length, calculated from the formulae of the mechanics of fracture, is bigger than the bearing layer thickness then this layer thickness is treated as the critical length "l_{cr}". It is also the case for multilayer bearing design. Curve "A" in the Fig. 3 is demonstrating the cracks development and its transition from micro to macro-crack fracture.

Intensity of this process depends on the range and character of the deformation in the region of the crack head as well as the energy absorption factor. Velocity of fatigue crack propagation dl/dN (where N means number of loading cycles) is dictated by velocity of elastic energy release in the region of growing crack. According to the explanations of some authors [1] the number of the bearing cycles is not exactly the same as the number of the shaft revolution but is rather equal to the number of the deformation cycles. This number is always higher by one order from number of shaft revolutions.

In addition the local deformations of the slide layer are taking place very quickly which is making the process adiabatic one. Local increase in temperature might be as high as dozen of centigrades.

During nucleation process small quasi-brittle fractures are generated as a result of slide layer deformation. These initial defects, at the boundary of the structural bearing layer, are developing and changing into fatigue cracks in the micro-volumes. These defects are developing very slowly and cyclic plastic deformations leads to the work hardening in the region bigger than the initial defects. During this stage the rearrangement of the stress and the fatigue type of the stresses are created.

Elements of these processes are strongly differentiated and difficult to predict since they depend on the initial structure of the bearing material. During the next stage of development the fractures are becoming of bigger density in the micro-volumes and are visible either as perpendicular to the slide layer surface or as typical pitting wear structure.

Developing of these cracks is often associated with corrosion and micro-cavitation in lubricating oil environment. “A_1” curve (Fig.4) presents uniform process of magistral type of fracture that is of plastic deformation type and blunted tip. Interaction with other sort of defects and influence of the initial structure are less important.

The resistance against the fracture propagation is dependent only on substructure and the size of plastic region. The amount of energy needed to create the free unit surface fracture is relatively big.

“A_2” curve is illustrated numerous stopping and bifurcating of the fatigue cracks and showing the joining the fractures of the second order with the main ones. These are the kind of breaking up, disintegration type of crack where structural development is taking place at the rather low portion of energy delivered. In order to equalize the elastic strain energy release the total increase in the surface fracture is taking place by bifurcation.

Random type of stopping and bifurcation of fatigue fracture can be observed at this stage of the process. Even the metal cracks are of plastic nature they have the tendency to transform into brittle breakage. Behaviour of the crack development is depended on the initial structure of the slide layer and interaction of the cracks with neighbour micro-defects.

The two types of fractures ductile and brittle can develop in the same material, which has been observed in many experiments (for example by Oliva [2], Sikora [3]), and may be explained by summary effects of loading proceeding and structure of material.

The curve “B” is defining the ductility of the material during bearing operation in its total volume. It means the increase of brittleness of the bearing material and lowering its strength against fracture, what is reducing the length of the vertical fracture. Point of “A” and “B” line intersection is showing the value of the fatigue resistance of the slide layer. The whole fatigue process can be divided into two phases: nucleation and propagation of the cracks that are determined by the numbers of cycles N_0 and N_p. In case of thin multilayer bearing structure the first stage of operation is usually much longer than the second one.

It has been proved that the velocity of fatigue crack propagation is strongly depended on the design of a multi-layers in the slide bearings. In particular it has been investigated that the fracture, which is approaching the interface layer from harder material side (in normal direction), is passing this separating thin layer without change of crack direction. On the other hand the crack, which is approaching the interface from softer material, is lowering its speed.

Some of bearing alloys investigations were dealing with the effects of micro component characteristic properties on the fatigue crack developments. In particular AlSn20 and AlSn12Si4 were investigated [4, 5]. It has been proved that nucleation’s of crack were started because of decohesion at the boundary region of the inclusions such as silicon Si particles (Fig.5b) or grains of the intermetallic compounds (Fig. 6).

The reason for breakage demonstrated in Fig. 5 might be the differences in variable deformation of the alloy components.

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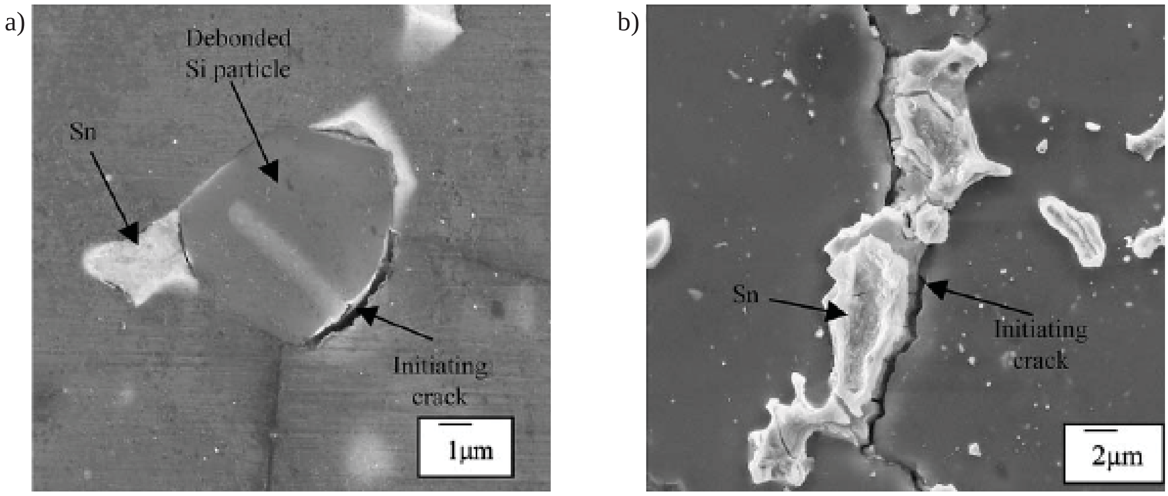

Fig. 5. Fractures on the boundary of Si particle in AlSn12 Si4 alloy (a) and Sn particle in AlSn20 alloy (b)[4]

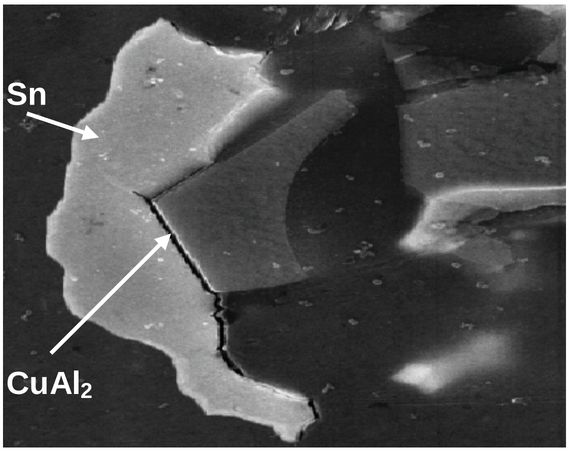

Fig. 6. Fractures on the boundary of the intermetallic compound grain $CuAl_2$ in AlSn20 alloy [4]

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