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Wear evaluation of journal bearings using an adapted micro-scale abrasion tester

Leonardo Israel Farfán-Cabrera, Ezequiel Alberto Gallardo-Hernández *

Instituto Politécnico Nacional, SEPI-ESIME, UZ, IPN, Grupo de Tribología, Col. Lindavista, Ciudad de México, C.P. 07738, Mexico

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ABSTRACT

To determine the wear resistance of journal bearings (JB′s) under lubricated condition, this paper aims to provide an alternative method using an adapted TE-66 micro-scale abrasion tester which was adapted to generate accelerated lubricated wear on actual JB′s. Two actual JB′s with different coatings were investigated. The load (in the range 1–3 N) and sliding distance (in the range 39.9–797.7 m) were varied to see the wear progression. The wear scars were assessed by SEM and optical profilometry, which exhibited the common abrasive and adhesive mechanisms of actual JB′s. In the paper, test procedures and wear behaviors were analyzed in detail. Thus, according to the coatings from the JB′s characterized, the wear resistances found were: 9.06E+13 N/m^2 for Pb–Cu–Al, 1.02E+15 N/m^2 for Cu–Al, and 1.33E+14 N/m^2 for Sn–Al–Si. Finally, the tester demonstrated good adaptability to reproduce accelerated lubricated wear in JB′s.

1. Introduction

Sliding bearings, also known as journal bearings (JB′s), are mechanical elements employed to allow rotation of a load-carrying shaft. The portion of the shaft at the bearing is referred to as the journal, and the stationary part, which supports the load, is the bearing. The working principle is that two surfaces move relative to each other without the benefit of rolling contact. This motion is facilitated by means of a lubricant which is squeezed by the motion of both components and generating sufficient pressure to separate them (elastohydrodynamic lubrication), thereby reducing frictional forces and avoiding wear [1]. The ideal operation of JB′s is that of working under elastohydrodynamic lubrication, however, boundary and mixed lubrication can occur due to different working conditions, such as: overloads, overheating, slow speeds, start/stop of machinery, lubricant degradation or starvation, etc. The major consequences of the presence of boundary and mixed lubrication are friction and wear increases. Due to these common lubrication situations in rotating machinery, several investigations dealing with wear resistance improvements of materials have developed [2]. Hence, Cu, Zn, Al, and Sn–Pb based alloys are specially used as journal bearing materials in automotive and industrial machine element applications since they meet properties, such as: low friction coefficient, high load capacity and heat conductivity, compatibility with lubricants, and high resistance to wear and corrosion [2]. Also, these alloys are coated to steel backs in order to reach high mechanical resistance.

Wear of JB′s is presented in different ways, namely, abrasion, adhesion, fatigue, fretting, corrosion, erosion, and cavitation, however, the abrasive and adhesive wear are the most predominant damages [3,4]. Abrasion, which is also termed as scratching, gouging or scoring (depending on the wear severity) can occur either by two-body abrasion or three-body abrasion. The first is generated because one surface is harder and rougher than the other, so the asperities from the hardest surface produce the material removal from the other. The second is generated by the interaction of hard particles (debris) between the surfaces. These damages are manifested by fine to clearly visible scratches. In practice, it is mainly produced either by film breakdown or by oil contamination with wear products [4].

On the other hand, adhesive wear happens when the interfacial adhesive joints lock together as two surfaces slide across each other under pressure. Under the action of a normal force, often the yield stress of asperities is exceeded, so they are plastically deformed until the real contact area is sufficiently increased to support the load applied. Initially, surface smoothing or polishing are produced by plastic deformation of asperities due to the collision between asperities in the sliding motion. In JB′s, this wear is also known as wiping. It can be recognized by shiny areas, which may be accompanied by change of color (dark blue to dark) due to local heating. In more severe cases, wiping is followed by seizure which exhibits surface melting and flow of the bearing material. Generally, it occurs by insufficient clearance between journal and bearing, and/or by oil film breakdown leading to formation of

* Corresponding author.
E-mail address: egallardo@ipn.mx (E.A. Gallardo-Hernández).

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boundary and/or mixed lubrication [4].

In order to study wear of JB′s, some methodologies have been performed by using different testers, such as: full-scale test rigs (high-speed diesel engines) [4], standard and adapted JB′s testers [2,5–7], and approaches by using tribometers (the ring-on-disc tester [8,9] and the pin-on-disc tester [8,10,11]). In the case of using full-scale test rigs and JB′s testers, the test comprises long runs and high accuracy measurement techniques to minimize errors in wear quantification [7]. Also, the test parameters (load, temperature, sliding speed, vibrations, etc.) cannot be accurately controlled because of the complexity of the rigs. On the other hand, the use of tribotesters has become a potential option to approach the working situation and tribological behavior of many mechanical elements including JB′s. It comprises conducting accelerated tests under particular test conditions [8]. However, according to the configuration of each tester, special specimens (depending on the tester configuration) should be manufactured and prepared, which could be a restriction and difficulty for the manufacturer and the experimenter. So, it is needed a suitable and reliable tribological test capable to reproduce and accelerate wear of actual JB′s.

The aim of this study is to propose an alternative and reliable method for the lubricated sliding wear evaluation of JB′s by using a test variation from the TE66 micro-scale abrasion tester. In general, the adaptations performed in the tester enables generating very small wear scars on small samples from JB′s by a rotating ball with continuous lubricated sliding. The wear scar reached elliptical cap shape, which allows an accurate and handy determination of wear volumes.

Currently, the tester has widely employed by other authors to reproduce micro-abrasive wear, exhibiting reasonable reproducibility and repeatability in coatings [12–14], bulk hard materials [15,16], dental restorative resins [17], “hard” polymeric materials [18], and rubber materials like silicone even in oily contact [19,20]. Furthermore, the low complexity of the original tester configuration permits a simple execution of testing, which makes it advantageous and useful compared with other wear testers. Thus, the exploration about the use of this tester for other tribological applications become an area of opportunity for research. Hence, in this work, the working situation of JB′s was approached by performing some particular adaptations to the original tester in order to generate, in particular, adhesive and abrasive wear. In coated materials, which is the case of most JB′s, the wear evaluation can be done by conducting perforating and non-perforating tests, which allow the determination the wear rates of bulk materials (substrates) and coatings, respectively [21,22]. In non-perforating tests, the wear process is limited to produce shallow cratering on the material in order to only wear away the coating, allowing the assessment of wear of the coating without influence of the substrate. On the other hand, in perforating tests, the wear process is continued until the coating has been worn and it has progressed into the substrate, allowing the evaluation of wear of the coating and the substrate, simultaneously [22].

Finally, the adaptations performed in the tester permitted conducting the testing under lubricated contacts, which produced the adhesive and abrasive patterns similar to those occurred in actual JB′s by the action of mixed and boundary lubrication situations. Moreover, the test was found to be cheap, fast, reliable and suitable as a potential alternative method for the wear assessment of actual JB′s under lubricated condition.

2. Theoretical considerations

2.1. Lubrication regime

According to the wear test arrangement used for this research, which is explained later in detail, a rotating sphere is pressed against the surface of a concave flat under a constant load, P, so a contact with elliptical geometry is produced, as it is shown in Fig. 1. In order to the theory developed by Hamrock et al. for elastohydrodynamic lubrication of elliptical conjunctions [23], the dimensionless minimum film thickness, H_{min}, can be estimated by Eq. 1 where U is the dimensionless speed parameter that is obtained by Eq. 2, being, η_o, the lubricant viscosity, u is the mean sliding speed, and R_x is the reduced radii in x-direction, see Eq. 3. The radius may be considered as positive (convex) or negative (concave). G is the dimensionless materials parameter. It can be estimated by Eq. 4 where α_{EHL} is the elasto-hydrodynamic lubrication (EHL) pressure-viscosity index that is calculated from Eq. 5, being Z the Roeland´s pressure-viscosity index, see Eq. 6, it can be obtained for most mineral oils from both their viscosities at 40 °C, μ_{40}, and at 100 °C, μ_{100}, see Eqs. 7–9 [24]. W is the dimensionless load parameter, which can be calculated from Eq. 10, and k is the ellipticity parameter, which is estimated by Eq. 11, where R_y is the reduced radii in y-direction, see Eq. 12.

$$H_{min} = 3.63U^{0.68}G^{0.68}W^{-0.073}\left(1 - e^{-0.68k}\right) \tag{1}$$

$$U = \frac{\eta_o u}{2E^* R_x} \tag{2}$$

$$\frac{1}{R_x} = \frac{1}{R_{1xx}} + \frac{1}{-R_{2xx}} \tag{3}$$

$$G = 2\alpha_{EHL}E^* \tag{4}$$

$$\alpha_{EHL} = Z\left[5.1 * 10^{-9}\left(\ln\ (\mu_o) + 9.67\right)\right] \tag{5}$$

$$Z = \left[7.81\left(H_{40} - H_{100}\right)\right]^{1.5}F_{40} \tag{6}$$

$$H_{40} = \log\left[\log(\mu_{40}) + 1.2\right] \tag{7}$$

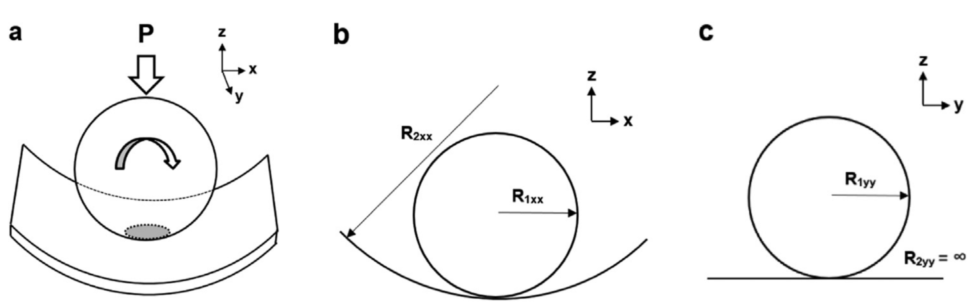

Fig. 1. Schematic of the contact of a ball against a concave-flat.