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Abrasive wear resistance of textured steel rings

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ABSTRACT

The fundamental aim of the present research is to study the effect of dimple shape and area density on abrasive wear in lubricated sliding. The other aims are to recommend a method of obtaining the local linear wear of a textured ring on the basis of profilometric measurement and to analyse the changes in the surface topography of this ring with selection of parameters that could monitor the "zero-wear" process.

The experiments were conducted on a block-on ring tester. The stationary block made from cast iron of 50 HRC hardness was ground. The rotated ground ring was made from 42CrMO4 steel of 32 HRC hardness. The rings were modified by a burnishing technique in order to obtain surfaces with oil pockets. Oil pockets of spherical and of drop shape were tested. The pit-area ratios were in the range: 7.5–20%. The tested assembly was lubricated by oil L-AN 46. Because of the great hardness of the co-acting parts the wear resistance test was carried out under artificially increased dustiness conditions. The dust consists mainly of SiO_2 and Al_2O_3 particles. Measurement of local microscopic ring wear was made using a three-dimensional scanning instrument. The tendencies of ring surface topography changes during wear were analysed. Various methods of obtaining the local wear value during a low wear process were proposed and compared. We found that a spherical shape of dimples was superior to a drop shape with regard to wear resistance of steel rings.

1. Introduction

Surface texturing is an option of surface engineering resulting in improvement in wear resistance, coefficient of friction and load capacity of lubricated machine components. Various techniques can be employed for surface texturing including laser texturing, etching techniques and machining [1]. The oil pockets (micropits, holes, dimples or cavities) may reduce friction by providing lift themselves by a cavitation mechanism or/and by acting as a reservoir of lubricant [2]. The dimples can be also micro-traps to capture wear debris. Such depressions should be large enough to trap and store the generated debris. It was found that surface texturing improved wear resistance of various machine elements, including cylinder liners [3], slide bearings [4] or mechanical seals [5]. A burnishing (embossing) technique seems to be very promising in the creation of textured surfaces. Special endings act as hammers to form pockets on metal surfaces. The results of experimental investigations of the effects of oil pockets (created by burnishing technique) on the tribological performance of sliding elements under mixed lubrication conditions are presented in Ref. [6]. A stationary block made from bronze contacted a rotating steel ring. Surface texturing of the block surface (area density between 20% and 26%) resulted in significant improvement in wear resistance in comparison to a system with untextured samples. The result of investigations with steel shafts, finished by grinding and vibratory burnishing, contacting with a rubber sliding bearing showed that the burnished surfaces possessed about 64% higher wear resistance than ground samples [7].

During the "zero-wear" process the wear volume or wear loss is within the limits of the original surface topography of the component [8]. Two possible wear mechanisms can occur: wear removal due to abrasion (or adhesion) or plastic deformation (redistribution of material without net loss). Qualitative 3D characterisation of cylinder surface wear was carried out by Dong and Stout [9] as well as by Pawlus and Michalski [10]. There were marked changes in skewness and kurtosis. As long as the honing texture existed, the texture direction did not exhibit significant change [9]. It was found that the change of amplitude parameters during wear process was large. The new surface topography created during the wear process is a two-dimensional structure, characterised by larger values of horizontal parameters in the axial direction of the cylinder in comparison to the circumferential direction [10]. The authors of Ref. [11] analysed the changes of piston skirt surfaces during "zero-wear". The worn piston skirt surfaces were observed to be smoothed. The ordinate distribution became asymmetric during "zero-wear". Summit density increased.

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During “zero-wear” the local wear amount is difficult to determine by common metrological methods. Therefore a profile measurement gauge was used to determine the amount of wear. Rosen at al. [12] believed that a practical problem of wear measurement was the difficulty of establishing a datum for changes in topography. They proposed transition points between the two topographies of plateau honed surfaces as an absolute height datum for successive measurements. The authors of paper [13] proposed a new procedure to evaluate cylinder liner wear volume and depth under a “zero-wear” regime. It was considered that 90% of the material ratio curve was the same before and after wear. The material ratio curve of the worn liner was transformed by the depth differences at 90% and the area between the two curves (of original and used liners) representing the material worn from the profiles parallel to the cylinder axis was calculated. The wear depth was obtained by the projection of the 30%–70% line on the depth axis of two material ratio curves and then finding their difference. This method was considered superior to gauging the changes in diameter (such determination is influenced by the cylinder liner distortion).

However, the methods presented require a relocation technique to find the same area for comparison. A very precise positioning of the 3D measurement area before and after wear test is required. Then the lateral matching of the two images is necessary. Unworn elements (for example the deepest valleys) may also serve as reference data [14].

A profilometric wear analysis method [15,16] could also estimate local wear without measuring unworn surfaces. Such an analysis proposed by Dunaevsky [15] could estimate local wear comparable to the surface roughness height by measuring the profile of the worn surface only. However, Dunaevsky only provided a formula for the wear evaluation of Gaussian surfaces. The objective of the study [16] was to develop a wear measurement method for general engineering surfaces during the microscopic wear process. This method does not require any information about the initial surface.

2. Purpose and scope of the experiment

The fundamental aim of the present research is to study the effect of dimple shape and area density on abrasive wear in lubricated sliding. The other aims are to recommend a method of obtaining the local linear wear of a textured ring on the basis of profilometric measurement and to analyse the changes in the surface topography of this ring with selection of parameters that could monitor the “zero-wear” process.

2.1. Experimental

The experiments were conducted on a block-on ring tester. The rotated ring samples, 35 mm in diameter, were made from hardened 42CrMO4 steel of hardness 32 HRC. The stationary ground block was a part of a bearing sleeve hardened EN-GJS 400-15 cast iron with a hardness value of 50 HRC. Fig. 1 presents the scheme of the tested assembly. The ring surfaces were modified by a burnishing technique in order to obtain a surface with oil pockets. Two versions of dimples were tested: oil pockets of spherical shape (depth about 60 μm, and diameter 900 μm) and of drop shape (depth about 55 μm, length 1600 μm and width 500 μm). Pits of drop shape were oriented with their wider side to the speed vector. The pit-area ratio S was in the range: 7.5–20%. The tested assembly was inserted in the reservoir of the lubricating fluid L-AN 46 (mineral oil, refined by anti-foaming, anti-oxidizing and anti-corrosive agents). This oil is commonly used for lubrication of many machine components. Because of the high hardness of the co-acting parts the experiment was carried out under artificially increased dustiness conditions. The particles of dust were chiefly SiO_2 (74%) and Al_2O_3 (15%). The results of grain composition examination are given in Table 1.

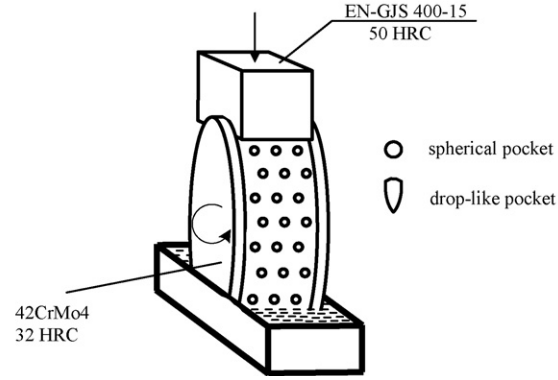

Fig. 1. The scheme of tested assembly.

Table 1
Results of grain composition examination.

Grain size range (μm)	Mass fraction (%)
0–2	15
2–5	13
5–10	16
10–20	21
20–40	23
>40	12

1 g of dust was added to the volume of 40 cm^3 of the oil. The initial temperature of the oil was in the range: 20–22 °C. The normal load was 900 N; speed was 0.27 m/s. The sliding distance was 3891.9 m (time 4 h). Each experiment was repeated three times.

2.2. Wear of ring

The surface topography of the worn ring was within the limit of the original surface topography, so the wear amount was difficult to determine. Therefore measurement of wear was done using a three-dimensional surface topography measuring equipment Talyscan 150. The measurement was done before and after the test. The measured area was 7 mm × 6 mm (sampling distance in perpendicular directions was 15 μm) in the same places (see Fig. 2).

In addition, measurements on a smaller area (2 mm × 2 mm) were made (sampling intervals were 5 μm). In order to measure the ring surface in exactly the same place a relocation method (mechanical and then digital) was used. Because the measured surface area contained the zones where wear did not occur, the areas in which the parameters were calculated were smaller (5 mm × 4 mm) – Fig. 2. After relocation, before calculation of parameters a 3rd degree polynomial was fitted to the measurement data, but digital filters were not used. We analysed the changes of some 3D surface topography parameters. Definitions of the majority of them are given in Ref. [17]. Table 2 presents a description of parameters.

The following amplitude parameters were analysed: Sa, Sq, Sp, Sv, St, Sz. Parameters obtained from the material ratio curve were studied: SHtp (height corresponding to material ratios: 20–80%), SΔHtp (height corresponding to material ratios: 5–95%), and SΔtp

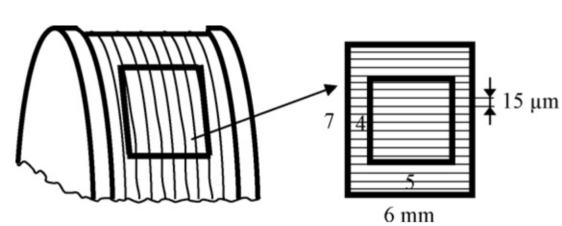

Fig. 2. The scheme of measured area.