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Original Research Article

Influence of surface preparation on surface topography and tribological behaviours

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ABSTRACT

Wear tests were conducted using a ball-on-disc tester. In the experiment, a 42CrMo4 steel disc with a hardness of 40HRC was placed in contact with a 100Cr6 steel ball with a diameter of 6.35 mm. The hardness of the ball was set to 62HRC. Disc samples were prepared to obtain surfaces in range to the Sq parameter but of less than 0.5 μm. Dry tests were carried out. During the tests, the friction force was monitored as a function of time. Disc and ball wear was measured after the tests using a white light interferometer Talysurf CCI Lite. To decrease variations in the experimental results, during the tests, wear debris was continuously removed from the disc surfaces. It was found that the initial surface topography has a significant influence on friction and wear levels under dry sliding conditions. It was also identified the correlation between several surface topography parameters and friction and wear.

1. Introduction

Friction and wear are caused by complex and multiplex sets of microscopic interactions occurring between surfaces that are in mechanical contact and that slide against one another [1]. Wear refers to the progressive loss of material due to interacting surfaces in relative motion. It is quantitatively measured as the specific wear rate V (defined as the volume loss per sliding distance and load) of a material. Friction is a measure of the resistance to motion (loss of energy) for two interacting surfaces. Friction is quantitatively described by the coefficient of friction μ (dynamic/static) [2]. The coefficient of friction and wear describe the state of contact between bodies in a tribosystem, and they are not material constants of bodies in contact [3,4]. They may be treated as material properties for technical convenience in an engineering sense and only for specific contact states.

Friction losses play a significant role in the performance and reliability of mechanical components. The ball-on-disc wear rigs are some of the most common configurations used in sliding wear studies [5–7]. According to ASTM G99-95a (reapproved 2000) standards, a spherical ball (or radius-end pin) against a flat disc is the recommended wear configuration. To facilitate the proper design of contact surfaces, it is very important to understand the influence of surface roughness parameters on friction and wear [8]. With the development of various manufacturing methods of mechanical components, one can obtain various surfaces. It is well known that different surfaces reflect various tribological properties, with roughness

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having a significant effect on friction levels under dry and lubricated conditions, conditions of lubricant film formation and load carrying capacity, etc. Unfortunately, standard surface roughness parameters normally used by designers do not sufficiently describe contact surfaces. In addition, different standards use differing parameters [9].

Although many experimental works have been carried out on the surface roughness and topography of contact surfaces, correlations between surface roughness and friction and wear are not yet clearly defined [10–14]. The results obtained by Wang et al. [15,16] show that roughness amplitudes have a considerable effect on the transition between friction regimes. The same authors' dry contact analysis of parameters Rsk and Rku in [17] shows that in comparison to the Gaussian distribution (Rku = 3, Rsk = 0), surfaces with high Rku values and positive Rsk values should result in a lower static coefficient of friction.

Wieleba [18] reported that different roughness parameters, as an average slope of the profile $\Delta\alpha$, denote that peak spacing (Sm) and the core roughness depth Rk can affect friction properties. The authors of [19] also showed that the average value of the coefficient of friction is strongly dependent on the mean slope of the profile under lubricated conditions. Singh et al. [20] reported that the amplitude parameter Sq (rms deviation of the surface), spatial parameters Sds (summit density), and Std (texture direction) play key roles in determining the frictional behaviour of surfaces. In [21], surface characterizations of electro-active thin polymeric film bearings were investigated. It was found that film surfaces with positive skewness values and kurtosis values exceeding 3 are the most advantageous for a low friction bearing. The authors of [22] reported that it is possible, by characterizing a given topography and by calculating parameters Ssc and Sdq, to predict the remaining lifetime of a sintered friction material in a wet clutch. Research results presented in [23,24] investigate correlations between surface roughness and friction based on ball-on-disc configurations. It was found that for dry tests, the coefficient of friction is lower when disc roughness levels are high, contrary to experiments conducted under lubricated conditions. However, in [23,24], specimen wear was not considered. Grabon et al. [25] found that the wear of a cylinder liner with negative surface roughness skewness is less pronounced than that with a skewness value of close to 0 for textures characterized by the same Sq parameter values.

Therefore, on the basis of a literature review, the aim of the present work was to investigate the influence of surface preparation on surface topography parameters and correlations between roughness parameters and friction and wear.

2. Experimental

Wear tests were conducted using a pin-on-disc tester with a ball-on-disc configuration. A steel disc of 40 HRC in hardness was placed in contact with a steel ball with a diameter of 6.35 mm. The hardness of ball was 62 HRC. Disc samples were prepared to obtain surfaces of a similar range to that of the Sq parameter but of less than 0.5 μm. Dry tests were carried out at room temperature (20–22 °C). Dry sliding tests were conducted at sliding speeds of 0.16, 0.24 and 0.32 m/s. The sliding distance was set to 282.6 m, and the normal load was set to 9.81 N. To improve the repeatability of the dry sliding test, wear debris was removed from the disc surface during the test period by blow-drying it with compressed air of a constant pressure. All tests were repeated at least 3 times. During the tests, the friction force was monitored as a function of time. Disc wear was determined after the dry sliding tests were completed by means of a surface topography analysis using a white light interferometer Talysurf CCI Lite with a vertical resolution of 0.01 nm. The measuring area of 3.3 mm × 3.3 mm contained 1024 × 1024 points. Profiles were taken in four positions (90° apart) perpendicular to the wear track. Then, using an interferometer software program, they were computed and averaged. Worn ball surfaces were also measured using the white light interferometer Talysurf CCI Lite.

Table 1 shows specifications of the machined disc sample surface topographies. The texture aspect ratio of the tested surfaces Str was lower than 0.2 [26]. This parameter is used to describe the isotropy of a rough surface (a value closer 0 denotes a perfectly anisotropic surface). The following surface topography height parameters were used: Sq, Ssk, Sku and Sz.

The root mean square height is defined as the root mean square value of surface departures, $z(x,y)$, within the sampling area:

$$\mathrm{Sq} = \sqrt{\frac{1}{A}\iint_A z^2(x,y)dxdy} \tag{1}$$

Skewness is defined as the ratio of amplitude values cubed to the cube of Sq within the sampling area, A:

$$\mathrm{Ssk} = \frac{1}{\mathrm{Sq}^3}\sqrt{\left[\frac{1}{A}\iint_A z^3(x,y)dxdy\right]} \tag{2}$$

This parameter describes the shape of the texture height distribution. For a Gaussian surface of a symmetric shape, the skewness is zero. For an asymmetric distributed surface, the skewness is negative when the surface texture includes more peaks under the mean plane.

Kurtosis is the ratio of the mean of the fourth power of height values to the fourth power of the Sq parameter within sampling area A:

$$\mathrm{Sku} = \frac{1}{\mathrm{Sq}^4}\sqrt{\left[\frac{1}{A}\iint_A z^4(x,y)dxdy\right]} \tag{3}$$

This parameter is a measure of the peaks or sharpness of the surface height distribution (it characterizes the spread of the height distribution).

The Sz parameter denotes the maximum height of the surface within sampling area A.

The autocorrelation length, Sal, is the horizontal distance of the autocorrelation function ACF (tx, ty), which exhibits the fastest decay rate to a value of 0.2:

$$\mathrm{Sal} = \min\sqrt{tx^2 + ty^2} \tag{4}$$

The texture direction parameter, Std, is a convenient parameter of anisotropic surface and is given in degrees between 0° and 180°.