Wear 278–279 (2012) 94–100

Contents lists available at SciVerse ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Short communication

Modeling of worn surface topography formed in a low wear process

Rafal Reizer [a], Pawel Pawlus [b,*], Lidia Galda [b], Wieslaw Grabon [b], Andrzej Dzierwa [b]

[a] University of Rzeszow, Poland
[b] Rzeszow University of Technology, Poland

ARTICLE INFO

Article history:
Received 14 June 2011
Received in revised form
15 December 2011
Accepted 21 December 2011
Available online 2 January 2012

Keywords:
Surface topography
Low wear
Simulation
Cylinder liner
Oil pockets

ABSTRACT

Two batches of experiments are described in this paper. The first tests were conducted on a reciprocating tester. Specimens were cut from cylinder liners from gray cast iron of hardness 2128 MPa after honing or plateau honing. They co-acted with counter-specimens made from chromium-coated steel C45. Lubricating fluid was supplied to the contact zone.

The second tests were carried out on a block-on ring tester. Stationary block prepared from cast iron with a hardness value of 5356 MPa was ground. Rotating rings made from steel of 2992 MPa hardness were modified by a burnishing technique to obtain surfaces with dimples. The tested sliding pair was lubricated. The abrasive wear resistance tests were conducted under artificially increased dustiness conditions.

Two types of worn surface topography modeling were used. For cylinder liners tests random one-directional Gaussian surface topography was imposed on the base surface (after honing). Worn surfaces of textured steel rings were modeled by simulation of actions of abrasive particles. After each kind of simulation selected parameters of measured and modeled surface textures were compared. We found that measured and simulated surfaces were correctly matched in the majority of cases.

1. Introduction

Simulation of surface created during wear ensures decrease of cost and time of experimental investigations. Researchers suggested several methods of Gaussian areal surface topography simulation. Computer generated surfaces ought to have required properties, such as auto-correlation function. Auto-Regressive and Moving Average (ARMA) method is popular in generating surfaces [1–4]. However, because time series approach often considers few orders systems, only the region of the origin in the autocorrelation function can be modeled properly. Methods based on Fast Fourier Transform (FFT) [5–7] can better simulate auto-correlation function. Examples of application of numerical generation of random rough surfaces by Moving Average and FFT methods in contact and friction problems are given in Refs. [8,9], respectively.

During low wear (the “zero-wear” process) the wear loss is within the limits of the original surface topography. Loss of materials was often simulated by truncation of surface peaks parallel to reference element [10,11]. However, truncation model is simplification. The more realistic is different approach. The resulting topography of worn surface is that of the original surface up to some height. Above this height another Gaussian distribution is superimposed [12]. This approach was used to worn surface modeling [13,14]. This method is based on imposition of random Gaussian surface on the original surface.

Abrasive wear may be defined as wear in which hard asperities on one body, moving across a softer body under applied load, penetrate and remove material from the surface of the softer body, leaving a groove. In the dominant view two-body abrasive particles or asperities are rigidly attached to the second body, however three-body abrasive particles are loose and free to roll [15]. From the point of view of modeling, it is easier to consider two-body wear. Plastic deformation and cutting are two of the major types of wear that occur in abrasion of materials. The estimation of plastic ridges distributed on both sides of groove is difficult, therefore many previous wear models did not include it. Pure microcutting wear mechanism without material displacement was included in model developed by Jacobson et al. [16,17]. In model of Jiang et al. [18] the ploughing model was considered. In work of Fang et al. [19] a stochastic process was proposed considering abrasive particle and their distributions with stochastic parameters. The decreases of wear volume due to groove ridges pushed aside by abrasive particles were also taken into account. An algorithm simulating an elementary abrasive wear process was developed by Bigerelle et al. [20,21]. The basic idea of this model is that the higher the height of a surface peak, the lower is its probability of resistance during a wear cycle. Jha and Jain [22] simulated change in surface roughness in abrasive flow finishing process. Ploughing was assumed as the mechanism of material removal. Andersson

* Corresponding author. Tel.: +48 178 543 112; fax: +48 178 543 112.
E-mail address: ppawlus@prz.edu (P. Pawlus).

0043-1648/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2011.12.012

et al. [23] developed a random wear model in order to characterize the interaction between a rough and smooth surface based on the generalized Archard's wear equation. In numerical simulation of abrasion circular shape of the end of abrasive particles is commonly used [16–19,21].

In this work two types of worn surface topography modeling in a low wear process were used. Firstly, for cylinder liners co-acted with piston rings under reciprocating sliding conditions random surface topography of Gaussian ordinate distribution was imposed on the base surface (after honing). Secondly, worn surfaces of textured steel rings operated under artificially increased dustiness conditions were modeled by simulation of actions of abrasive particles.

2. Modeling of worn cylinder liner surface topography

2.1. Test description and presentation of result

Experimental investigations were conducted on a reciprocating tester. Specimens were cut from cylinder liners from pearlitic gray cast iron with phosphide eutectic after honing. Hardness of cast iron was 2128 MPa (218 HB) and minimum tensile strength was 320 MPa. A plateau honed cylinder surface is the typical example of two-process texture. It consists of smooth wear-resistant and load-bearing plateaux with intersecting deep valleys working as oil reservoirs and debris traps. Plateau-honed cylinder surfaces were formed by the two last honing steps: coarse honing and plateau honing. One-process honed surfaces of approximately Gaussian height distribution were also tested. The cylinders were honed or plateau honed in order to obtain the same (within tolerance limits) values of the Sq parameter of one-process and two-process surfaces: 0.4 μm, 0.7 μm and 1.0 μm. Two one-process cylinder liner samples described by Sq parameter values of 0.2 μm and 1.8 μm were also tested. Three other two-process surfaces had also oil pockets, formed by a burnishing technique. Dimples were oriented with their shorter dimension to the sliding direction. The honing angle of all specimens was about 50°. Specimens co-acted with counter-specimens made from chromium-coated steel C45. The coating micro-hardness was 8191 MPa (835 HV1/10), the roughness height of counter-specimens characterized by the Ra parameter was 0.3 μm. The operating parameters were as follows: sliding velocity: 0.44 m/s, unitary pressure: 8.3 MPa, the amount of lubrication: 0.0012 dm^3/h, sliding distance: 6480 m. The lubricant SUPEROL SAE CB 40 was supplied to the contact zone. Each tribologic test was repeated 3 times. Three-dimensional surface topographies of specimens were measured before and after the test by stylus Talyscan 150 measuring equipment with a nominal tip radius of 2 μm. The measured area was 1 mm × 4 mm; sampling interval was 5 μm.

Wear of two-process cylinder liner samples was lower than that of one-process specimens described by the same Sq parameter. The typical feature of the wear process is a decrease in skewness Ssk and an increase in kurtosis Sku of cylinder liner surface topography. Amplitude parameters describing the summit surface part: summit height Sp, reduced summit height Spk and core height Sk decreased. Detailed description of test procedure and experimental results is given in Ref. [24].

2.2. Modeling procedures

It was found that during wear one-directional surface oriented parallel to surface movement was created. Two scales of roughness on worn surfaces can be found: a relatively rough valley structure and quite smooth finer plateau structure. This was confirmed during the analysis of material probability curve, in which the surface

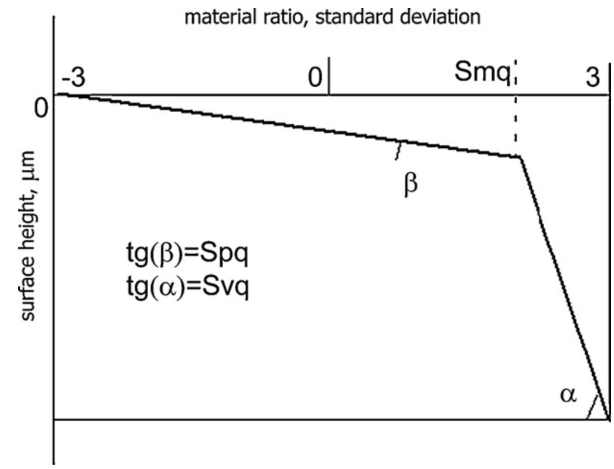

Fig. 1. Graphical interpretation of Spq, Svq and Smq parameters.

material ratio is expressed as Gaussian probability in standard deviation values, plotted linearly on the horizontal axis. For two-process random surface the material probability curve consists of two linear regions. The Spq parameter (standard deviation of plateau part) is the slope of a straight line performed through the plateau region, but Svq (standard deviation of valley part) – through the valley region. The intersection point of abscissa Smq defines the separation of plateau and valley regions. Spq, Svq and Smq are the extension of Rpq, Rvq and Rmq parameters defined in ISO 13565-3 standard. Fig. 1 shows graphical interpretation of Spq, Svq and Smq parameters. The worn cylinder liner surface topography was modeled by imposition of anisotropic (one-directional) random surface topography of Gaussian ordinate distribution on machined cylinder liner surface topography. Imposed topography can be completely defined by three parameters: surface standard deviation Sq (equal to Spq parameter of worn cylinder liner surface) and correlation lengths CL in perpendicular directions. Based on empirical observations exponential shape of autocorrelation function was used. Correlation length is the distance, in which autocorrelation function of profile slowly decays to 0.1 value. Correlation lengths were assessed on the basis of the analysis of worn cylinder liner surfaces. The CL parameter in the direction of liner axis was 800 μm, but in perpendicular direction 25 μm. The method of prediction of worn cylinder liner surface depends on the imposition of computer created fine surface topography of Gaussian ordinate distribution on the measured based surface topography after machining. From

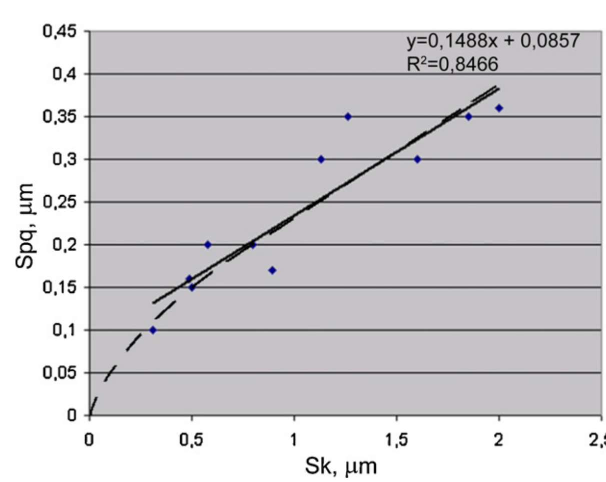

Fig. 2. Dependence between Sk and Spq parameters of worn cylinder liner surfaces.