TRANSFORMATION OF SURFACE LAYER AND SURFACE ISOTROPY CHANGES

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Abstract
The article presents possibilities of using the surface layer isotropy degree changes for a description of the surface structure operational transformation. Tribologic experimental tests were conducted for different external factors, and the occurring changes were described by the isotropy degree determined on the basis of the surface function of autocorrelation. The carried out analysis verified the usability of the surface layer isotropy degree change for a description of a surface operational transformation.

Key words: *tribological experimental tests, surface geometric structure, wear process, surface autocorrelation function.*

INTRODUCTION

Functional qualities of kinematic pairs, e.g. durability, reliability, motion resistance largely depend on the condition of the surface layer (SL). This has been confirmed by results of tests presented in numerous publications (*Horng, et al., 1995; Krawczyk, 2010; Krzyżak & Pawlus, 2006; Matuszewski, 2008; Nosal & Grześkowiak, 2004; Pawlus & Gałda, 2007; Zhu, et al., 2003*). The state of SL is determined by a set of characteristics which are described by parametric and nonparametric values. These characteristics can be external ones, usually connected with the surface structure geometry, (SSG) and internal ones which result from mechanical, physical and material properties.

Due to that fact that cooperation of components in a friction pair is accompanied with interaction of their surfaces, the surface structure has a significant influence on the functional qualities and tribological characteristics. Therefore, it is important to make a proper choice of methods and tools for evaluation of stereometric features of the surface. The metrological measurements of the topography should represent the actual texture of the structure in the best possible way which in turn will enable to provide an appropriate assessment of functional qualities of elements of friction pairs.

Roughness parameters are used in literature for a description of changes occurring during operational transformation of the surface layer, in particular the surface geometric structure, which largely determines functional qualities of the friction pair components (*Bernardos & Vosniakos, 2003; Lawrowski, 2008; Nosal & Grześkowiak, 2004; Ohlsson, et al., 2003*). These parameters are certainly an important element in the description of the process of wear and its intensity both for distributed and concentrated contact, though they do not characterize fully the SL and, therefore they do not account for all the changes in the contact area of two cooperating components. This drawback of tribological tests is indicated in many publications (*Trzos, 2011*).

Additionally, a big number of roughness parameters causes some problems in evaluation of the state of SSG (*Kedziora, et al., 2004; Panicz, 2000*). Creation of a universal set of parameters to be equally useful for assessment of a surface in terms of its functional qualities is not possible in practice. Even for similar values of basic amplitude parameters the remaining parameters can significantly differ (*Oczoś & Lubimow; Wieczorowski, et al., 2003*). Assessment of a surface can then be equivocal as they can have similar or the same values of roughness, and different functional qualities related to the stereometric shaping of SSG. However, attempting to evaluate the SSG by means of only one parameter, which unfortunately is still reported in industry, would be a big simplification. Selection of roughness parameters for determination of tribological characteristics is performed on the basis of scientific research statistical relations between them and availability of the equipment. There are no norms specifying when particular parameters should be used. The respective literature includes only recommendations which parameters of roughness provide the most adequate information for assessment of given functional qualities. Therefore, the selection of roughness parameters to be used for assessment of the SL condition will always be burdened with smaller or bigger subjectivism.

Internal features of a surface layer which largely affect its transformation, apart from roughness, include orientation of the surface structure, especially for the distributed contact which characterizes the surface structure in a specific way. Mutual orientation of irregularities of the cooperating surfaces – intersection angle between characteristic directions of their surfaces – affects the contact mechanics and the lubrication conditions. There are many measures of a surface direction assessment (*Dong, 2001; Thomas, 1999*). The most advanced and at the same time the most objective are methods for measurement using mathematical functions for a description of SSG. Direction of the structure is then referred to isotropy or its opposition – anisotropy. If a structure was entirely isotropic, it would mean that its geometric shape shows the same features in all possible directions – structure ideally symmetric in relation to all the symmetry axes. In practice, such a situation is not possible to achieve, therefore describing stereometrics shaping of a structure by isotropy whose degree is accepted for the description, which expressed, e.g. in percentage, is a measure of the structure direction.

In this paper, isotropy degree determined on the basis of frequency function of SSG, and more precisely, on the basis of surface autocorrelation function, was accepted to be used for a description of SSG changes. This function is a measure of the dependence of data values in one position on its values in the second position. Estimation of the surface function of autocorrelation is defined according to formula (*Oczoś & Lubimow, 2003)*:

$$R(\tau_i, \tau_j) = \frac{1}{(M-i)(N-j)} \sum_{l=1}^{N-j} \sum_{k=1}^{K-i} z(x_k, y_l) z(x_{k+i}, y_{l+j}) \tag{1}$$

where:

- M, N – areas of sampling ,
- $z(x_k, y_l)$ – residual surface,
- $z(x_{k+i}, y_{l+j})$ – bearing surface,
- x, y – directions of sampling;

whereas: $i = 0, 1,..., m < M$; $j = 0, 1,...., n < N$; $\tau_i = i\Delta x$; $\tau_j = j\Delta y$.

For anisotropic surfaces the shape of the autocorrelation function diagram is asymmetrical, slender and prolonged in one direction, whereas for isotropic surfaces – round and symmetrical.

Experimental test were supposed to verify usability of surface isotropy degree for a description of transformation of the surface layer under the influence of external factors.

MATERIALS AND METHODS

The process of changes was observed for steel 102Cr6 specimens prepared for tests by grinding with 99A electrocorundum grinder with dimensions Ø 350 x 50 with the following parameters: circumferential velocity of grinder v_s = 26 m·s^{-1}; the table feed rate v_{ft} = 13.4 m·min^{-1}; grinding depth a_p = 0.04 mm, with conventional cooling and emulsion lubrication. So the machined surfaces were characterized by the following mean (eight measurements) values of SSG basic roughness parameters SSG: *Ra* = 1.37 µm; *Rq* = 1.73 µm; *Rt* = 7.39 µm. The values of isotropy degree of the test specimens were included in the interval 7.98÷8.04 %. In Fig. 1, there is an image of the obtained surface structure.

Fig. 1 Image of the tested surface structure (zoom x150)

Tribological tests were carried out on a specially designed test stand (*Matuszewski & Styp-Rekowski, 2008; 2004*). Variable operational forces were: force (*F*) and specimen hardness (*H*), whereas the constants were: velocity of relative motion (3 m·min^{-1}) and lubrication conditions (machine lubricant L – AN 68). The following values of variables have been accepted on the basis of literature: *F* = 300, 450 and 600 N (due to expected pushes); *H* = 30,.40 and 50 HRC. Taking into consideration the specimen surface contact with the counter-specimen – 300 mm^2, the accepted loading generated the following theoretical pressures: 1.0; 1.5 and 2.0 MPa. Fig. 2 shows the principle of the specimen and counter-specimen cooperation during tests. The tested object was a kinematic pair consisting of a specimen in the form of a cube with dimensions 10x10x10 mm and a counter-specimen prepared in the form of a flat ring shaped plate.

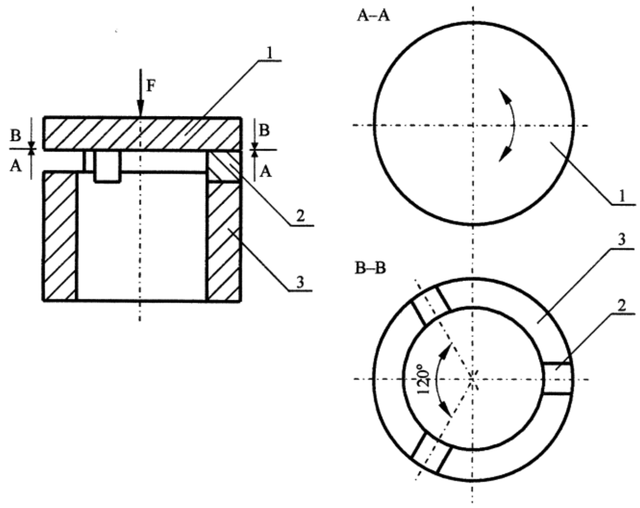


Fig. 2 Scheme of cooperation of sample – counter-sample of the tested friction pair: 1 – counter-sample, 2 – specimens, 3 – receiving sleeve samples

The tested samples (2) are immovably fixed to the head surface of the receiving sleeve sample (3) in three grooves, every 120°. Thus, a three surface, uniformly spread clamp of cooperating elements is obtained which is performed by the spring tension. Relative, oscillating motion is performed by the counter-sample (1), which is made of X210Cr12 steel hardened to 60±2 HRC. Hardness of the counter-sample definitely exceeded hardness of the samples to make transformation of the surface layer occur first of all on the samples.

The situation of machining traces in relation to each other was a very important factor – direction on the samples and on the counter-sample. The situation accepted for tests was chosen in such a way that the resultant cooperation angle was 90° due to the direction of the cooperation. It ensured theoretically optimal conditions for application of the lubricant.

As mentioned before, the surface isotropy degree and its changes were described as a surface autocorrelation function, by means of Talyscan 150 device of Taylor-Hobson company with the use of TalyMap Expert software. The measurements were taken along friction distance equal to 100 m, and observation of changes was being performed until it reached the length of 2000 m. However, stabilization of changes was recorded after 600 m – which is consistent with the assumed wear mechanism and, therefore the initial period of cooperation when the intensity of change is the highest, was accepted for analysis. The study was conducted for eight replicates.

RESULTS AND DISCUSSION

The results of experimental tests are presented in the form of diagrams. In Fig. 3 there are changes in isotropy degree (*Iz*) in the function of friction distance, for three different loadings, whereas for different values in Fig. 4.

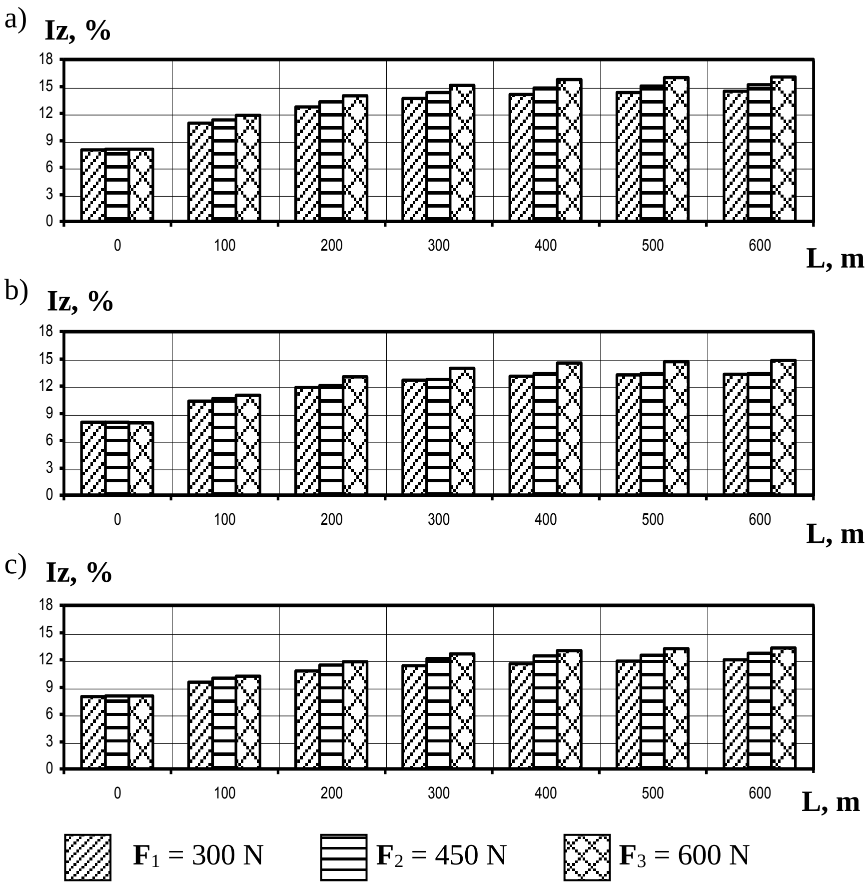
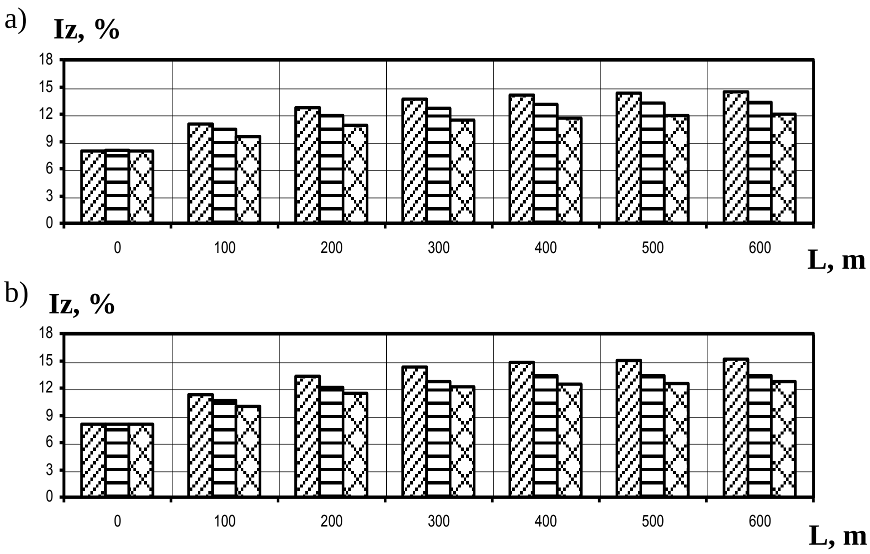


Fig. 3 Change of isotropy degree *Iz* in the function of friction distance for different loads *F* and for the following hardness: a) H_1 = 30 HRC, b) H_2 = 40 HRC, H_3 = 50 HRC



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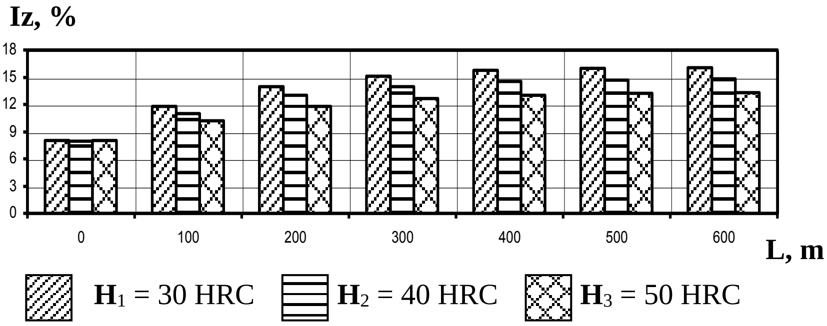

Fig. 4 Change of isotropy degree *Iz* in the function of friction distance for different hardness *H* and for the following loads: a) F_1 = 300 N, b) F_2 = 450 N, F_3 = 600 N

The scatter of results of SSG isotropy degree measurement did not exceed ±2.5% for all the analyzed cases.

It can be said, on the basis of the results presented in the diagrams, that the isotropy degree changes along with the friction distance increase. These changes reflect transformations of the surface structure during its operation. Generally, the value of isotropy degree increases which can be interpreted in such a way that stereometric formation undergoes ‘flattening’ and symmetry of this formation increases.

Particular peaks and ridges of micro-irregularities are partially or entirely cut off. Machining traces, which determine dominant directions of the surface formation, undergo deformation along with an increase in the isotropy degree, which can affect the conditions of lubrication and the motion resistance. The direction of machining traces is visible all the time, even for the maximum value of the isotropy degree obtained during the tests, whose value was app. 16 %.

Isotropy degree changes also depend on the acting forces. On the basis of analysis results of different loads (Fig. 3) it can be said that the lowest force – 300 N – generates the smallest changes, whereas the highest force – 600 N – generates the largest changes. Force equal to 450 N produces medium changes. This observation is rather obvious as elastic deformation is more likely to occur for a higher load, whereas after exceeding a certain level of stress, plastic strains are observed which lead to bigger changes in the controlled quantity. A similar dependence can be observed on the basis of analysis of the changes in terms of the sample hardness (Fig. 4). Stereometric structure of the surface of samples with the lowest hardness (30 HRC) is most susceptible to changes – easily deformed. Whereas, the smallest changes are observed for the highest hardness(50 HRC), when the structure is resistant to elastic and plastic deformation. Medium hardness– 40 HRC – produces changes as well.

Moreover, it can be observed, on the basis of the diagrams, that the changes in isotropy degree distribute more uniformly and proportionally throughout the accepted research range for hardness rather than for different force values. Moreover, it is particularly visible in Fig. 3b.

However, considering the research goal, it can be said that the changes in the surface isotropy degree recorded during tests, confirmed advisability of its application for a description of operational transformation of the surface layer.

CONCLUSIONS

The presented analytical and experimental verification has confirmed usability of a surface structure isotropy degree change for a description of operational transformation of the surface layer.

Due to the fact that the isotropy degree characterizes topographic formation of a surface it can be, apart from roughness parameters, an important element of characterization of the surface layer current condition.

In order to extend the possibilities of using SSG isotropy degree complex, experimental tests concerning the relations of isotropy changes with direct measurements of wear should be carried out.

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