ROUGH SURFACE PEAK INFLUENCE ON THE WEAR PROCESS OF SLIDING-FRICTION PAIRS

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Abstract. The problem of evaluating the working period of different sliding-friction pairs is of great importance nowadays. However, there is still no exact wear calculation model that could be applied to all cases of wear processes because of difficulties connected with a variety of parameters involved in the wear process. One of the wear calculation methods is dealing with the calculation of rough surface peaks that make contact between two surfaces. Taking into account the number of these peaks and applying the fatigue wear model to them in case of sliding-friction movement it is possible to make the wear calculation of fitting under definite working conditions. The wear model is based on 3D surface micro-topography, assessing the material's physical and mechanical characteristic quantities and considering definite service conditions of sliding friction pairs.

Keywords: sliding-friction pairs, wear calculation model, surface.

Surface roughness modelling

The description of the friction surface's micro-topography, particularly in the case of irregular surface roughness, is rather a complicated process owing to the different height of surface roughness peaks and their various configurations. In practice, the roughness description models have been developed based on correct geometrical shapes, for example, of bar shape, spherical, cone-type (also truncated cone), elliptic, cylindrical, prism shape, etc. At the same time, the real irregular surface roughness profiles strongly deviate from the ideal. Therefore, scientists are striving to apply as complete as possible rough surface profile descriptions [1].

For studying the irregular surface roughness (which is very important in practice) the random function theory is efficient, thus the surface micro-topography can be described by a 2D *random function*, i.e. random field $h(x, y)$ with two variables (x and y) [1]. In this case it is the normal random field, i.e. ordinates of such field are distributed according to the normal distribution law.

For characterizing the random function the *correlation function* is of importance, which shows correlation between the random function points, thus the faster the correlation function diminishes the more chaotic is the random function. The correlation function depends on two variables: τ_1 and τ_2, which are the projections of vector τ connecting two surface points on the abscissa and ordinate axes in the Cartesian's coordinate system [1]. The irregular surface roughness can be seen in Fig. 1.

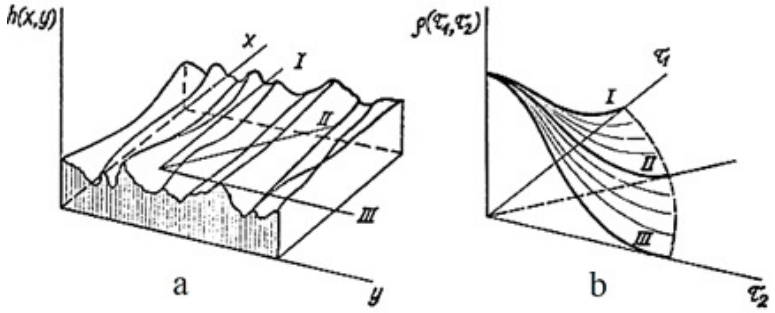

Fig. 1. **Schematic depiction of irregular surface roughness (a) and corresponding standardised correlation function (b)**

The proposed calculation model has the following initial parameters: one surface roughness height parameter – S_a (the standard arithmetic deviation from the mid-plane) that results from the normal random field theory and two roughness step parameters RS_{m1} (a step perpendicular to the processing trace direction along midline) and RS_{m2} (a step towards the processing trace along the midline), which are connected with assumed correlation function.

Step parameters RS_{m1} and RS_{m2} allow determination of the anisotropy coefficient c [2]:

$$c = \frac{RS_{m1}}{RS_{m2}}. \quad (1)$$

The anisotropy coefficient c varies from 0 to 1. At $c = 1$ the area is isotropic, while at $c = 0$ it is maximum stretched.

It must be noted that with the help of the above mentioned initial parameters it is possible to calculate many 3D surface roughness parameters [2].

Rough surface peak calculation

One of the most important parameters in wear processes is the number of peaks of contacting surfaces. The surface $h(x, y)$ peaks (roughnesses) are the part of the rough surface situated above the level u (which is being determined as the cut height from the average value of the field) (see Fig. 2a). Unlike the profile cutting in the given case takes place along continuous curves, which can be seen in Fig. 2b (a view of a cut off surface from above) [2].

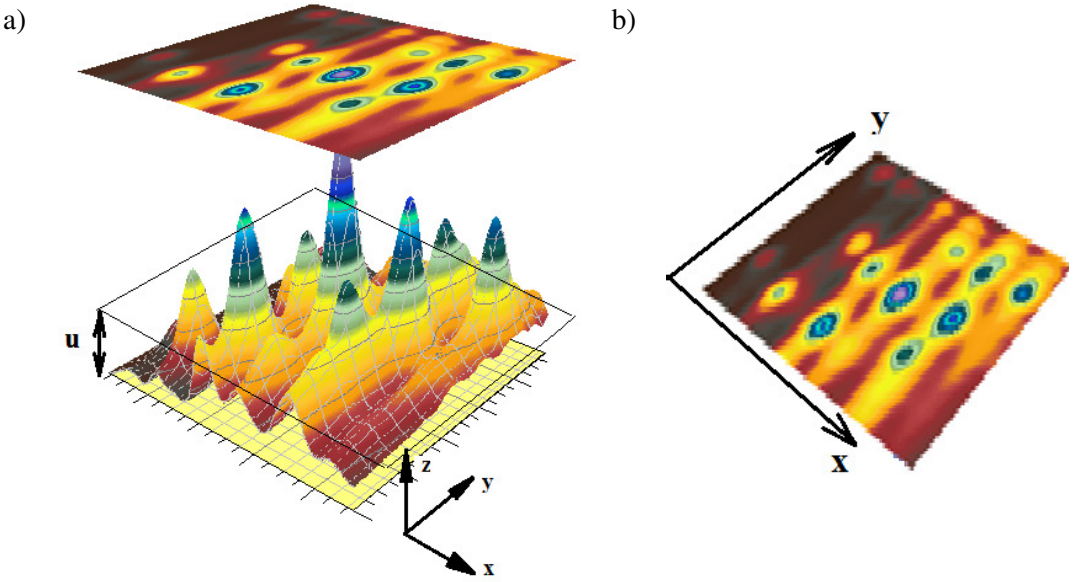

Fig. 2. **Graphic representation of number of surface peaks [2]:** a – 3D surface cut off at level u; b – cut off of surface peaks at level u, view from above

The number of peaks per field unit is determined by the following formula [2]:

$$E\{N_\gamma\} \approx k\gamma e^{-\frac{\gamma^2}{2}}, \quad (2)$$

where γ – relative cut off height standardized with σ, $\gamma = u / \sigma$ [2];
σ – standard deviation of surface roughness;
e – designation of the exponent function;
k – coefficient that takes into account elements of the correlation matrix.

Coefficient k is calculated according to the following expression:

$$k = \frac{\sqrt{k_{22}k_{33} - k_{23}^2}}{2\pi\sqrt{2\pi}\sigma^2}, \quad (3)$$

where k_{22}, k_{33}, k_{23} – are the elements of the correlation matrix.

The correlation matrix elements connect the random field and its derivatives [2].

According to the arbitrary function theory [2] the correlation matrix elements k_{22} un k_{33} are calculated according to the following expression:

$$k_{22} = \frac{\partial^2 K(\tau_1, \tau_2)}{\partial \tau_1^2} \Big|_0 = \sigma_{11}^2, \quad (4)$$

$$k_{33} = \frac{\partial^2 K(\tau_1, \tau_2)}{\partial \tau_2^2} \Big|_0 = \sigma_{12}^2, \quad (5)$$

where $K(\tau_1, \tau_2)$, – random field correlation function;
σ_{11} *un* σ_{12} – standard deviations of the first derivative of random field towards τ_1 (towards x axis) and towards τ_2 (towards y axis).

In its turn, if the coordinate axes x and y are directed so that they coincide with the directions of principal radiuses of the correlation function surface $\rho(\tau_1, \tau_2)$,it follows that $k_{23} = 0$.

The correlation matrix elements k_{22} and k_{33} can be expressed with special profile points, which are calculated using the following expressions [3]:

$$E\{N_{sp}(x)\} = \frac{1}{\pi}\left(- \frac{\rho_{\tau_1}^{(2n+2)}(0,0)}{\rho_{\tau_1}^{(2n)}(0,0)} \right)^{\frac{1}{2}}, \quad (6)$$

$$E\{N_{sp}(y)\} = \frac{1}{\pi}\left(- \frac{\rho_{\tau_2}^{(2n+2)}(0,0)}{\rho_{\tau_2}^{(2n)}(0,0)} \right)^{\frac{1}{2}}, \quad (7)$$

where $E\{N_{sp}(x)\}$ and $E\{N_{sp}(y)\}$ – special random field points per a length unit in x and y directions that coincide with τ_1, τ_2;
n – a line of special points. If n = 0 then special points are zeroes, i.e. $E\{N_{sp}(x)\} = E\{n_1(0)\}$, $E\{N_{sp}(y)\} = E\{n_2(0)\}$
$\rho(\tau_1, \tau_2)$ – standardized correlation function that is connected with the random field correlation function $K(\tau_1, \tau_2)$ in the following expression [3]:

$$\rho(\tau_1, \tau_2) = \frac{K(\tau_1, \tau_2)}{\sigma^2}. \quad (8)$$

In general case special random field points in perpendicular directions are understood as the number of profile zeroes, maximum number and number of bends. In its turn, in the given case it is necessary to use only the number of profile zeroes, because k_{22} and k_{33} can be determined as follows [3]:

$$k_{22} = \pi^2 \sigma^2 E^2\{n_1(0)\}, \quad (9)$$

$$k_{33} = \pi^2 \sigma^2 E^2\{n_2(0)\}, \quad (10)$$

where $n_1(0)$ and $n_2(0)$ – number of profile zeroes towards x and y axes.

An example of determination of the number of zeroes (profile crossings with midline) is given in Fig. 3.

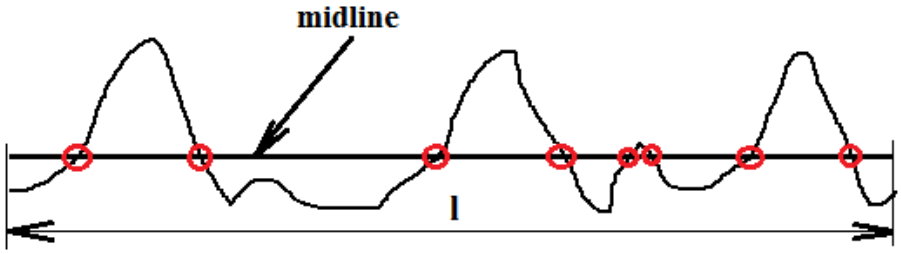

Fig. 3. **Points on profilogram midline characterising numbers of zeroes**

Taking into consideration expressions (9) and (10) and introducing the necessary changes in expression (2) as a result the coefficient k is calculated as follows:

$$k = \frac{\pi E\{n_1(0)\}E\{n_2(0)\}}{2\sqrt{2\pi}}. \quad (11)$$

Using the anisotropy coefficient, which can be found according to formula (1) and introducing the necessary changes the coefficient *k* will look as follows:

$$k = \frac{\pi c E^2\{n_1(0)\}}{2\sqrt{2\pi}}. \quad (12)$$

In its turn, the number of profile zeroes *n*(0) is connected to the surface roughness step parameter *RSm* in the following expression:

$$RSm_1 \approx \frac{2}{n_1(0)}, \quad (13)$$

$$RSm_2 \approx \frac{2}{n_2(0)}. \quad (14)$$

Then the number of peaks can be calculated as follows [2]:

$$E\{N\gamma\} \approx \frac{\pi c}{\sqrt{2\pi}RSm^2}\gamma e^{-\frac{\gamma^2}{2}}. \quad (15)$$

Rough surface peak experimental determination

To check the conformity of the given formula an experiment was carried out and it was checked how a theory that concerns calculation of the number of surface peaks coincides with experimental results. Experimental measurements were made on the processed surface (see Fig. 4), using Taylor Hobson Intra surface roughness measuring device.

The given surface is characterised by the following principal parameters: $Sa = 0.811$ μm; $S_t = 9.33$ μm; $Sds = 11624$ pks·mm^{-2}.

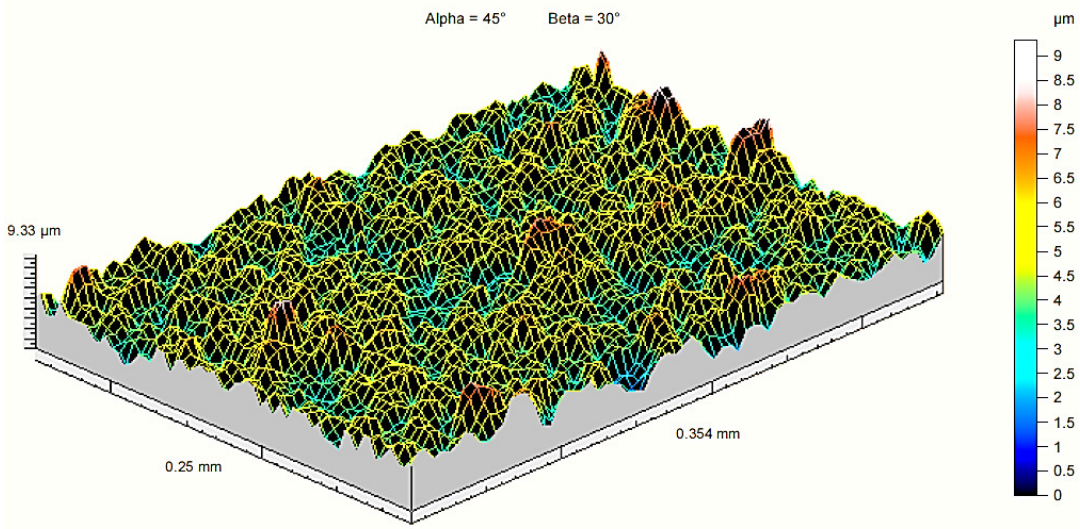

Fig. 4. **Surface micro topography**

The number of zeroes and values needed for theoretical calculation can be found using the profile parameters (see Fig. 5 and Fig. 6) that are summarised in Table 1.

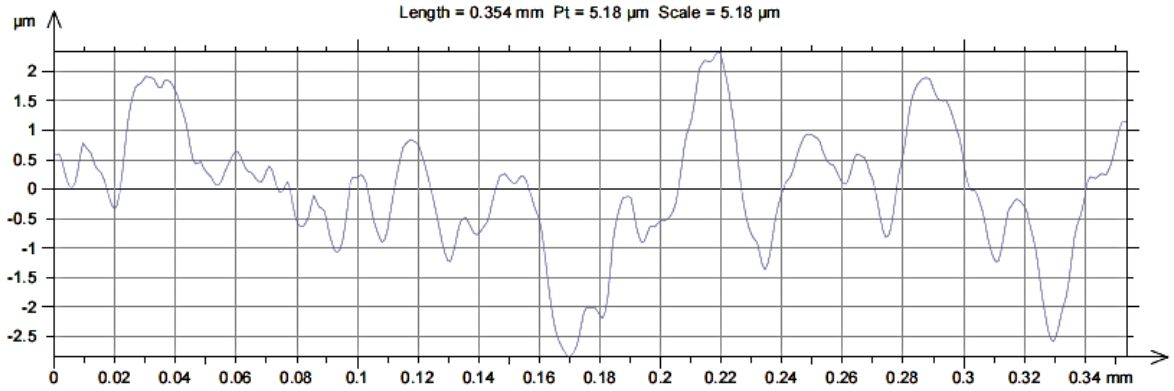

Fig. 5. **Profile towards x-axis** (along the longest sample's side)

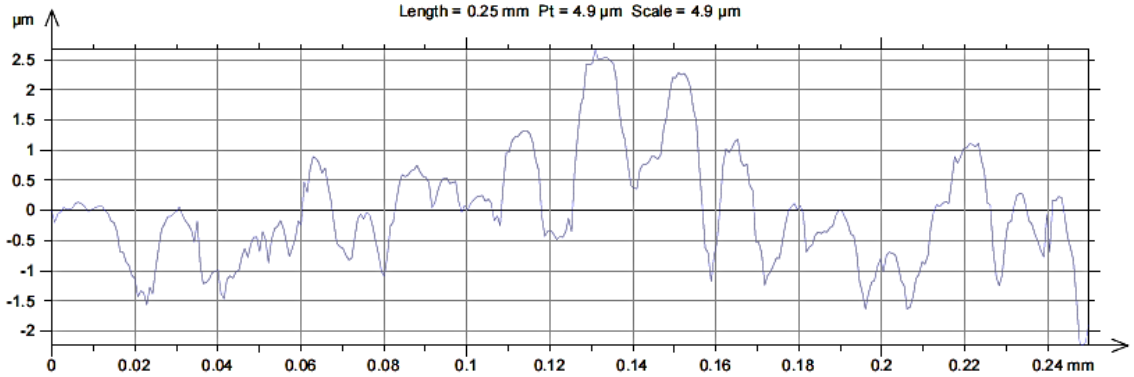

Fig. 6. **Profile towards y-axis (along the shortest sample's side)**

Table 1

Surface profile parameters

Parameter	Value
R_a	0.723 µm (along the longest side)
RS_{m1}	0.0253 mm
R_a	0.611 µm (along the shortest side)
RS_{m2}	0.0166 mm

To determine the number of surface peaks depending on the level u, the surface was cut off on different levels, counting from the middle plane. Examples of cut offs at u=1σ, u=2σ, u=3σ and u=4σ are given in Figure 7.

The number of roughnesses depending on the level of surface cut off is given in Table 2.

Table 2

Number of surface roughnesses

Level of surface cut off	Number of peaks Sds, pks·mm^{-2}
Surface cut off along midline	8942
1σ above midline	3679
2σ above midline	713
3σ above midline	158
4σ above midline	22.6

The measurement results and theoretical calculations are summarised in Fig. 8.

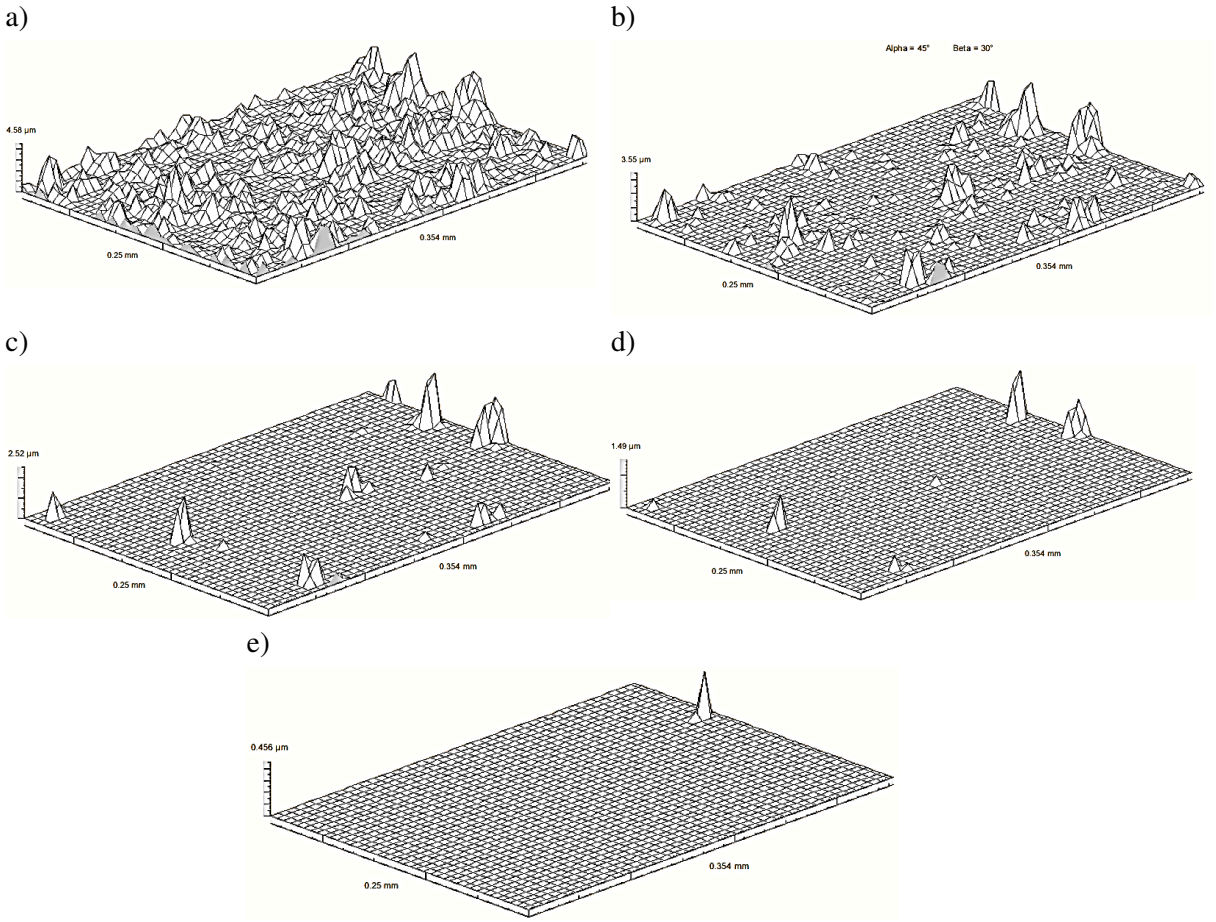

Fig. 7. **Surface cut offs on different levels:** a – surface cut off along midline; b – surface cut off 1σ above midline; c – surface cut off 2σ above midline; d – surface cut off 3σ above midline; e – surface cut off 4σ above midline

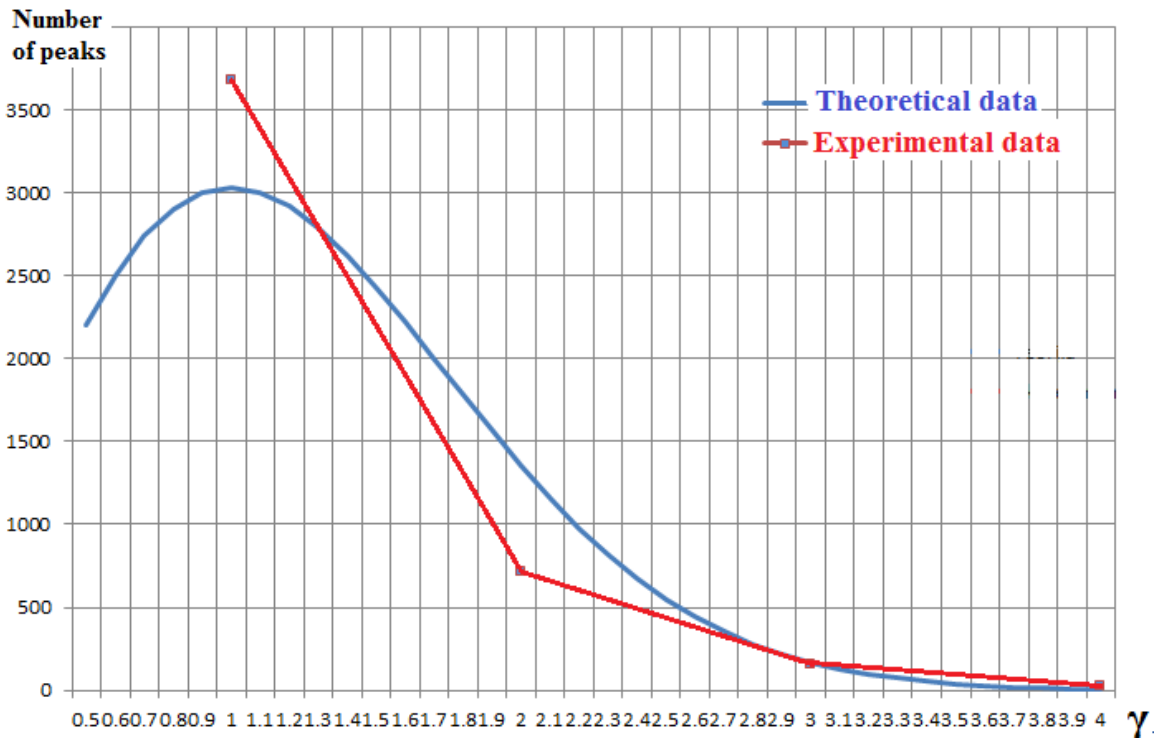

Fig. 8. **Experimental and theoretical number of peaks**

Conclusions

The number of surface roughnesses (rough surface peaks at definite level) obtained according to the above calculation model at high γ levels close enough coincides with the experimental data, thus we can conclude that the theoretical calculation formula can be used for calculation of the peak number. However, for more precise results it is necessary to make further investigations.

References

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