Dependence of physical and mechanical properties of metal surfaces on microgeometric parameters

V V Kalmykov¹, M V Mousokhranov¹, E V Logutenkova¹

¹Kaluga Branch of Federal State Budgetary Educational Institution of Higher Education "Moscow State Technical University named after N.E. Bauman (National Research University)," 2, Bazhenova Street, Kaluga 248600, Russia

E-mail: kalmykovvv@bmstu.ru

Annotation. This study examines the interrelation between surface microgeometry parameters after external influence by line-by-line microdeformation and the level of surface energy. The measurements were performed on experimental samples of C20, C45, X10Cr13. The values of surface energy were determined by the static capacitor method. It was established that the highest and lowest levels of surface energy correspond to the microgeometric parameters of the substrate. The results of the study can be used for industrial provision of the required physical and mechanical properties.

1. Introduction

Substrates are characterized by microgeometric parameters (Fig. 1) and physical and mechanical properties. They are formed by production operations accompanied by external mechanical influence. Traces from the cutting tool can be seen on the surface of the substrates, the shape and direction of which depend on the pattern and type of influence. External influence is carried out line by line and the choice of the line interval depends on the requirements for accuracy and surface cleanliness [1-3]. To ensure high values of these parameters, additional tool movements are used to compensate for errors caused by the elastic properties of structural materials. Besides, there is an informed judgement that additional movements of the tool on the surface of the substrate change its energy state [4–9].

Figure 1. Schematic representation of microgeometric parameters of the surface

External impact leads to microdeformation of the surface layer, local compression and distortion of the crystal lattice, local breakdown of lattice parts and individual atoms due to frictional forces, a change in the surface microgeometry, which leads to a change in the physical and mechanical properties of the structural material’s boundary layer [10, 11].

This study aims to examine the relationship between surface microgeometry parameters after line-by-line microdeformation and the level of surface energy (SE).

2. Materials and methods

The changes in the SE of materials and microgeometry of surfaces under external mechanical influence with line-by-line microdeformation were studied on experimental samples made of C20,
C45, X10Cr13. The material of the influencing tool was hard alloy GC1040. The blunting radius of the edges of the tool was 0.02 mm. Microdeforming was performed on a vertical milling machining centre with a MiniMill 450 CNC machine. The SE value was determined using the static capacitor method [12–15]; the surface microgeometry parameters were determined using an ABRIS–PM7 profilograph-profilometer. The hardness of the material under study was determined on the Brinell scale using a hardness meter.

Samples of rigid structures (\( h_y \approx 0 \mu m \)) and structures prone to elastic recovery after surface shaping (\( h_y \approx 2 \mu m \) and \( h_y \approx 4 \mu m \)) were studied.

### 3. Results and discussion

A comparative analysis of the mean absolute error of the substrate profile from the ideal plane within the evaluation length was performed. The profilogram of the surface after preliminary shaping by removing a layer of material (\( h_y = 300 \mu m \)) and microdeforming with external influence traces line interval \( f_z = 40 \mu m \) is shown in Fig. 2.

![Profilogram of the surface](image)

Fig. 2. The profilogram of the surface after preliminary shaping by removing a layer of material and microdeforming (C45)

The profilogram (Fig. 2, microdeformation \( h_y \approx 0 \mu m \)) shows peaks of the surface irregularities jammed into depressions, which corresponds to the highest SE values. The profilogram (Fig. 2, microdeformation \( h_y \approx 2 \mu m \)) shows slightly jammed peaks of the irregularities without the material moving into depressions. The profilogram (Fig. 2, microdeformation \( h_y \approx 4 \mu m \)) shows jammed peaks of the irregularities with the material moving into depressions, which corresponds to the lowest SE values. The deformation of the height combs of the irregularities is mostly observed during microdeformation of the surface of rigid structures (\( h_y \approx 0 \mu m \)).

As a result of the analysis of the microgeometry of the surfaces exposed to external mechanical influence, it can be concluded that the greatest manifestation of ruptured zones caused by the distortion of crystal lattices occurs in the substrate of rigid structures. This corresponds to the highest SE values.
Also, a comparative analysis of the mean absolute error of the profile was performed within the evaluation length after preliminary surface shaping and microdeformation of steel 20. The surface profilogram with line interval $f_z=40 \, \mu m$ is presented in Fig.3.

![Surface Profilogram](image)

Fig. 3. The profilogram of the surface after preliminary shaping by removing a layer of material and microforming (C20)

The analysis of the results showed that deformation of the height combs of the irregularities is mostly observed during microdeformation of the surface of rigid structures ($h_y \approx 0 \, \mu m$).

Also, the mean absolute error of the substrate profile was analysed within the evaluation length after preliminary surface shaping and microdeformation of X10Cr13. The surface profilogram with line interval $f_z = 40 \, \mu m$ is presented in Fig.4.

The deformation of the height combs of the irregularities is also mostly observed during microdeformation of the surface of rigid structures ($h_y \approx 0 \, \mu m$).
4. Conclusions
As a result of the analysis of the change in microgeometry of the surfaces exposed to external mechanical influence by line-by-line microdeformation, it can be concluded that the greatest manifestation of ruptured zones caused by the distortion of crystal lattices occurs in the substrate of rigid structures. This corresponds to the highest SE values.

References
[1] Musokhranov M V 2005 Surface energy as an indicator of the quality of the surface layer. Engineering journal with the app 12 (105) 62-64
[2] Musokhranov M V, Kalmykov V V, Avramenko M U 2016 Technological prerequisites for improving the performance of the guide elements Fundamental research 8-1 55-58
[3] Musokhranov M V 2005 The role of surface energy in the formation of parts in precision engineering Assembly in mechanical engineering, instrumentation 6 9-11
[4] Kachejev A Z, Kumykov V K, Manukyanc A R, Sergeev I N, Sozaev V A 2008 Pressure Influence on the surface energy of metals In the book: Physics of low-dimensional systems 289-292
[5] Malyshev E N, Musokhranov M V, Kalmykov V V, Antanuk F I 2015 Distribution of energy technological impact in the formation of working surfaces of machine parts made of metal materials Modern problems of science and education 1-1 58
[6] Musokhranov M V, Kalmykov V V, Logutenkova E V, Sorokin S P 2016 Energy state of the surface layer of machine parts Modern high technology 5-2 276-279
[7] Kalmykov V V, Musokhranov M V, Logutenkova E V, Malyshev E N, Gorbunov A K 2017 Generation of surface energy in metals using row-by-row microdeformation International Journal of Applied Engineering Research T. 12. 24 15621-15626
[8] Musokhranov M V, Kalmykov V V, Malyshev E N 2017 Experimental research of variability of surface energy value of Fe37-3FN, C45 and 41Cr4 steels International Journal of Applied Engineering Research T 12 17 6428-6433
[9] Musokhranov M V, Kalmykov V V, Malyshev E N, Zenkin N V 2015 Energy of surface layer
of metals as a tool of impact on the value of friction coefficient Fundamenta 1

[10] Chertovskikh S V, Semenov V I., Shuster L Sh 2015 The Influence of surface energies of the contacting materials on the tribological characteristics of Actual directions of scientific researches of the XXI century: theory and practice Vol.3 4-1 (15-1) 134-141

[11] Patent Nikolin S V, Timashev M Yu, Volkov S S, Suvorov G V, The method of measuring the contact potential difference FindPatent.ru -patent search

[12] Kushnir F. V. 1983 electrical measurements (textbook for universities Leningr. otd-nie) 320 p

[13] GOST R 8.736-2011 state system for ensuring the unity of measurements (GSI). The direct measurement repeated. Methods of processing of measurement results. Fundamentals

[14] Frolenkova L Yu, Shorkin V S 2013 Method of calculation of surface energy and adhesion of elastic bodies Bulletin of Perm national research Polytechnic University. Mechanics 1 235-259