

Influence of parameters of discretely textured oil-retaining contact surfaces on the fretting resistance of tribosystems

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The study investigates the efficiency of improving the fretting resistance of tribosystems by forming oil-retaining discretely textured surfaces (DTS) with regularly arranged microdimples. Phenomenologically, such surfaces were considered as having a discrete texture, and the microdimples acted as reservoirs providing continuous regeneration of boundary lubricant layers in the frictional contact zone. The DTSs in the form of a system of prismatic and spherical microdimples with specified texture parameters were created on the working surfaces of samples using an impact–plastic deformation method. Friction pairs with different hardness of contacting materials were studied. Pairs with DTS formed on samples with hardness higher than that of their counterbodies were usually called direct pairs. In contrast, pairs with lower DTS hardness compared to the counterbody were called inverse pairs. It has been established that under fretting conditions with lubricated polished surfaces, lubrication does not provide a significant increase in the fretting resistance of the studied materials, both in direct and inverse pairs; this indicates insufficient stability of boundary lubricant layers on such surfaces. Under identical fretting wear and lubrication conditions, friction pairs with DTS demonstrated significantly increased resistance to fretting-corrosive wear. The most pronounced improvement in wear resistance was achieved in direct pairs with spherical dimple profiles. Compared to the baseline version, the wear of samples with pairs of spherical dimples was more than six times lower. At the same time, the wear of counterbodies and the total wear of the pair also decreased significantly. It was shown that for given DTS formation parameters and fretting conditions, the spherical profile ensured the higher lubrication efficiency of microdimples compared to the prismatic profile. Based on the experimental results, statistical analysis was performed, and regression models were developed to describe the dependence of wear on the technological parameters of surface texturing and fretting conditions.

Keywords: frictional contact, oil-retaining surface, lubrication, fretting, wear, mechanical energy.

Вплив параметрів дискретно-текстурованих мастилоємних поверхонь контакту на фретингостійкість трибосистем. *М. В. Кіндрачук, В. С. Марчук, В. В. Харченко, М. С. Стечишин, А. О. Юрчук, В. В. Марчук, М. А. Гловин, І. В. Костецький*

Виконано дослідження з визначення ефективності підвищення фретингостійкості трибосистем формуванням дискретно-текстурованих мастилоємних поверхонь у вигляді регулярно розташованих мікрозаглиблень. Феноменологічно такі поверхні розглядались як дискретно-текстуровані, а мікрозаглиблення – як резервуари, що забезпечують постійну регенерацію граничних мастильних шарів в зоні фрикційного контакту. Формування дискретно-текстурованих поверхонь у вигляді системи лункових пірамідальних і сферичних мікрозаглиблень з заданими параметрами текстури на робочій поверхні зразків здійснювалось методом ударно-пластичного деформування. Досліджувались пари тертя з різним розташуванням матеріалів в парі за твердістю. Пари, у яких дискретно-текстурована поверхня формувалась на зразках з більшою твердістю, ніж твердість контртіла, умовно називали прямими парами. Пари з меншою твердістю дискретно-текстурованої поверхні ніж твердість контртіла називали оберненими. Встановлено, що у разі тертя шліфованих поверхонь за прийнятих умов фретингу мащення не забезпечує суттєвого підвищення фретингостійкості досліджуваних матеріалів як у прямих, так і у обернених парах тертя, що свідчить про недостатню високу стійкість на таких поверхнях межових мастильних шарів. За таких же умов фретингу і умов мащення стійкість до фретинг-корозійного зношування пар тертя із дискретно-текстурованими поверхнями помітно зростає. Найбільший ефект підвищення зносостійкості досягається у прямих парах при сферичному профілі лунок. У порівнянні з базовим варіантом за абсолютним значенням величини зносу зразків із сферичним профілем лунок у прямих парах зменшився більш ніж у 6 разів. Одночасно помітно зменшився також знос контрзразків і сумарний знос пари. Очевидно, що за прийнятих параметрів формування дискретно-текстурованих поверхонь і параметрів фретингу, сферичний профіль забезпечує найбільшу змащувальну ефективність мікрозаглиблень у порівнянні із призматичним профілем. За результатами експерименту проведено статистичний аналіз та побудовано регресивні моделі залежностей величини зносу від технологічних параметрів формування дискретно-текстурованих поверхонь і параметрів фретингу.

1. Introduction

One of the traditional methods for ensuring antifriction properties and reducing the intensity of wear of friction unit components is lubrication. Friction under lubrication conditions reduces the frictional load on the components and, due to the presence of special active additives in the lubricant, promotes the formation of secondary non-oxide structures on the surface of the frictional contact that are more resistant to wear [1]. At the same time, in nominally immobile joints subjected to vibration loads, conventional finishing methods and both liquid and even consistent lubricants are of low efficiency. In such joints, the positive lubricating effect is observed only during the initial incubation stage of fretting, when the boundary lubrication layer formed by the lubricant still retains its integrity.

The concept underlying the proposed method for enhancing the fretting resistance of tribosystems is based on minimizing the mechanical energy supplied to the tribosystem and reducing the dynamic load on the surfaces by creating conditions for the regeneration of boundary lubricant layers in the tribocontact zone. For nominally immobile joints, this problem can most effectively be solved by forming oil-retaining surfaces with regularly arranged microdimples. Phenomenologically, such surfaces

are considered as discretely textured surfaces (DTS), and microdimples serve as reservoirs that retain lubricant in the frictional contact zone [2-7].

The mechanism of the influence of oil-retaining DTSs on the processes of friction and wear under fretting conditions has not been sufficiently studied. Obviously, in this case, the main role in the formation of tribological properties of friction pairs is played by the parameters of a discrete surface. The optimal arrangement, shape, and dimensions of microdimples will promote lubricant penetration into the zones of direct frictional contact, reduce their frictional load, and accordingly lower the level of mechanical energy supplied to the tribosystem. In this regard, the purpose of this work was to test friction pairs with different dimple profile shapes, perform statistical analysis and develop regression models of wear dependence on the studied parameters.

To evaluate the efficiency of the method for forming oil-retaining DTSs under fretting–corrosion wear conditions, first of all, comparative test experiments were carried out at the initial stage. Tribological characteristics of friction pairs with non-textured polished surfaces and discretely textured dimpled surfaces under fixed fretting parameters were determined and compared.

Table 1. Materials of the studied friction pairs

No	Type of pair		Material	Hardness, HRC
1.	Direct	Sample	Steel 45, quenched	50...52
		Counter body	Steel 45, normalized	20...22
2.	Inverse	Sample	Steel 30XГCA, as-delivered	18...20
		Counter body	Steel 45, quenched	50...52

2. Materials and Methods

The experiments were carried out on an MFK-1 friction testing machine. DTSs in the form of systems of microdimples with specified texture parameters were created on the working surfaces of samples using the impact-plastic deformation method. Before texturing, the working surfaces of samples and counterbodies were polished to a surface roughness of $R_a \approx 0.32 \mu\text{m}$.

For test trials, friction pairs with different dimple profile shapes and different hardness ratios of the materials being joined were prepared. Pairs in which a DTS was formed on samples of the higher hardness than that of the counter body were usually called direct pairs. Pairs with the lower DTS hardness compared to the counterbody were called inverse pairs. The materials of the studied friction pairs are listed in Table 1. The technological schemes of surface texturing and the parameters of the textured surfaces are shown in Fig. 1 and Table 2, respectively.

As a base version for comparison, friction pairs made of the same materials with polished working surfaces were used. Tests were carried out under dry friction and lubrication conditions in a lubrication starvation regime, with a single application of the CIATIM-201 grease to the sample surface. The vibro-contact loading parameters during the test trials were as

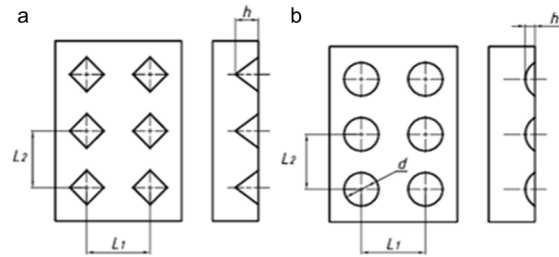


Figure 1. Schemes of forming discretely textured oil-retaining surfaces. Profile shape of microdimples: (a) prismatic; (b) spherical.

- amplitude of relative displacement: $A = 175 \mu\text{m}$;
- specific contact pressure: $P = 19.8 \text{ MPa}$;
- oscillation frequency: $\nu = 25 \text{ Hz}$;
- test duration: $N = 5 \times 10^5 \text{ cycles}$.

3. Results and Discussion

Fig. 2 shows the absolute wear values obtained during the tests and determined gravimetrically based on the loss of mass of the samples. As can be seen, in the case of polished surfaces under applied fretting conditions, lubrication did not provide a significant increase in the fretting resistance of the studied materials in both direct and inverse friction pair types. This indicates an insufficient stability of boundary lubricant layers formed on such surfaces.

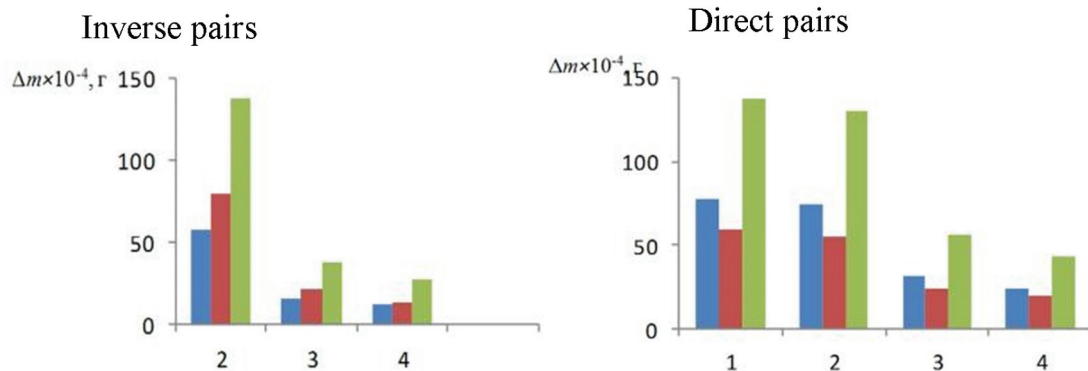


Figure 2. Diagram of absolute values of the weight wear of samples and counter bodies and the total wear of friction pairs during wear tests under fretting corrosion conditions. Versions of sample surface preparation: 1 – polishing, without lubrication; 2 – polishing and lubrication with CIATIM-201; 3 – DTS No. 1, lubrication with CIATIM-201; 4 – DTS No. 2, lubrication with CIATIM-201.

Table 2. Technological parameters of DTS of studied friction pairs

Surface variant	Dimple profile	Distance between dimples in a row, L_1 , m	Distance between rows of dimples, L_2 , m	Dimple depth h , m	Dimple volume V , mm^3
1	Prismatic	$2.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$0.15 \cdot 10^{-3}$	0.006
2	Spherical	$2.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$0.08 \cdot 10^{-3}$	0.021

Under the same fretting and lubrication conditions, the resistance of friction pairs with DTS to fretting–corrosion wear increased significantly. The greatest improvement in wear resistance was observed in direct pairs with a spherical dimple profile. Compared to the base version, the absolute wear of samples with spherical dimples in direct pairs (Table 1, variant 2) decreased by more than six times. At the same time, the wear of counterbodies and the total wear of the pair also decreased significantly. Therefore, under the chosen conditions of surface texturing and fretting, the spherical profile provides higher efficiency of lubricating microdimples compared to the prismatic profile. Moreover, as shown in Fig. 3, spherical microdimples are characterized by a lower rate of decrease in the volume of oil-holding microdimples with increasing linear wear of the sample.

Thus, it can be stated that the formation of DTS with a developed system of microdimples, even in cases where one element of the friction pair has relatively low hardness, can serve as a simple and effective way of improving the wear resistance and extending the service life of tribosystems under frictional wear conditions with insufficient lubrication. The mechanism of the improved tribological properties of tribosystems with DTSs, as expected, is associated with the creation of more favorable conditions for the preservation and regeneration of boundary lubricant layers in the tribocontact zone. The loads on the tribosystem act through the lubricant layer located in the inter-dimple space, which prevents direct metal-to-metal contact. Since the shear strength of boundary lubricant layers is much lower than that of metals, the creation of conditions that ensure their continuous regeneration provides stable low friction coefficients and, accordingly, a low level of frictional loading of the tribosystem. From a rheological point of view, this approach increases the dissipative capacity of the lubricated frictional contact [8], which leads to an increase in the proportion of the system’s dissipated energy and a decrease in the proportion that contributes to wear and damage to the surface.

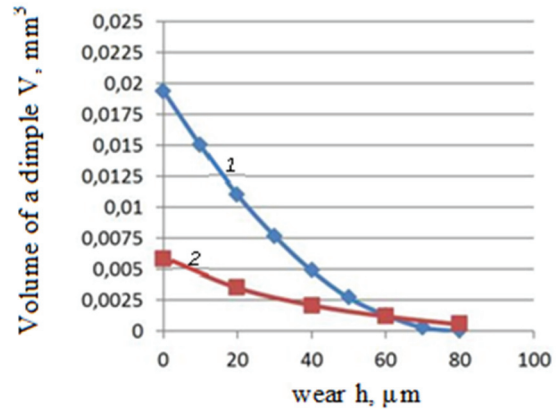


Figure 3. Calculated dependences of the changes in the volume of an individual dimple in direct pairs on linear wear. Dimple profile: 1 – prismatic; 2 – spherical. Parameters of DTS are identical to those in Table 2.

To determine the influence of DTS parameters and fretting parameters on the resistance to fretting–corrosion wear of the tribosystem under the above-defined lubrication conditions, a study was carried out for the coupling of materials in a reverse friction pair (Table 1) with a prismatic profile of microdimples as the least favorable option in terms of wear intensity. The study used the method of multifactorial experimental design and mathematical data processing, which allows obtaining the corresponding functional dependencies of the output parameters (wear values) from the input ones (geometric parameters of the formation of DFS; parameters of the vibrocontact during load during fretting). The model was created in several stages: formalization of the problem; construction of the experimental plan; preliminary statistical analysis of the experimental results; construction of mathematical models based on the experimental results; analysis of the reliability of the obtained model; obtaining calculated dependences using the model.

Based on the results of the experiment, a statistical analysis was carried out, and regression models of the dependence of the wear (response function Y) on the studied parameters were constructed; the ranges are presented in Table 3. The models were calculated using the

Table 3 Code values and limits for alignment of discrete-hole surface parameters and fretting parameters

No	Variation parameters	Code designation	Range of variation
1.	Parameters of discrete-hole surfaces: distance between rows, $\times 10^{-3}$ m distance in a row (step), $\times 10^{-3}$ m depth of holes (deforming head stroke) $\times 10^{-4}$ m	X1	1.5 ... 3.0
		X2	1.5 ... 3.0
		X3	0.5 ... 1.5
2.	Fretting parameters: specific normal load on the contact, MPa	X4	10...30
	amplitude of relative slip of the samples, μm	X5	100...300

application program package “Planning, Regression, and Analysis of Models”. The matrix design and the data obtained from the experiment were used as initial data.

The regression models describe in coded values the dependence of wear results by weight of structural steel 30KhGSA in the delivery condition (sample), hardened medium-carbon steel 45 (counterbody), and the total wear of the friction pair with boundary lubrication in the lubrication starvation mode on the parameters of DTS and fretting amplitude-load parameters.

It should be noted that the chosen method of constructing a mathematical model of the process allows us to get rid of the two main shortcomings of the classical theory of experiment planning and regression analysis, which limit their application, namely, the design and processing models of a predetermined structure and the use of the standard region of design.

According to the results of the calculations, mathematical models were obtained that describe in code values the dependence of wear results by weight of structural as-delivered steel 30KhGSA having a DTS with the prismatic profile of microdimples (sample), structural hardened medium-carbon steel 45 (counterbody), and the total wear by weight of the fretting friction pair under boundary friction conditions in the oil-starvation mode on the parameters of the DTS and fretting:

- Weight wear of the sample

$$Y_5 = 0.00524817 - 0.0015448x_3 + 0.00172928x_5 + 0.00101434x_4x_5 + 0.000970422x_4 + 0.000572524x_1x_3 + 0. \quad (1)$$

- Weight wear of the counter body

$$Y_6 = 0.00439672 - 0.00182549x_3 + 0.00150567u_1z_2 - 0.000541859x_2 + 0.000827717u_2z_5 - 0.000784443z_2x_4 + 0.00340455z_2u_5 + 0.00097213x_5 \quad (2)$$

- Total weight wear of the pair

$$Y_7 = 0.00971511 - 0.00387282x_3 + 0.00299399u_1z_2 - 0.00142182x_2 - 0.00182509z_2x_4 + 0.00165128u_2z_5 + 0.00693571z_2u_5 + 0.00184508x_5 \quad (3)$$

Thus, as a result of statistical analysis, it was established that the obtained regression dependences are adequate and informative, the results are reproducible, and the coefficients b_o and b_i are statistically significant. This indicates that the regression dependences adequately describe processes and can be used to analyze and optimize the technological process of forming DTS for parts operating under conditions of fretting corrosion wear and boundary friction. In the studied factor’s space, the most significant technological parameters that affect the fretting resistance of the tribosystem are the depth of microdimples and the density of their location, related to the pair interaction of parameters XI and X2.

As known, distinct features of tribological processes during vibration sliding are small amplitudes of relative surface displacement, low sliding speeds, and the dynamic nature of the acting loads [9-11]. Under such conditions, the duration of the protective action of boundary lubrication film (BLF) (the duration of the latent period) is controlled by the ratio of the rates of their destruction and restoration and is determined both by the properties of the lubricant itself and by the nature and condition of the hard surfaces of the tribo-pair elements. Taking into account that the friction and wear processes in tribosystems with oil-retaining DTSs occur in the contact areas located in the inter-dimple spaces [12], the mechanism of destruction of the friction surfaces of such tribosystems under fretting can be represented by the following three-stage model (Fig. 4).

Stage 1 includes the formation of a primary level of boundary lubrication, when natural oxides and adsorbed films on the joined metal surfaces are destroyed as a result of plastic de-

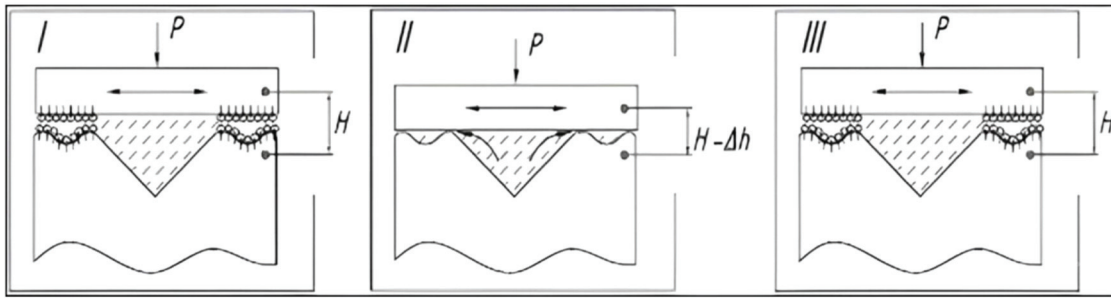


Fig. 4. Modeling of tribological processes in the zone of a separate contact area of a tribosystem with a discretely textured oil-retaining surface under conditions of fretting corrosion wear: I – stage of formation of a primary boundary lubrication layer; II – stage of destruction of the boundary lubrication film and development of fretting corrosion wear of tribocontact surfaces; III – stage of restoration of the integrity of the boundary lubrication film.

formation along the tops of micro-dimples. The formed local micro-sections of the metal surface, activated by repeated elastic-plastic reformation, play the role of active centers for the adsorption of polar molecules of surfactants coming from the lubricant. This process ends with the formation of a mono- or poly-molecular layer of BLF. Such layers, according to [13], have high resistance to compression and low resistance to tangential displacement, which provides the protection of the metal surface from destruction.

At Stage II, in the loaded areas of contact under the action of normal and vibration tangential loads [14] and the simultaneous catalytic action of the metal surface on the lubricant, complex irreversible processes of structural rearrangement occur, accompanied by a qualitative change in the rheological characteristics of the tribocontact materials [15-18]. This ultimately leads to the progressive destruction of BLF [19]. At the same time, in spots where the integrity of BLF is violated, the destruction of the metal surfaces of the tribocontact proceeds by the usual mechanisms of fretting corrosion.

If coupling is modeled as a finite number of triboelements [16, 20], then the elementary acts of destruction of the contact surfaces at stage II will cause a decrease in the size of the triboelement pairs by the value Δh in the direction perpendicular to the surface. Due to the reduction in the volume of microdimples, the excess lubricant is forced out into the inter-dimple space.

Stage III is associated with the restoration (regeneration) of the integrity of BLF.

The above-mentioned stages of the tribological process, developing in the zone of frictional contact, will be periodically repeated until, as a result of wear, the microdimples lose their lubricating ability. It is obvious that in this regard, tribosystems with discretely textured oil-

receiving surfaces can be considered as adaptive self-healing tribosystems.

To sum up, in the obtained models, the coefficients were statistically significant, indicating that the models are informative and can be used to analyze and optimize the technological process of forming DTSs operating under fretting-corrosion wear and boundary lubrication. Visual analysis of regression surfaces (families of partial regression plots) provides a graphical representation of the response function; this allows for a detailed study of the influence of various factors and the identification of ranges in which they have the greatest or least impact. Thus, the statistical analysis confirmed that the obtained regression dependences are adequate and informative, the results are reproducible, and the coefficients are statistically significant. This indicates that the models can be applied for the analysis and optimization of technologies for forming DTSs of components operating under fretting-corrosion wear and boundary lubrication. Among the technological parameters affecting fretting resistance in the studied factor space, the most significant were the depth of dimples and their spatial density.

4. Conclusions

The greatest improvement in wear resistance was achieved in direct pairs with spherical dimple profiles. Compared to the base version, the absolute wear of samples with spherical dimples arranged in direct pairs was reduced by more than six times. At the same time, the wear of counterbodies and the total wear of the pair also decreased significantly. It is obvious that, given the selected parameters for the formation of DTSs and fretting conditions, the spherical profile provides the highest lubricating efficiency of microdimples compared

to the prismatic profile. Thus, it can be concluded that the formation of DTSs with a developed system of microdimples, even with a relatively low hardness of one of the elements of the friction pair, can be a simple and effective way to improve the wear resistance and prolong the service life of tribosystems under fretting and insufficient lubrication conditions.

References

1. Kostetsky B.I., Nosovsky I.G., Karaulov A.K., et al. "Surface strength of materials under friction." Kyiv: Tekhnika, 1976.
2. Marchuk V.Ye., Dukhota O.I., Gradinsky Yu.O., Yenin O.M. Fretting resistance of discrete surfaces under boundary lubrication conditions. "Bulletin of Kharkiv National Technical University of Agriculture named after Petro Vasylenko", (1000), 147–152 (2010).
3. Marchuk V.E., Dukhota O.I., Naumenko N.O. Investigation of the wear resistance of electrospark coatings under fretting wear conditions. "Problems of Friction and Wear", 56, 84–93 (2011).
4. Tsybanov H.V., Marchuk V.E., Dukhota O.I., Gradinsky Yu.O. Fretting fatigue of 30KhGSA steel with discretely oriented textured surface. "Issues of Design and Manufacture of Aircraft Structures", 3(71), 124–127 (2012).
5. Marchuk V.Ye., Kudrin A.P., Dukhota O.I. Influence of parameters of discrete-dimpled contact surfaces on fretting resistance of structural steel under boundary lubrication conditions. "Problems of Friction and Wear", 58, 58–64 (2012).
6. Shamrai V., Mikosyanchyk O., Zaboykina N. Strengthening and increasing the wear resistance of agricultural machine parts with composite coatings of discrete structure. "Problems of Friction and Wear", 4(101), 60–72 (2023). [https://doi.org/10.18372/0370-2197.4\(101\).18080](https://doi.org/10.18372/0370-2197.4(101).18080) [<https://doi.org/10.18372/0370-2197.4%28101%29.18080>]
7. Marchuk V.E., Lyashenko B.A., Dukhota O.I., Morozov V.I., Budyonny I.S. Wear processes in tribosystems with DTSs. In: "Proc. XI Int. Sci. Tech. Conf. AVIA-2013", Kyiv, Vol. 3, pp. 15.45–15.46 (2013).
8. Shevelya V.V., Orlovich V.O., Kirilkov V.A., Fedyna V.P. Dissipative properties and fretting resistance of plastic lubricants. "Problems of Tribology", 13, 55–66 (2007).
9. Golego N.L., Alyabyev A.Ya., Shevelya V.V. "Fretting corrosion of metals." Kyiv: Tekhnika, 1974.
10. Waterhouse R.B. "Fretting corrosion." Leningrad: Mashinostroenie, 1974.
11. Shevelya V.V., Kalda H.S. "Fretting fatigue of metals." Khmelnytskyi: Podillya, 1998.
12. Marchuk V.E., Dukhota O.I., Morozov V.I. "Friction and Wear", 57, 128–138 (2012).
13. Akhmatov A.S. "Molecular physics of boundary lubrication." Moscow: State Publishing House of Physics and Mathematics Literature, 1963.
14. Kindrachuk V.M., Galanov B.A., Kartuzov V.V., Dub S.N. Refined model of elastic nanoindentation of a half-space by the blunted Berkovich indenter accounting for tangential displacements on the contact surface. "Journal of Materials Science", 44, 2599–2609 (2009).
15. Dmytrychenko M.F., Mnatsakanov R.H., Mikosyanchyk O.O. "Tribology and the fundamentals of machine reliability." Kyiv: INFORMA VT-ODOR, 2006.
16. Sorokatyi R.V. Modeling the behavior of tribosystems using the triboelement method. "Friction and Wear", 23(1), 16–22 (2002).
17. Kindrachuk M.V., Dushek Yu.Ya., Luchka M.V. The local character of the stress–strain state of a composite loaded by friction forces. "Powder Metallurgy", (9–10), 56–61 (1994).
18. Kindrachuk M.V., Dushek Yu.Ya., Luchka M.V., Gladchenko A.N. Evolution of the structure and properties of eutectic coatings during friction. "Powder Metallurgy and Metal Ceramics", 34(5–6), 321–326 (1995).
19. Kindrachuk V.M., Klunker A. Phase field modeling of Hertzian cone cracks under spherical indentation. "Strength of Materials", 52, 967–974 (2020).
20. Shafiei M., Fattah-Alhosseini A., Mazaheri Y., Babaei K. Recent advances in electrospark deposition for surface modification: a review. "Journal of Manufacturing Processes", 54, 1–15 (2020).