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Research paper

Increase wearproofness of steel cylindrical details by discrete electromechanical strengthening

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Abstract

On the basis of theoretical and experimental researches tribotechnology of the discrete electromechanics strengthening has been offered for the increase of wearproofness of steel details. The new way of discrete electromechanical treatment has been developed. Analytical dependences and numeral models have been received for determination of contact descriptions at co-operation of instrument and detail for the electromechanics strengthening. By the method of finite elements the conducted analysis tensely deformed to the state of surface after its treatment by discrete electromechanics treatment with different geometrical layout of the locally fixed areas charts. The developed criteria of choice of optimum geometry of the discrete strengthening are on the basis of minimization of level of tensions in a superficial layer. For prognostication of wearproofness the model of wear and method of determination of descriptions of wear as a result of experimental tests have been developed. For the analysis of influence of the tensely deformed state of discrete surface on wearproofness the experimental tests at the discrete electromechanical strengthening have been conducted.

Keywords: *Electromechanics Strengthening; Wearproofness; Tensely Deformed State; Discrete Surface; Wear Test.*

1. Introduction

One of the main reasons for the high wear of machine parts and mechanisms is the insufficient use of modern methods of surface engineering (methods of applying protective coatings and hardening). The methods of surface engineering reduce the consumption of expensive materials, increase the reliability of machines and mechanisms, and increase the life of their machines. Strengthening technologies can differ in energy costs, equipment costs and environmental damage caused. The technology of hardening by the creation of coatings of a discontinuous discrete structure occupies a special place among the known technologies for hardening surfaces. Discrete coatings harden individual areas located on working surfaces in a certain order. Discrete surfaces increase wear resistance due to the effective use of the phenomenon of structural and energy adaptability of materials by means of a special friction surface architecture. Discrete sections in the surface layer of increased hardness, optimal geometry and depth of penetration into the surface eliminate the concentration of stresses from contact loads. Such structures interrupt the processes of formation of cracks, plastic deformation, reduce the propensity to contact bonding of parts, which significantly increase the strength and operational reliability of friction pairs. The main advantage of discrete surfaces is the possibility of mobile changes in the size of discrete sections on the surface of the substrate and the selection of materials on the physical and mechanical characteristics. This allows you to create conditions for regulating the temperature regime, achieving the lowest coefficient of friction and wear, managing and minimizing the stress-strain state of the surface.

2. Literature review and problem statement

In modern researches progressive methods of hardening and increase of wear resistance of cylindrical tribo systems are considered. Such methods of hardening include methods of discrete hardening of friction surfaces. The work [1] was devoted to technological methods of ensuring wear resistance of sliding bearing parts. A regular profile of lubrication grooves was proposed for the boundary lubrication mode. A surface layer with improved antifriction properties is formed in the process of discrete hardening. The work did not place emphasis on the effect of regular lubrication profiles on the wear resistance of the bearing parts. In the work [2] the study of the efficiency of hardening the parts working in spalling conditions through reeling with rollers were performed with the help of physical simulation and showed the high effect of hardening cast steels. In the work [3] the influence of the stress-strain state on the parameters of discrete hardening is investigated. In [4] the characteristics of the stress-strain state in work-pieces are investigated by the experimental method to coordinate grid during new intensive modes of a stretch-forging in combined dies. The dependence of the surface layer stresses resulting from the shaft-sleeve contact interaction in the sliding bearing on its wear resistance was considered. Instead of contact pressures, surface stressed state which was numerically estimated by the finite element method was taken as the determining factor of the wear rate. It is difficult to use this approach in the engineering practice of calculating bearing wear at the design phase. In work [5] it is shown that the combination of scientific research on friction and wear processes in different scientific and engineering areas, such as mathematical statistics, mechanics of contact, physics of surfaces and magnetism and hydrodynamics, provides a deeper explanation of the processes that take place on discrete surfaces of contact elements. A calculation-experimental method for determining tangential contact frictional stresses using a variational principle was proposed in work [6]. In the article [7] authors substantiate the possibility of application of the method of electric-spark alloying of the surface layers of 40Kh steel by electrodes made of T15K6 and VK8 hard alloys for the purposes of hardening of the working surfaces of elements of the drilling equipment. The following works consider the problems of calculations and tests on friction and wear of cylindrical sliding pairs. The authors of [8] proposed theoretical dependences for a wear testing method using a standard four-ball scheme with determination of wear resistance parameters. The approximating function of the wear spot diameter on the friction path obtained by the results of wear tests was taken as the base of the method. The general methodology of this study can be used to develop a theory of test methods for other geometric schemes. The work [9] was devoted to experimental study of friction losses in friction pairs made of materials. The experimental method for measuring the characteristics of friction was applied in article [10] for examining special features of high-speed friction under conditions of thermal loading and at limited lubrication. The criterion of damping the friction fluctuations proposed in this case is not applicable to the case of viscous friction, where such fluctuations are practically absent as a result of the damping action of a layer of lubricant. Therefore, the purpose of the work is to develop an effective method for increasing the wear resistance of cylindrical parts of the "shaft" type by discrete electromechanical treatment on the basis of modeling the stressed surface state and wear tests.

3. Fundamentals of the method of discrete hardening of cylindrical parts

The principle of the electromechanical processing (Fig. 1) is to surface hardening with concentrated energy flows. In this case there is a thermodeformation action in the transmission of electric current of high density (100 - 110 A / m2) and low voltage (2-7 V). The electric current passes through the contact area 3 of the component and the deforming electrode tool 5 with roller 4 or plate. Current strength and secondary voltage are regulated by 1 depending on the contact area and the quality requirements of the surface layer.

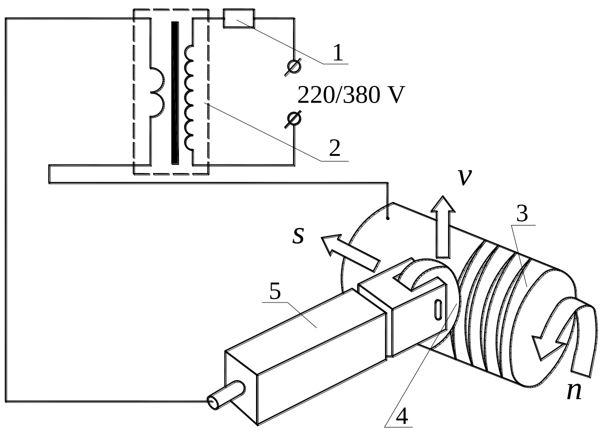

Fig. 1: Scheme of Discrete Electromechanical Hardening: 1 - Regulator, 2 - Transformer, 3 - Detail, 4 - Roller, 5 – Tool.

When a large amount of Joule's heat is emitted, there is a high-speed heating (1000C / sec) of micro-volume surface with its plastic deformation. Then there is an intense cooling due to the dissipation of heat inside the material. As a result, a fine-dispersed and solid martensitic structure "white layer" with high durability and wear resistance is formed in the surface layer. For electromechanical hardening, the tool design is proposed (Fig. 2). The tool includes a body 1 with a rod 2 and a working head 3 with a carbide roll 4. Electric current is fed to the roller 4 through current collectors 5,6. In the adaptation, the tool is fixed through the beam 7.

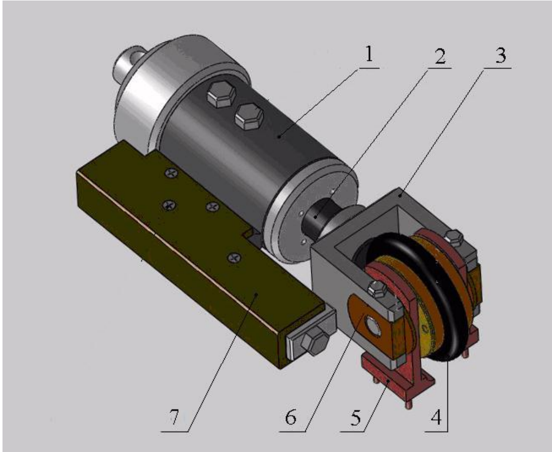

Fig. 2: Tool for Electromechanical Hardening.

Discrete hardening when using this tool is carried out due to the pitch of the screw tracks on the cylindrical surface. In addition, the surface of the workpiece is strengthened and is smoothed out of mechanical grinding by a carbide grinding roller. The hardening technology makes it possible to form both unidirectional and cross reinforcement paths with a given pitch. To study the efficiency of discrete trip using linear tracks, metallographic studies were carried out using the ZEISS EVO 40XVP microscope. On the surface a thin reinforced layer of marten site is formed (Fig. 3a) with a hardness of 500 ... 600 MPa for Vickers and a sublayer of considerable depth h = 0.6 ... 0.8 mm. The structural structure of the sublayer is complex: martensitic quenching, sorbitol quenching, release troostate as a result of the decomposition of austenite in different temperature zones.

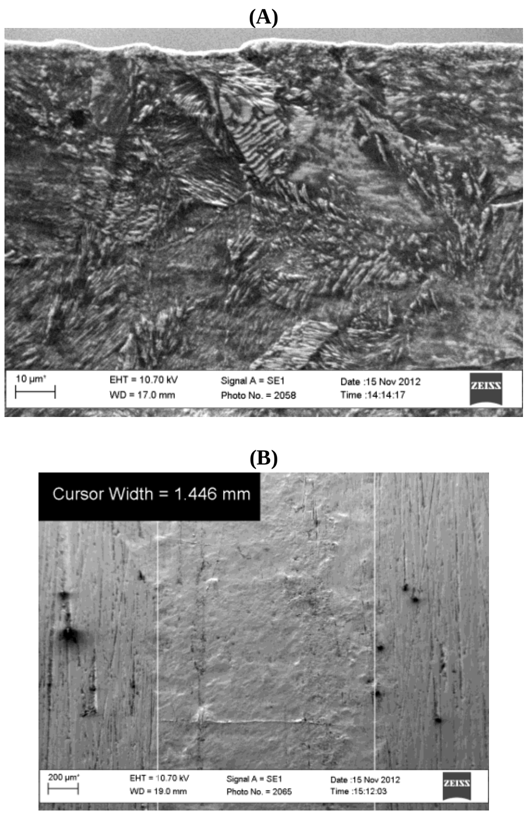

Fig. 3: The Investigation of the Structure of A Hardened Surface Layer, B Topography of the Strengthening Track.

Fig. 3 b shows the topography of the strengthening track obtained at a load of 500 N. On topography significant smoothing of the lines after grinding is possible due to surface-plastic deformation processes.

4. The calculation model of the contact tool-detail

The choice of technological modes of discrete strengthening of steel parts of the "shaft" type requires the need to assess the depth of the wear-resistant "white layer". This value is close to the contact depth of the tool with the sample. To determine the contact parameters of the roller-tool and the cylindrical part, computer simulation was carried out using the ANSYS software. To evaluate the contact interaction of the tool with the detail, a computer simulation of the ANSYS software system was performed. The calculated finite element model (Fig. 4) consisted of 380 thousand elements.

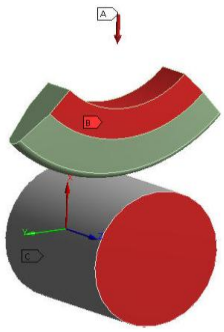

Fig. 4: The Calculation Model of the Contact Tool-Detail.

As a result of the numerical solution of the problem, the dimensions of the contact area were obtained and the stress-strain state was estimated (Fig. 5). At a maximum load of 500 N, the length and width of the elliptical contact area are, respectively, 1.7 by 0.6 mm (Fig. 8). The analysis showed that maximum stresses and deformations arise at a certain distance from the surface and reach values of 300 MPa. Relative plastic deformations make up about 5%.

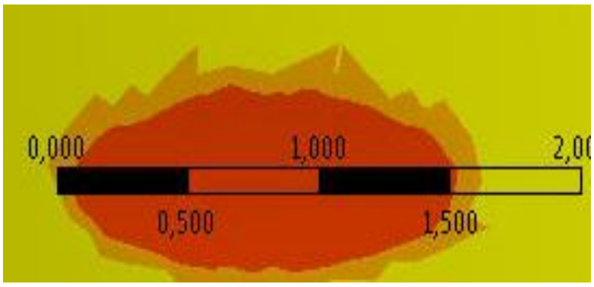

Fig. 5: Estimated Area Contact When Loading on A Roller 500 N.

To the contact area was applied an external thermal flow with a given equivalent temperature and the temperature distribution along the depth of the material was investigated. The analysis of the isotherms in depth (Fig. 6) showed that the minimum temperature (700 ... 800 ° C), at which the "white layer" is formed, is located at a distance from the surface of about 200 ... 250 microns.

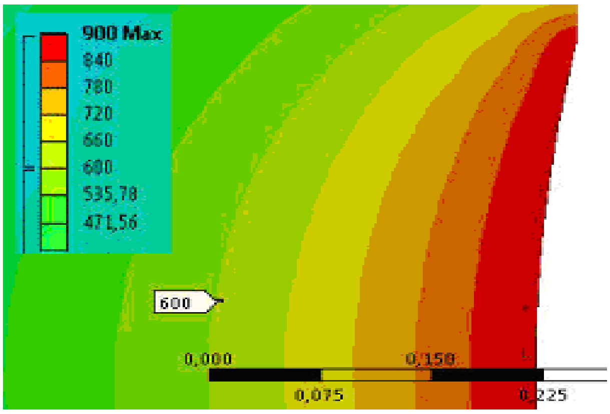

Fig. 6: Distribution of Temperature Fields along the Depth of the Part.

It should be noted that the maximum stresses and deformations are at the same distance from the surface, which contributes to the formation of a strengthened zone. Relative deformations from the temperature action reach values of 1%, with relative total deformations of 0.7%.

5. Stress-deformed state and geometrical parameters with the electromechanical strengthening

Electromechanics treatment forms on-the-spot a structure with the set distributing of properties of durability on the local volumes of surface. The fixed surface shows by itself a regular discrete structure which consists of elements of “white layer”. Researches show on the study of mechanisms of formation of elements of ‘white layer’ that it is possible to form discrete structures with the necessary location of the surface fragments with changing the technological parameters of electromechanics treatment (EMT). It is necessary for effective work of surface EMT, that the mutual location of the fixed fragments and area of coverage of surface took into account the features to construct details. Optimum from point of operating descriptions EMT of surface will be fixed with the formed specific structures and fragments of white layer. Further, an analysis of the behavior of a heterogeneous material whose surface is modified by elements of a white layer with a higher strength is compared with the matrix material under friction conditions. For the simulation, a finite-element model of a bar measuring 15 × 15 × 6 mm, each of which was presented in the form of 30 elements, consisting of 27,000 elements (Fig.7), was used.

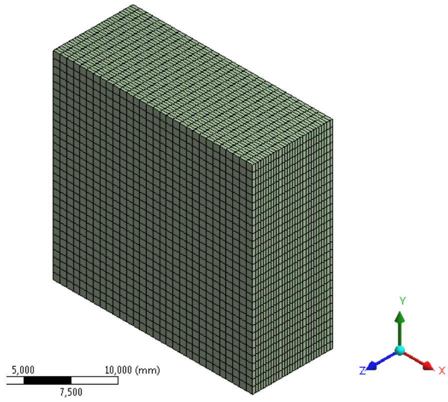

Fig. 7: Finished Element Model of Hardened Body.

Friction conditions were modeled by applying to the hardened surface normal and tangent stresses, respectively, 1 and 0.1 MPa. Samples after electromechanical treatment are bodies with a non-uniform surface, which is reinforced by locally strengthened zones. The formation of a discrete structure in the surface layer leads to a change in the stress-strain state. The stress - deformed state of the body will depend on the nature of the applied loads and on the relative position of the strengthened areas. When simulating a surface that is reinforced by non-intersecting tracks, the equivalent stresses on the Mises are about 400 MPa (Fig. 8).

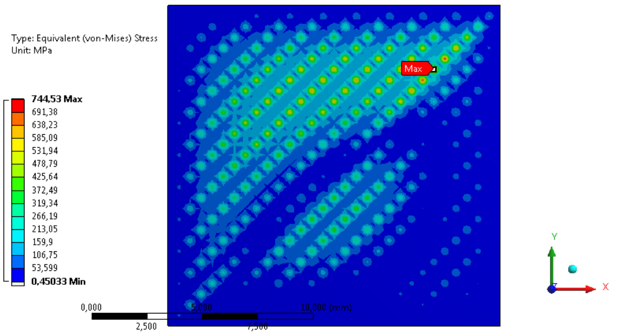

Fig. 8: Distribution of Mises Stresses for Non-Intersecting Tracks.

When choosing the parameters of electromechanical strengthening, one must strive to minimize the stress-strain state of the surface layer. The analysis of various geometric variants of surface treatment showed that the scheme with cross strength tracks would be most optimal. The analysis of the obtained results showed that due to the optimum mutual arrangement of the strengthening of the sites, it is possible to achieve a minimum influence of stress concentration. A comparative analysis of equivalent stresses (by Mises), strengthened according to the optimal pattern of the sample, shows that the maximum stresses are 3.77 MPa (Fig. 9).

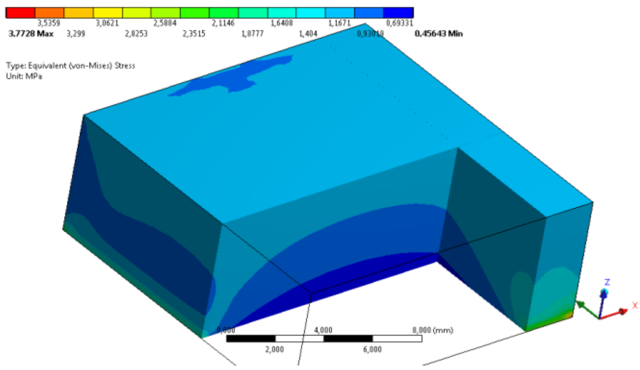

Fig. 9: Equivalent (Mises) Stresses of an Optimally Strengthened Body.

An analysis of the distribution of tangential stresses has shown that there are stretching and compression tangential stresses of absolute magnitude on the surface. The maximum values are 0,02 MPa, which is equal to the maximum value of stresses of the unstable body 0,019 MPa (Fig. 10).

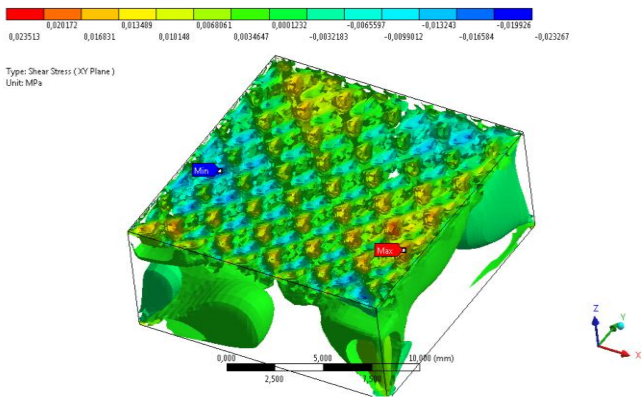

Fig. 10: Iso-Surface of the Distribution of Tangential Stresses in the Plane XY of an Optimally Strengthened Body.

Thus, by the right choice of the treatment scheme, the mutual arrangement of wear-resistant elements, a minimum stress concentration in the surface layer can be achieved. In the course of operation, the wear resistance of the surface will significantly increase. An analysis of various geometric variants of surface treatment showed that for the chosen scheme, the optimum area of surface hardening was 0.54. Increasing or decreasing the coverage area resulted in an increase in all components of the stress-strain state

6. Calculation-experimental investigation of wear resistance at discrete hardening

For a comparative evaluation of wear of cylindrical parts after a discrete electromechanical strengthening, the theoretical model of wear is proposed in the form of a dependence of the wear intensity on the dimensionless parameters of contact pressure and speed in the form:

$$\frac{du_w}{dS} = K_w \left(\frac{\sigma}{HB}\right)^m \left(\frac{V}{V^*}\right)^n , \qquad (1)$$

Where σ is pressure in contact, MPa; HB is the Brinell hardness, MPa; u_w is linear wear of cylindrical surface, m; S is the friction path for the cylinder, m; K_w , m , n are the parameters of wear; V ,V^* is the test speed and the base speed, m/s.

In the wear model (1) the parameters K_w , m , n characterize the influence of determining factors of contact pressure and slip speed on wear. These parameters characterize the conditions of wear of the tribosystem and are determined as a result of solving the inverse of wear-contact task based on the results of experimental tests according to the "cylinder-ball" scheme (Fig. 10).

The main stages of the solution are as follows. Distribution of contact pressure: $\sigma = \frac{Q}{\pi \bar{a}^2}$. Geometric condition in contact: $u_w(S) = \frac{a(S)^2}{2R^*}$ as the dependence of wear on the path of friction.

Experimental dependence of the radius of the cylinder's wear track on the friction path in the form of power approximation $\bar{a}(S) = cS^\beta$, where c , β are the parameters of approximation, which are determined by the results of the tests. As a result of the substitution of the relations in the model (1) we obtain the equation of solving the problem:

$$\frac{\bar{a}^2(S)}{2R^*} = K_W \int_0^S \left[\left(\frac{Q_1}{\pi \bar{a}^2(S)}\right)\frac{1}{HB}\right]^m \left(\frac{V}{V^*}\right)^p dS \qquad (2)$$

After integration (1) for the tests with two slip rates, the expressions for calculating wear parameters are obtained:

$$m = \frac{1-2\beta}{2\beta} \; ; \; n = (2m+2)\frac{\lg(c_1/c_2)}{\lg(V_1/V_2)} \; ; \; K_w = \frac{\beta c_1^{2m+2}}{R^*}\left(\frac{HB}{Q}\right)^m \left(\frac{V^*}{V}\right)^n , \qquad (3)$$

To test samples that were strengthened by electromechanical treatment, a multifunctional laboratory installation was modified (Fig. 12).

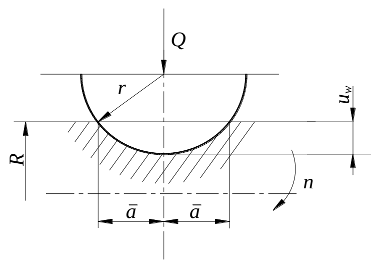

Fig. 11: Scheme of Contact "Cylinder - Ball": Q Is Load; n Is the Speed of Rotation; $\bar{a}$ Is the Half-Width of the Contact; R, r are the Radius of the Cylinder and Balls.

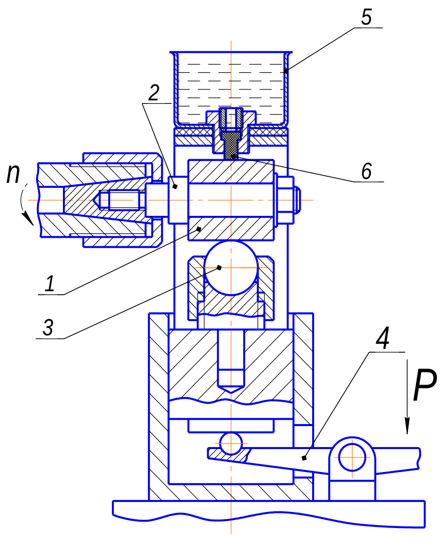

Fig.12: Modernized Test Setup: 1-Shaft; 2-Control Sample.

The samples from 40Kh steel in a normalized state and after processing with non-cross and cross paths were tested. The force of pressing the ball was 50 N, the lubrication of the surface of the sample was carried out with Castrol 10W-40 oil.

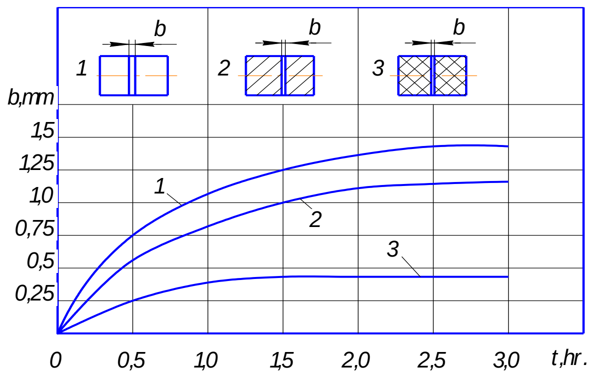

Fig. 13: Dependence of Wear on the Duration of Tests.

The test results showed that the wear resistance of the samples after electromechanical treatment is 1.26…3.62 times higher than the wear resistance of the non-hardened sample. The increase in wear resistance is due both to the formation of discrete zones of higher hardness, and to the magnitude and distribution of stresses in the surface layer.

When processing according to scheme 2, there are significant tangential tension stresses, which are practically absent in the processing under scheme 3. The tensile stresses reduce wear resistance. The reduction of wear on sample 2 compared to the sample without processing is due to the positive effect of discrete strengthening. The results of determination of wear parameters are presented in Table 1.

Table 1: Parameters of Wear Resistance

sample	m	n	K_w
1	1,058	0,685	$2,571 \cdot 10^{-11}$
2	1,079	0,5184	$1,939 \cdot 10^{-11}$
3	1,1896	0,130	$5,522 \cdot 10^{-12}$

The obtained results indicate that the wear of unstable samples significantly depends on the slip speed. Examined electromechanical treatment samples have a high wear resistance at high slip speeds. Dependence (1) calculated the intensity of wear of samples depending on the contact pressure (Fig. 14).

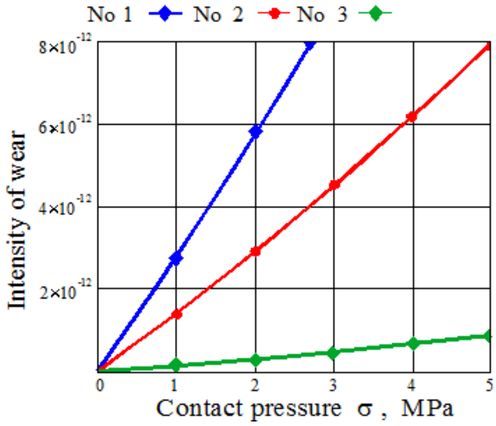

Fig. 14: Dependence of the Intensity of Wear on the Contact Pressure.

As a result, they increased the wear resistance by 3 times during cross-turning compared to unidirectional discrete rolling. This can be justified by the fact that the cross-sectional formation of discrete zones results in a greater strengthening effect due to a more favorable stressed surface condition.

7. Conclusions

1) It has been established that continuous strengthening of surfaces does not allow to provide the necessary durability in tough operating conditions.
2) A new method of increasing the wear resistance of steel parts by discrete electromechanical processing has been developed by forming linear reinforcement areas with controlled geometry.
3) A computer simulation of the conditions of the contact between the tool roller and the machined shaft has been carried out. The contact areas, contact stresses, depths of deformation and temperature distribution in depth are calculated.
4) It has been established that the main factor controlling the wear resistance of discrete surfaces is their surface tension under friction conditions. Computer simulation of the stress state of the surface showed that the scheme would be optimal in the form of cross-sectional areas of processing.
5) The results of the calculation of the intensity of wear showed that for a cross-section discrete profile wear resistance of samples from steel 40Kh was 3 times higher.

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