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FEATURES OF MECHANICS DESTRUCTION TRIBOUNITS AT DIFFICULT DYNAMIC LOADING

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The mechanics of contact destruction tribounits at a friction in the conditions of difficult dynamic loading is considered. Possibility of mathematical description of complex damage knots friction is shown, intensities of wear taking into account the features of forming superficial layer at a contact. Methodology of calculation superficial durability and longevity of tribounits is presented and the examples of practical estimation of this interdependence are shown. The model of destruction surface at a friction with a different dynamic loading is offered, methods of estimation wearproofness on the change of the structural state of superficial layer by a tribospectral method and the electron work function.

Keywords: wearproofness, tribounits, superficial layer, structural state, loading

Introduction

Presently results of researches in area of wear materials in especially heavy kinds mechanical and thermal loading, that carry dynamic character, does not allow with the high degree of authenticity to choose (or to work out) one or another structurally-technological measures that is sent to the increase of longevity wares. It is caused, foremost by the kinds of realization researches that often fall short of the real kinds of exploitation of the friction pair, as greater part of details tribounits works in the conditions of difficult dynamic loading related to the vibrations operating in various directions, which influences on unstable synergetic processes.

Processes of friction and wear, and also destruction of superficial layers of tribounits is determined by dynamic character loading in a contact, by amplitudes of the mutual moving, creating the specific kinds of pin co-operation [1]. In particular, in the process of exploitation the kinds of shock with slippage (two-component loading) and shock are possible with slippage in two mutually perpendicular directions (three-component loading). Such complex of kinds loading causes the difficult tense state of superficial layers of contacting pairs. It results in limitations of possibility application of general's theory friction, and also most the results of experimental researches [2]. Decision of contact task of mechanics destruction tribounits, that is exploited in the conditions of difficult dynamic loading, maybe within the framework tribofatigue based on model of account correlation processes mechanical (volume) destruction and friction fatigue.

Obviously, that at the contact kinds of loading the superficial layers of material are damaged stronger, than deep. At a repeated loading fatigue, the microcracks appear on a surface even in default of the contact loading with disposition in active planes slippage in that are situated maximal tensions of shear [3]. It is possible to distinguish four successive stages of processes in material in accordance with the features of deformation and destruction of materials at a tiredness: strengthening of material from the increase of density dislocations in local volumes to the critical value; conception and development of submicroscopic cracks; development of microcracks to the sizes macrocracks; development and confluence of macrocracks to the separation of elements surface.

The characteristic features of basic structural elements of material determine the accumulation of defects, resulting in formation of microcrack. The initial structure of the deformed material changes substantially under the action of the repeated impulsive loading. Undersurface zone (in depth from a few units to hundreds micrometres) is the plastic deformed layer of material with a certain size and orientation of the crystallites.

Correlation of mechanical properties and parameters of structure resulted in work [3], shows that resistance to fragile destruction depends not only on the size of grain but also from the size of block mosaic.

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Thus, the size of grain does not determine mechanical properties of metal simply. The conclusion is made about the determining influence of the degree of misorientation on the fracture resistance of the metal.

1Theoretical part

Taking into account that greater part of tribounits work in the kinds of difficult three-component dynamic loading: shock and slippage in two mutually perpendicular directions, investigated wearproofness of tribounits of flat details at the oscillating differently directed slippage with the shock loading (Fig.1). Studies were conducted on the specially worked instruments allowing realizing a difficult contact loading and test samples in the kinds of close to the natural.

Researches by means of electronic microscope allowed to set that as a result of plastic flow the developed cellular structure oriented along direction of friction is formed in superficial layers [4]. Destruction by the verges of cells is initiated, perpendicular to direction of slippage, and a primary crack passes along these verges. Therefore, at the relative slippage of surfaces the origin of the differently oriented cracks is possible. Especially in case of friction with slippage in two mutually perpendicular directions.

In general case formation and growth of microcracks at a cyclic loading substantially depend both on the structural state of material and from the number of cycles of loading of N. For description of development microstructure of short cracks the equation presented in work is applicable [5]:

$$\frac{db}{dN} = C(\Delta\gamma)^m (d-b), \tag{1}$$

where b – a depth of crack; $\Delta\gamma$ – a scope of deformation shear; d – a characteristic size of element structure; C and m – the experimentally determined constants of material.

It ensues from this equation, that as far as the increase of crack to the size of grain its speed diminishes up to a zero. At tensions higher of limit of endurance a crack is not stopped, and only slows the growth or can stop on any time.

Thus, character of accumulation of deformations at the action of the repeated impulsive and pulsating loading is approximately identical [6]. So, at a shock loading dependence of contact deformation on the number of cycles carries nonlinear character with three areas: on the first area - there is contact deformation the stage of strengthening (approximately to N = 20); on the second area a slow accumulation of contact deformation is with approximately permanent speed (N = 10^3 ... 10^4); there are a considerable growth of deformation and intensive destruction of surface on the third area.

It is set [1], that a wear at a shock loading is a nonlinear function from the number of cycles and normal tension:

$$W = C N^n \sigma^m \tag{2}$$

where C, n, m – coefficients.

Thus normal tension σ and maximal contact pressure are determined by the power of a shock, which in turn depends on speed, geometry of contact and properties of material.

Cyclic tensions result in the origin of fatigued damage both on a surface and on some depth. The phenomenon of superficial fatigue is corollary of normal collisions of microroughness, that result in an origin under the roughness of tangent tensions operating on the depth of order of heights ledges (micrometers). Under a ledge maximal tangent tension operates:

$$\tau'_m = \left(E'/\pi^2\right)\varphi \tag{3}$$

where E' - the reduced modulus of resiliency; φ – an angular coefficient of ledge.

Obviously, that microscopic (second kind) maximal tangent tensions really can be reason of formation embryonic cracks under a surface. A general case over calculated scheme of vertical superficial and horizontal cracks at a friction with a three-component dynamic loading is presented in a Fig. 2.

A surface is loaded with normal variable tension of q(z) at influence of shock loading and tangential tensions τ_x and τ_y at the oscillating slipping in two mutually perpendicular directions of samples. Taking into account probability of substantial influence of speed moving to the size of coefficient friction, the contact area between the two bodies is determined by the following conditions:

$$\begin{cases} \tau_{xy} = -q(z)\sqrt{k_x^2 + k_y^2} + \left(E'_m / \pi^2\right)\varphi \\ \sigma_z = -q(z) \end{cases} \quad (4)$$

where k_x and k_y – coefficients of friction on the axis of x and y.

Material in a superficial layer it is possible to examine in the first approaching as resilient. In case of fragile destruction necessary and sufficient is a force criterion – a coefficient of intensity tensions K that quantitativly characterizes the field of tensions at the top of crack.

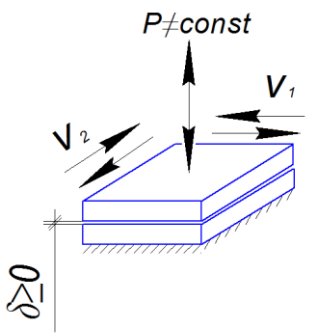

Fig. 1. Layout of the three-component loading of tribounits of flat parts.

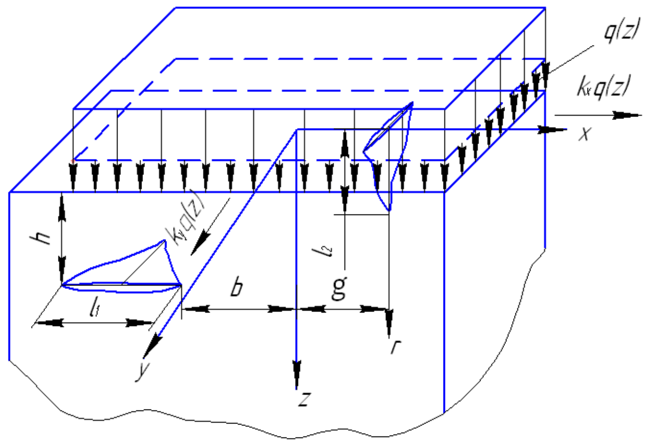

Fig. 2. Scheme of locations horizontal and vertical cracks at a friction with a three-component dynamic loading.

When calculation coefficient K a crack will attain the critical value will begin to spread. The linear resilient mechanics of destruction and force criterion the destructions worked out for fragile bodies are applicable, if the size of zone of plasticity does not exceed 1/10 thicknesses of sample.

Therefore, for the examined case the coefficients of intensity of tensions are determined [6]:

for a horizontal crack

$$\begin{cases} K_I(-b-l_I) = \lim\limits_{x\to(-b-l_I)} \sqrt{2[x-(-b-l_I)]}\sigma_z(x,h) \\ K_{II}(-b-l_I) = \lim\limits_{x\to(-b-l_I)} \sqrt{2[x-(-b-l_I)]}\tau_{xy}(x,h) \end{cases} \quad (5)$$

$$\begin{cases} K_I(-b) = \lim\limits_{x\to(-b)} \sqrt{2[x-(-b)]}\sigma_z(x,h) \\ K_{II}(-b) = \lim\limits_{x\to(-b)} \sqrt{2[x-(-b)]}\tau_{xy}(x,h) \end{cases}$$

for vertical crack

$$\begin{cases} K_I(l_2) = \lim\limits_{z\to l_2} \sqrt{2(z-l_2)}\sigma_x(g,z) \\ K_{II}(l_2) = \lim\limits_{z\to l_2} \sqrt{2(z-l_2)}\tau_{xy}(g,z) \end{cases} \quad (6)$$

Using the apparatus of singular integral equation the decision of task about the resilient is possible and maximum equilibrium of flat plastins weakentd by the system of the arbitrarily oriented rectilineal cracks of longitudinal change, i.e. determinations of the tensely-deformed state of surfaces at a friction.

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The decision of contact task of mechanics destruction tribounits, which is exploited in the conditions of difficult dynamic loading, is indissolubly related to strength and deformation properties of superficial layer. It is thus necessary to take into account connection of ledges of actual contact with the structural state of superficial layer and origin of the equilibrium roughness, related to the uneven making of fragments, formation of microkinks, them unorientation. The model of superficial layer appears as the located by chance fragments (crystallites), which possessing the certain level of durability and differ in direction glide planes conditionally shown by different direction of shading areas. The corresponding model of structural organization and destruction of superficial layer at a friction under conditions of multicomponent dynamic loading is presented in a Fig. 3. Reverse slippage (one-component dynamic loading) results in drawing out of fragments. Taking into account forming here comparatively big on a size fragments the got particles of wear are large.

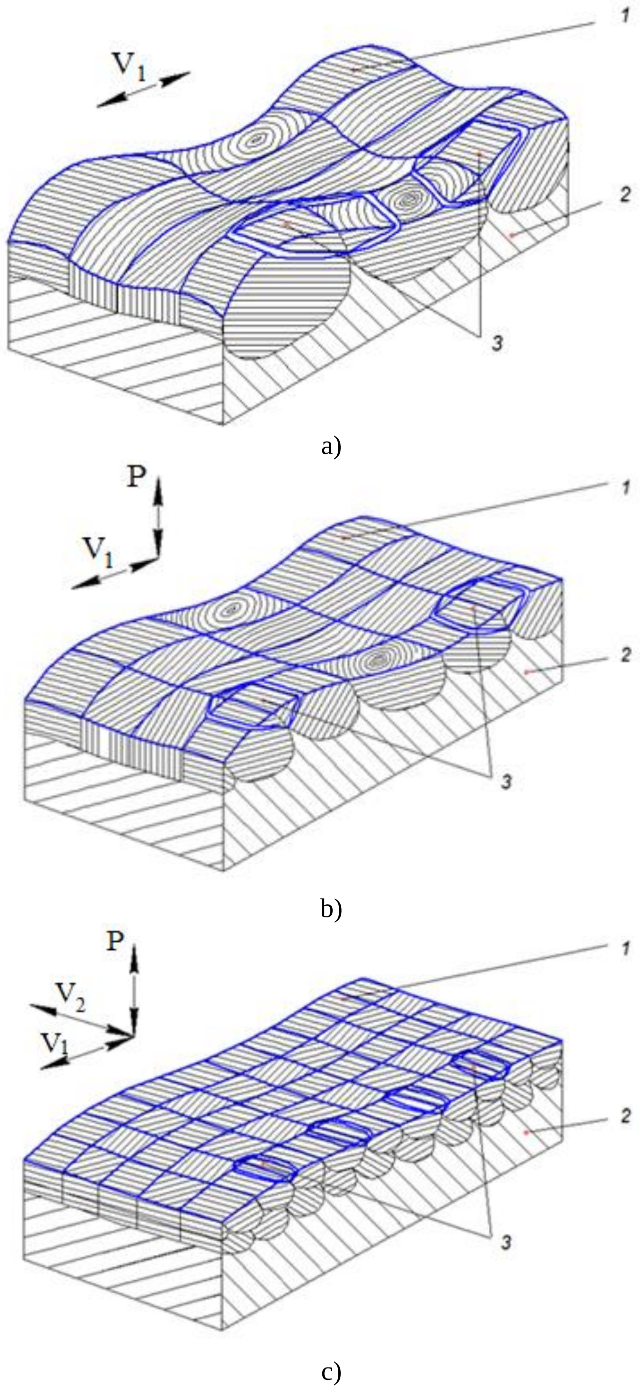

Fig. 3. Model of destruction of surface at a friction with a multicomponent dynamic loading:
a) one-component; b) two-component; c) three-component.
1 – fragments of superficial layer; 2 – a basic layer; 3 – particles of wear

For their separation enhanceable energy is required, that is accompanied by insignificant speed of wear (Fig. 3a). The got equilibrium roughness is considerable, especially in transversal direction and characterized by the presence of longitudinal scratches.

Adding to the reverse slippage of shock loading (two - component loading) results in diminishing of size fragments and their strength, increase of is uniform strength of superficial layer, that assists diminishing of particles wear and decline of equilibrium roughness (Fig. 3b). Speed of wear increases here. A three-component loading is characterized by shredding of fragments with formation of superficial layer high uniform strength and homogeneity (Fig. 3c). Shredding the fragmentation of the surface layer and reducing their strength facilitates the separation of wear particles. Fine wear particles, appearing in great numbers, result in high-rate of wear. At the same time, a low equilibrium roughness is formed, both in longitudinal and in transversal directions.

As the preliminary conducted researches showed [7], a difficult three-component loading (shock are possible with slippage in two mutually perpendicular directions) promotes intensity of wear materials by comparison to a wear at a two-component loading (shock and longitudinal slippage) to 2,5 times due to the change of strength and size of fragments superficial layer. With the increase amplitude of the transversal slippage a from 0 to 0,2 mm, the roughness of surface goes down in transversal direction in 1,3 - 10 times; longitudinal - in 1,3 - 2 times. Conditions are being created for forming of fragments superficial layer with the relatively easy passing of dislocation through crystallites to their borders. It assists the decline of level external tensions necessary for the action of mechanism rotary plasticity in analysable structures. As a result, a superficial layer appears with more even texture, which by an enhanceable wear is accompanied.

The change of character loading causes the change of the state of superficial layer and, as a result, change of wearproofness tribounits. Possibility to determine wearproofness by changing of the structural state of superficial layer appears. Estimating the state of superficial layer maybe on a device for sclerometric studies of materials [7], where force of friction of the diamond-pointed pyramid in the process of scanning is modulated with frequency of location crystallites, characterized by near value amplitudes as a result of change of strength on borders and inside local areas. Wherein the samples of the investigated steel or alloy with known wearproofness, state of superficial layer and kinds of loading in tribounits can be reference material.

2 Experimental part

As an example to concrete realization of method determination wearproofness and estimation of the state surface details by a tribounits tribospectral method in a Fig. 4 shows the tribograms of indenter scanning of steel samples 60S2A (C60E - AFNOR) at a two-component and three-component loading

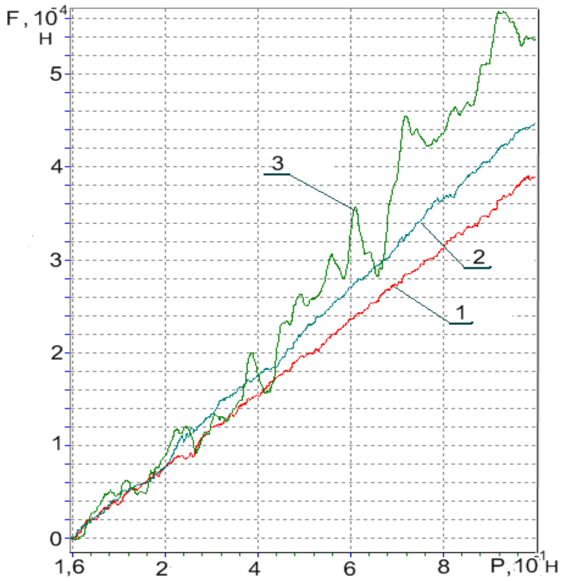

Fig. 4. Tribograms obtained in scanning of steel 60S2A samples after testing at different amplitudes of transverse slip (P is loading on an indenter): (*1*) A_{trs} = 0.08 mm; (*2*) A_{trs} = 0.06 mm; (*3*) A_{trs} = 0 mm (two-component loading).

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A two-component loading in the process of tests (tribogram 3) unlike three-component with the presence of the transversal slippage (tribograms 1 and 2) results in formation of superficial layer with the structure of greater strength and heterogeneity that has fragments (crystallites) of different size with enlarged scatter of strength. Thus the change of strength superficial layer made to 35%. Taking into account the increase of wear at a three-component loading it is possible to establish, that over the increase amplitude of the transversal slippage results in diminishing of strength superficial layer, which is accompanied by the decline of size force friction indenter and decline of wearproofness.

In addition, the state of the real surface of metals is related to forming on the surface of electric dipole moments that determine the size of electrostatic barrier the electron work function (EWF). Because of the heterogeneous state of metallic surface there is a corresponding level of electrostatic barrier, qualificatory divergence of electron work function for the different areas of surface. Thus, for this surface of metal there is the characteristic energy relief conditioned by distribution of EWF on a surface [8-10]. By comparing energy relief of the standard material with the relief of the tested material, it is possible to estimate the change in the structural state of superficial layer. Measuring of EWF produced with the use of method dynamic condenser of Kelvin, in which the measurement is made from the contact potential difference arising between the measured surface and the surface of the reference sample. Thus measureable and reference sample form a flat condenser and does not contact each other, however in this case an effective exchange becomes possible by electrons under the action of difference of EWF of the used metals [7, 11, 12].

Concrete the example of realization of the offered method is presented in a Fig. 5. Investigated samples from the alloy of KhTN-61(Standard of Ukraine) at a two-component (shock with slippage) and three-component loading (slippage in two mutually perpendicular planes and shock). The condition of superficial layer samples before the friction practically identical (EWF about 4,1 eV). As a result of friction with different amplitude of the transversal slippage, the state of superficial layer of samples changed. A two-component loading (A_{trs} = 0) results in formation of superficial layer with a large value and increased dispersion of EWF. It is related to that the new structural state of surface, near to amorphous and, as a result, EWF increases. A friction with amplitude of the transversal slippage results in diminishing of size and dispersion of EWF, which testifies to the increase of homogeneity of the structural state of superficial layer and accompanied by the increase of wear.

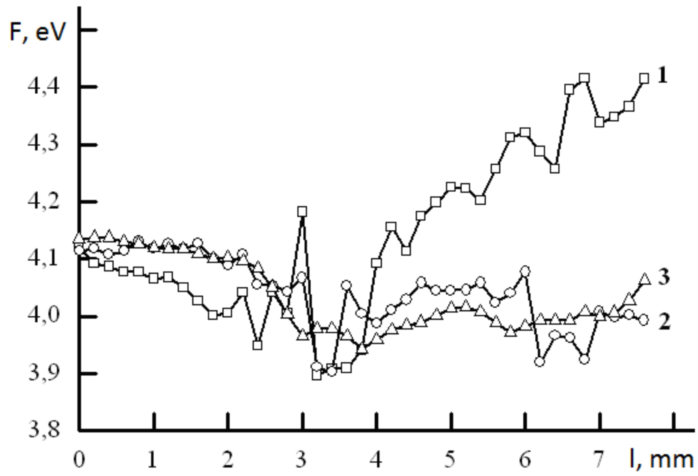

Fig. 5. Distribution electron work function along the surface of standards from the steel KhTN-61(Standard of Ukraine) after a wear with different amplitude of the transversal slippage: (*1*) A_{trs} = 0 mm; (*2*) A_{trs} = 0.05 mm; (*3*) A_{trs} = 0,1 mm.

Thus, deformation of metal at a friction with the different kinds of loading results in structural alterations of superficial layer and, accordingly, change of energy relief surface. The change of dynamics ladening assists transformation of superficial layer and, as a result, change of wearproofness tribounits.

Increased number of micro cracks and enhanceable wear take place at details with homogeneous on the size of fragments a uniform strength superficial layer. The increase of the transversal slippage at a friction with a three-component loading assists formation of similar superficial layer, decline of ego of strength, to the receipt of more even micro geometry of surface that is accompanied by the decline of size and dispersion of electron work function on a surface. The degree of these changes substantially depends here chemical-physical properties of materials and kinds of friction [7, 12, 13]. Conception of wearproofness tribosystems and tribotechnical principle of minimization wear materials is offered on the basis of the use phenomenon structural and energy adaptation of materials at a friction with the different types of loading. It's about creating of such kinds contact, when a superficial layer is formed with heterogeneous on strength and size of fragments the structural state. Thus, management possibility appears wearproofness of contacting details varying of kinds contact taking into account the features of forming superficial layer.

Conclusions

The presented models confirm actuality of mathematical description of complex damage of knots friction. The estimation of mechanics contact destruction must be produced on the basis of study behavior of superficial layers of materials in connection with the features of thermomechanical loading of tribounits in the real kinds of exploitation. In turn development of methods calculation of estimation superficial strength is necessary pre-condition of development more wearproof tribounits.

For the estimation of wearproofness steel details of tribounits at a multicomponent dynamic ladening, using of complex approach of determination interconnections tribotechnical and structural properties of contacting materials is needed for the different kinds of loading. Thus, the plastic-destructive pattern of behaviour metal at a friction should be considered as physical and chemical, i.e. process that is accompanied by the complex of structural, physical and physical-chemical changes of superficial layer the deformed metal.

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