UDC 621.431.73: 621.2.082.18

STUDY OF BEARING UNITS WEAR RESISTANCE OF ENGINES CAREER DUMP TRUCKS, WORKING IN FRETTING CORROSION CONDITIONS

Juri OLT[1], Vyacheslav V. MAKSAROV[2], Viktor A. KRASNYY[2]
[1] *Estonian University of Life Sciences, Tartu, Estonia*
[2] *Saint-Petersburg Mining University, Saint-Petersburg, Russia*

The occurrence of fretting corrosion on nominally fixed surfaces of high-loaded parts of mining machines and mechanisms is considered. Examples of wear and damage of critical parts, bearing assemblies of engines of dump trucks in fretting conditions are given. The mechanisms of fretting corrosion when using wear-resistant coatings are considered. It is noted that when choosing protective thin-layer coatings that provide an increase in the fretting-resistance of surfaces of tightly contacting parts, it is necessary to take into account both their wear resistance and the ability to resist shear. At the same time, the thickness of such coatings allows preserving, during operation, those provided during the assembly of the tension, without disturbing the maintainability of the nodes. The results of research of fretting wear of a number of coatings on a special installation are given. The mechanisms of wear of a number of thin-layer coatings based on friction-mechanical brazing, polymer fluorocarbon composition, solid lubricant coating using scanning electron microscopy were studied. Recommendations on the use of the studied thin-layer coatings for high-loaded parts of mining machines operating in fretting corrosion conditions have been developed.

The aim of the work was to study the effect of a number of thin-layer coatings on the wear of highly loaded connections of the mechanisms of mining machines, in particular bearing assemblies of quarry dump trucks operating under fretting corrosion conditions.

***Key words*:** wear resistant coatings; fretting corrosion; mining machines, bearing unit; internal combustion engine; friction-mechanical brassing; polymeric fluorocarbon composition; hard lubricating coating

***How to cite this article*:** Olt Ju., Maksarov V.V., Krasnyy V.A. Study of Bearing Units Wear Resistance of Engines Career Dump Trucks, Working in Fretting Corrosion Conditions. Journal of Mining Institute. 2019. Vol. 235, p. 70-77. DOI: 10.31897/PMI.2019.1.70

Introduction. Improving the performance properties of machine parts should be viewed as a very urgent task, which requires its development for both general and mining engineering, while in recent years there has been a significant increase in the power used in quarries and mines mining, transport and mineral processing equipment, high-performance integrated units, which is accompanied by their operation in conditions of high vibrations and loads.

The equipment of most mining and processing plants, in particular, quarry equipment, is operated under similar conditions, although it often differs depending on road and climatic conditions. Due to the cyclical nature of the load on vehicles when moving rock mass due to a change in operating modes of about 30-40 times per hour, diesel engines operate in unsteady modes, which is accompanied by dynamic loads leading to increased displacement, bending and twisting of the mating parts.

Dynamic loads arising from heavy and difficult operating conditions of equipment, in some cases, are accompanied by significant wear of working surfaces (gripping, jamming, tearing, abrasive wear, fretting corrosion), which leads to damage to mechanisms. Most often such damage occurs in the mates of various one-piece and detachable joints (hinged, bolted, riveted splined and keyed), as well as in the contact area of loaded gears, rolling bearings, spring assemblies, and also in parts of diesel engines of quarry units [7].

Under conditions of increased alternating loads, one of the types of surface wear is fretting corrosion, which often manifests itself with minor vibrations of tightly contacting nominally fixed parts with small friction amplitudes. The resulting wear products due to their small oscillation amplitude cannot leave the contact areas of the contacting surfaces; they concentrate in the local area, which is accompanied by an increase in pressure and additional surface destruction [2, 8]. Fretting corrosion is often the cause of reduced operational reliability and, in some cases, leads to damage that leads to the destruction of a number of critical parts and joints of internal combustion engines. The most similar phenomena occur in heavily loaded assemblies and mechanisms of heavy-duty mining dump trucks, parts of drilling equipment and others venerable to vibration during operation.

DOI: 10.31897/PMI.2019.1.70

Fretting corrosion damage occurs, in particular, at the interfaces of the diesel engine block and the lateral surface of the crankshaft main bearing caps of the quarry dump trucks, on the bearing surfaces of the working cylinder sleeve, on the outer surface («nape») of insert and in a number of other connections, despite creation of high contact loads during their assembly [6, 7].

It can be argued that the reliability of the mining equipment and the stability of its operational characteristics are closely related to the choice of protective wear-resistant coatings of working surfaces and methods of their finishing and finishing processing, influencing the processes occurring in the surface area of the contacting parts.

An example of fretting corrosion damage during operation on overloading modes can be a mating pair of engine dump truck engine parts: a main bearing cover and a block. Figure 1 shows a typical mounting design of a bearing cap with fretting-prone surfaces, using the example of a V-shaped dump truck engine.

The observed fretting phenomenon on the mating surfaces of engine covers allows us to state that the initial center of fretting formation was located in the center of the lower contact areas of the cover with the shell. Further, the surface exposed to fretting increases and spreads towards the lower edge of the lid. Figure 2 shows the results of fretting wear on the side surfaces of the bearings after operating for 10230 hours.

In the literature [1, 4, 5, 19] numerous examples of fretting corrosion damage of various parts and assemblies and methods of protection against fretting corrosion are given. However, a single look at the mechanism of fretting corrosion and, accordingly, the choice of measures to prevent it, has not been worked out.

To improve fretting resistance, various types of coatings of tightly contacting working surfaces of parts are usually used [1, 6, 11-13].

Selection of wear-resistant coatings to protect parts from fretting corrosion. The choice of protective coatings in this case is determined by a number of features that characterize wear under fretting corrosion conditions. Among the features of fretting corrosion that distinguish this process from other types of wear, it is necessary to single out: a small shear amplitude, upon reaching which one of the parts of the friction pair begins to move in the opposite direction; the presence of an air environment conducive to the development of corrosion; step-by-step increase in the contact area of parts. It should be particularly noted that with low-amplitude fretting, wear products are only partially removed from the contact zone and perform the role of the «third body» in the process of friction and wear [3].

Simplified, the fretting wear process in the initial period can be considered in several stages of development: the occurrence of shear deformations of surfaces under the

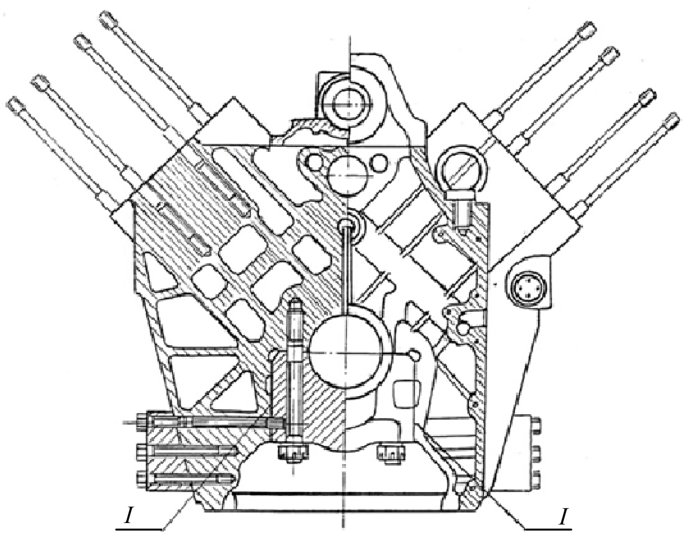

Fig.1. Fastening design of the main bearing cap of an engine dump truck (I – surfaces exposed to fretting wear)

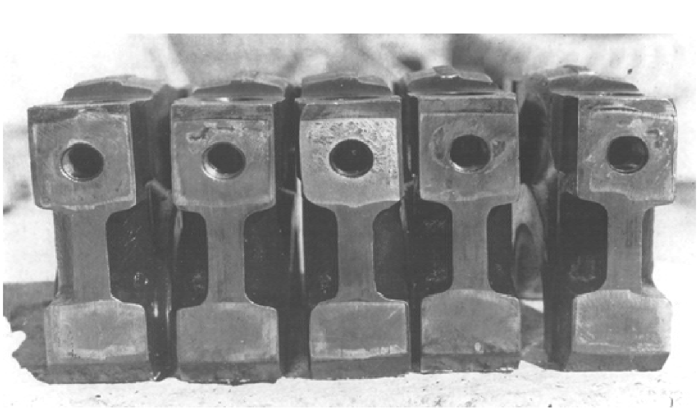

Fig.2. Fretting on the side surfaces of the main bearing caps after operating for 10230 hours

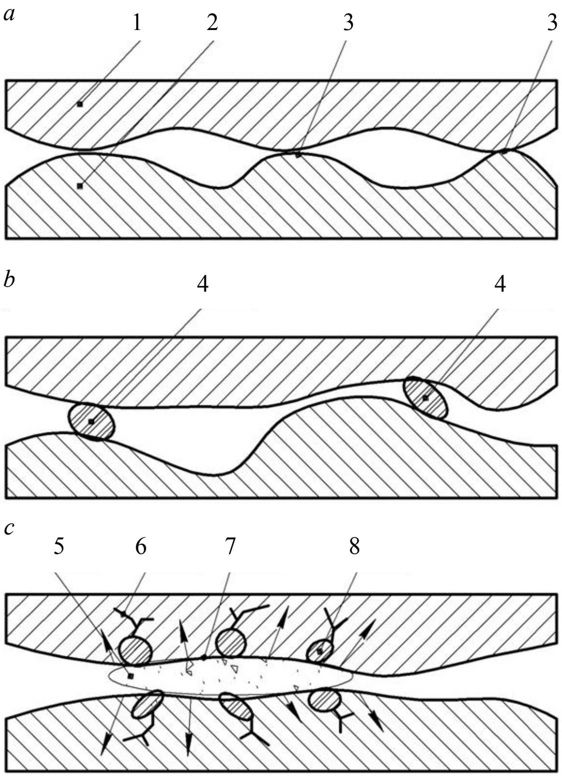

Fig.3. The simplified scheme of the mechanism of wear during fretting
1, 2 – details of a friction pair; 3 – points of initial contact; 4 – small caverns; 5 – cavern formed; 6 – microcracks; 7 – breakaway metal particles; 8 – breakaway oxidized metal particles with a solid structure

action of alternating shear stresses followed by oxidation; the subsequent destruction of oxide films; development of setting sites with subsequent corrosion of the metal surface.

A similar scheme of the mechanism of wear during fretting is shown in Fig.3 [2]. Primary contact occurs at local points on the surface (Fig.3, *a*). With a low-amplitude vibration, the destruction of oxide films occurs with the formation of small cavities (Fig.3, *b*). Gradually, the oxide films are concentrated in the cavities, increasing in size, forming in the future one large cavity (Fig.3, *c*). The small amplitude of friction prevents the escape of oxides from the contact zone, which leads to the formation of microcracks. Further, the cracks are connected, causing the chipping of metal particles. In this case, wear products are formed in the form of solid oxides, and an enhanced abrasive effect on the mating surfaces occurs. As a result, increased pressure and friction forces of oxide particles affect the friction surfaces with a simultaneous increase in pressure in the contact zone, accompanied by an increase in temperature.

Obviously, taking into account the given scheme of the mechanism of fretting corrosion, it is necessary to make the choice of materials of protective coatings, and the ability of the coating material to take on shear deformation should be taken into account, thereby preventing the development of fatigue damage. This allows us to consider the use of thin wear-resistant coatings promising. The use of thin-layer coatings also makes it possible not to disturb the maintainability of the assemblies and to preserve the tightness created during the assembly process during operation [2, 4].

In some cases, effective types of treatment with fretting show special types of treatment, in particular, vibration rolling with the creation of a regular microrelief on the surface [12, 17, 18]. Considerable attention is also paid in the literature to the influence of various characteristics of the friction process, which help prevent fretting corrosion and reduce wear [9-11, 13-16].

The aim of the work was to study the effect of a number of promising thin-layer coatings (polymer fluorocarbon composition, friction-mechanical brass coating, solid lubricating coating) on the wear of highly loaded connections of the mechanisms of mining machines operating under conditions of fretting corrosion.

Materials and methods of experiment. At the initial stage, field studies were conducted on the nature of the development of fretting-corrosive damage to the side covers of the working bearing of a dump truck engine. Figure 2 shows the character of fretting wear after 10230 hours of work. Figure 4 presents the results of the fretting wear study on the side surface of the main bearing cap after operating 7640, 10830 and 12480 hours. From Figure 4, we can conclude about the nature of the development of fretting-corrosion damage corresponding to the wear mechanism described above.

Laboratory tests to assess the effectiveness of the application of the considered coatings were carried out on steel (steel 15) and cast iron (gray cast iron SCH 25) specimens on a special installation using a standard friction machine drive (Fig.5). In all cases, the coatings were applied to the

DOI: 10.31897/PMI.2019.1.70

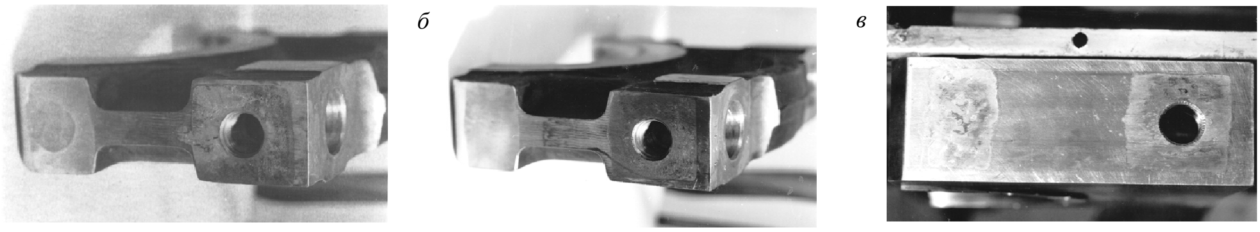

Fig.4. Fretting on the side surface of the main bearing cap after operating 7640 hours (*a*); 10830 hours (*b*); 12480 hours (*c*)

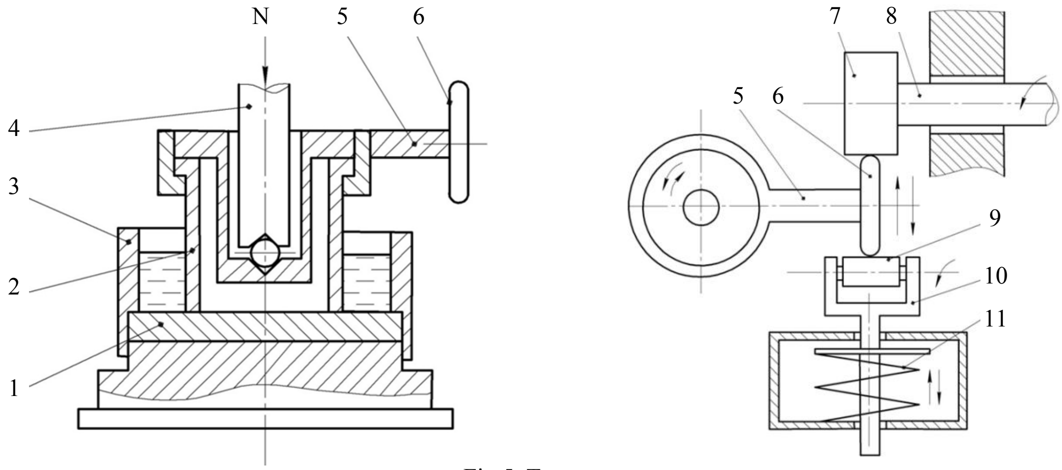

Fig.5. Test setup
1 – lower stationary sample; 2 – upper movable contra-sample; 3 – capacity for technological liquid medium; 4 – push rod; 5 – rocker; 6 – roller; 7 – eccentric; 8 – drive shaft; 9 – pressure roller; 10 – fork; 11 – spring

fixed samples, and the movable counter samples of the coatings did not have. The test method was consistent with the generally accepted, based on reciprocating friction of the samples on the ring contact.

The fixed sample (1) was made in the form of a disk with a diameter of 35 mm and a thickness of 7.5 mm. The movable countersample (2) represented a hollow cylinder with an outer diameter of 25 mm and an inner diameter of 20 mm, creating an annular contact with an area of 0.5 cm^2. Due to the use of an eccentric (3) with a given eccentricity and a shoulder created by the rocker (5), the cylinder made reciprocating rotational oscillations. Along the axis, loads were applied to it, creating specified normal pressures on the contact. The installation made it possible to vary the fret-ting amplitude on the contacting surfaces from 40 to 200 μm, to change the normal pressure from 10 to 50 MPa and to create an oscillation frequency from 200 to 1000 cycles per min due to the use of a friction machine drive. An eccentric was used as the upper roller in the standard «roller-roller» test pattern, which made it possible to obtain reciprocating rotational oscillations of movable counter-specimens, as well as to use the measurement capabilities of a friction machine (torque and coefficient of friction).

Discussion of research results. In our studies, we studied wear under fretting conditions of samples without coating and surface treatment with samples having different coatings. Polymeric fluorocarbon composition, friction-mechanical brass coating and solid lubricant coating were used as surface coatings. A number of widely used methods of applying protective coatings (laser treatment, electrolytic deposition or vacuum deposition of coatings, etc.) are technologically unacceptable for large-sized parts of complex shape. At the same time, the technology of applying the considered thin-layer coatings is quite simple and to a lesser extent related to the size and shape of the treated surface.

Samples and contractions of steel 15 were tested under a pressure of 25 MPa with a frequency of 900 cycles / min under conditions of reciprocating rotational slip with an amplitude of 100 μm.

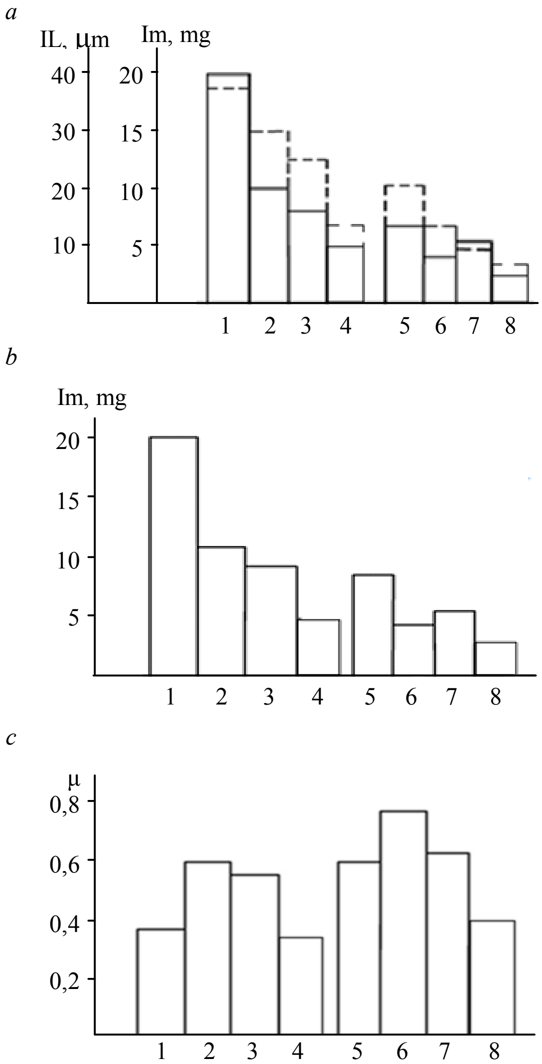

Fig.6. Comparative results of laboratory tests:
a – wear of the fixed sample (contour line – mass, dashed – linear); *b* – wear of movable contra-ridges; *c* – value of friction coefficients μ

Samples of cast iron SCH25 paired with countersample of steel 15 were tested under a pressure of 50 MPa and a frequency of 250 cycles / min with an amplitude of reciprocating rotational slip of 20 μm. The number of test cycles for each pair of samples was taken 5 × 105, which made it possible to obtain an annular friction track on the sample suitable for the necessary measurements. For each test series, at least four samples were examined. After testing, the samples were weighed to the nearest 0.1 mg, linear wear was determined by measuring the friction tracks using a profile record. The friction coefficients were determined in accordance with the methodology used when testing on a friction machine.

Figure 6, a shows the test results that evaluate the sample wear (IL – linear wear, μm; Im – wear by change in sample mass, mg); in Fig.6, *b* – wear of contrasamples; in Fig.6, *c* – the values of the steady-state friction coefficients μ. Figure 6 presents: 1-4 – values for steel samples (1 – uncoated sample, 2 – with friction-mechanical brass treatment with a thickness of 3-5 μm, 3 – with a 5 μm thick polymer fluorocarbon composition, 4 – with treatment with solid lubricant coating thickness of 25 microns); 5-8 – values for cast iron samples (5 – uncoated, 6 – with friction-mechanical brass treatment, 7 – with a polymer fluorocarbon composition, 8 – with a solid lubricant coating).

An analysis of the results of the tests carried out makes it possible to note a decrease in both mass and linear wear for all the investigated coatings. It should be especially noted that the values of the friction coefficients obtained in tests under fretting conditions do not always correlate with the data on the sample wear and even exceed the values of the initial base sample. It can be assumed that this phenomenon is due to the fact that the tests were carried out with a relatively small area of contact of samples (0.5 cm^2), while the pressure and amplitude were chosen taking into account the actual operating conditions. It should also be noted that the operating conditions of the friction units at high normal loads under fretting conditions are more stringent compared to conventional sliding friction.

Analysis of the literature suggests that there is no single view on the mechanism of fretting corrosion using different protective coatings. In this paper, an attempt has been made to study the mechanisms for the development of fretting corrosion for thin-layer coatings that reduce wear. For this purpose, the friction tracks of the samples after the tests were studied using scanning electron microscopy methods.

Figure 7 presents the results of studies of basic steel samples without coating. The presence of typical for fretting wear areas of relief in the form of cavities filled with oxidized wear particles can be noted. The areas with oxidized particles (Fig.7, *a*) occupy a relatively small area, however, you can also observe areas with particles of a few micrometers in size with no traces of oxidation, where brittle fractures are noticeable (Fig.7, *b*).

DOI: 10.31897/PMI.2019.1.70

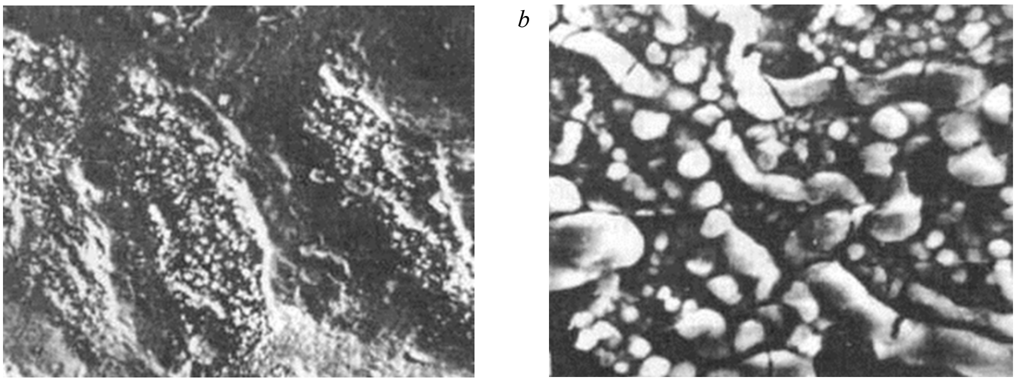

Fig.7. The nature of the friction track during fretting of a steel sample: *a* – cavities filled with wear parts (×160); *b* – wear particles on the friction surface (×2000)

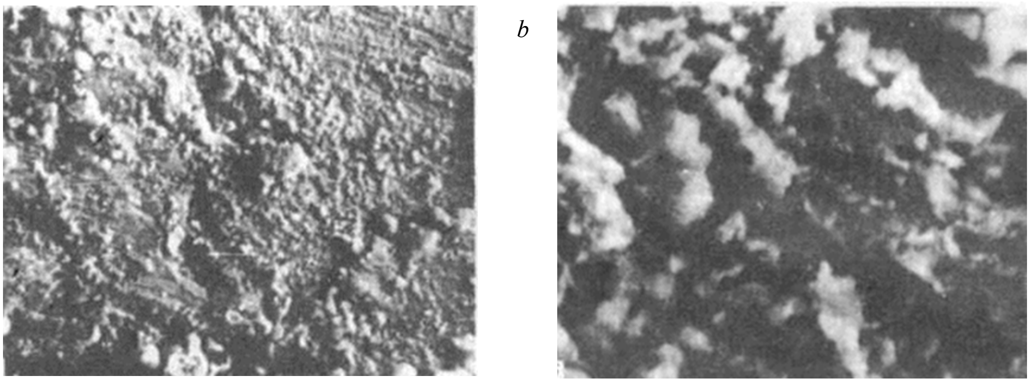

Fig.8. The nature of the friction track during fretting of samples with a polymer coating: *a* – friction surface (×200); *b* – dispersed particles on the friction surface (×2000)

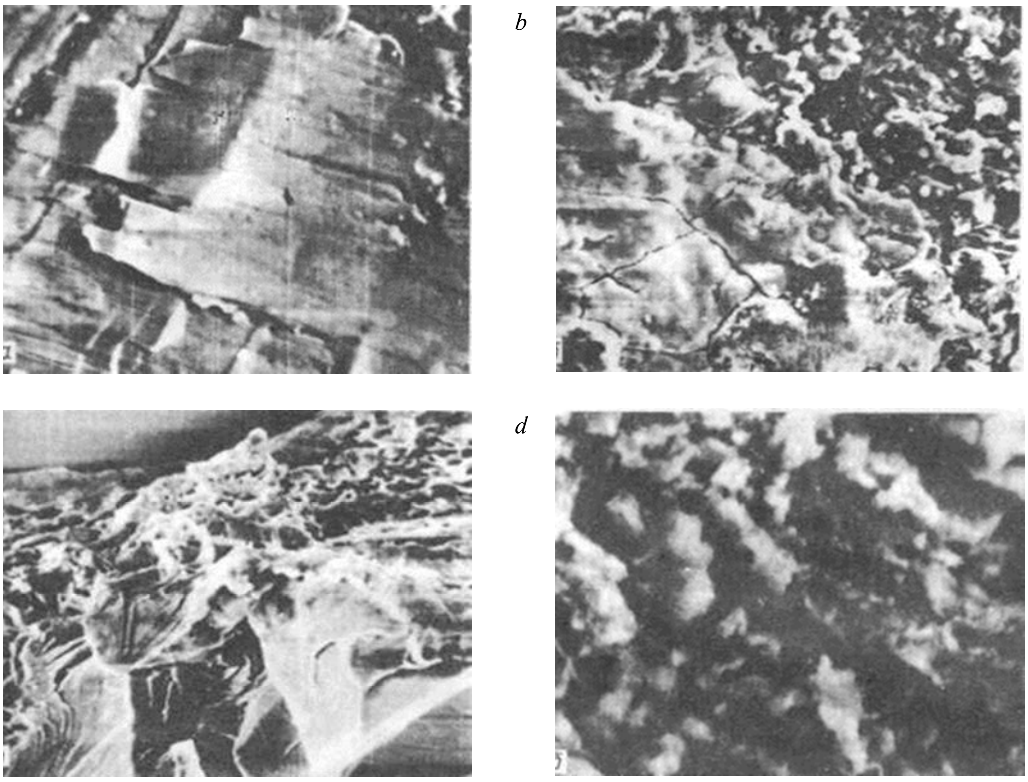

Fig.9. The nature of the friction track during fretting of brass-plated specimens: *a* – brass coating on the friction surface (×150); *b* – the resulting grid of cracks in the brass coating (×300); *c* – structure of the transverse fracture of the sample in liquid nitrogen – porous brass coating on a coarse-grained steel base (×400); *d* – structure of a low-temperature fracture of a brass coating with a finely dispersed structure (×7000)

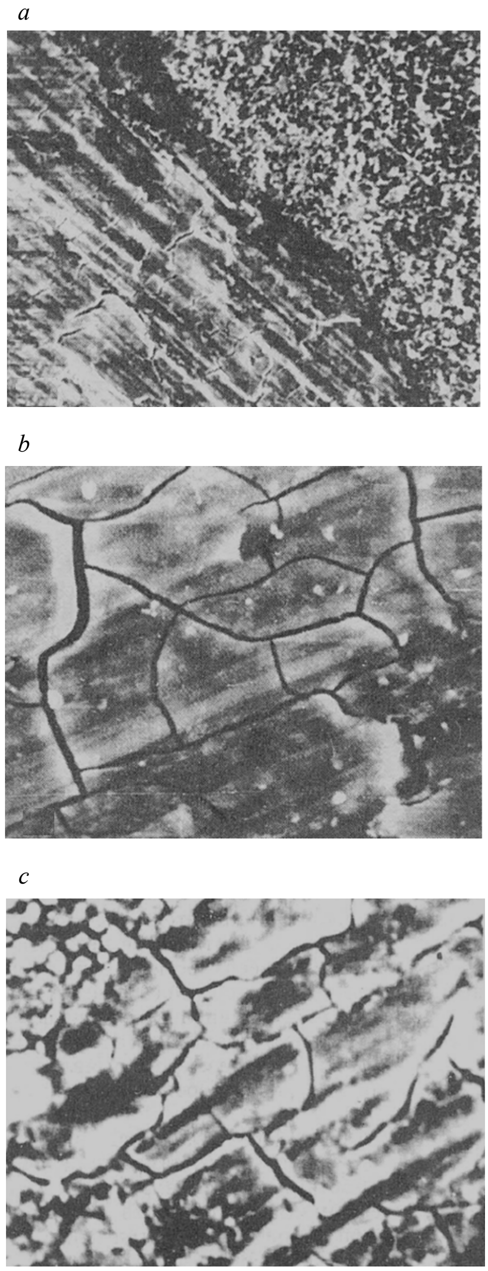

Fig.10. The nature of the friction track on the solid lubricant coating: *a* – ×130; *b* – ×1000; *c* – section of the friction track on the surface of the steel counter body, ×500

The application of the polymer fluorocarbon composition to the sample surface in the form of a solution, followed by drying, created on the surface a thin polymer film that protected the friction surfaces from oxidation and the formation of cavities (Fig.8, *a*). Comparing Fig.8, *a*, *b*, it can be noted that the use of such a coating somewhat increases the dispersion of particles and thereby prevents the mechanism of their brittle fracture.

The friction surfaces of samples treated with friction brass are shown in Fig.9. It is noticeable that on the steel sample very smooth brass layers with different adhesion bonds with the surface appear, both with poor, up to their peeling (Fig.9, *a*), and with good adhesion (Fig.9, *b*). In the latter case, the formation of a grid of cracks does not lead to the destruction of the brass coating, with which its efficiency is probably related. With a subsequent increase (×400) in Fig.9, *c*, you can notice the grains of the steel base, on which lies a plastic layer of brass several micrometers thick with a high content of pores. With an even more significant increase (×7000), it can be seen that the structure of such a layer consists of individual spherical particles with dimensions of about 1 μm and less (Fig.9, *d*). Obviously, in the process of frictional coating, a fine structure is formed, which provides a deformation mechanism under the action of shear stresses during fretting by reciprocal rotation and slippage of small elements of the structure.

The best results were obtained with a solid lubricant coating. The wear of samples and contrasts during the test did not exceed 5 mg. This pronounced anti-wear effect is likely to be associated with a high dispersion of the coating deposited on the sample surface, followed by heating. Fig.10, *a* shows a view of the friction track during fretting, where, against the background of the initial dispersed structure, the friction surface is covered with a smooth layer with a specular gloss and the same grid of non-destructive microcracks as on the brass surface, but unlike the brass surface, the entire friction surface is covered with this layer, rather than individual sections. At high magnifications (Fig.10, *b*), a subsurface fine structure with micron and submicron particle sizes appears through the mirror layer. The surface of the steel counterbody (Fig.10, *c*), to which the coating substance was transferred during friction, has the same appearance.

Microprobe X-ray analysis of the friction surface formed as a result of fretting on a sample with a solid lubricating coating showed an increased carbon content on the friction track as compared to the initial coating, which is characteristic of the implementation of the mechanism of selective transfer [2].

Based on the conducted research, recommendations on the technology of applying the studied coatings for high-loaded parts of a number of mining machines and mechanisms.

Conclusion. 1. As a result of the tests carried out, it was established that the increase in wear resistance during fretting for coatings based on a polymer fluorocarbon composition and friction-mechanical brass coating is associated with a similar mechanism for the formation of a contact layer of fine particles. The considered coatings practically exclude or significantly level the corrosive component during fretting. The size of dispersed particles (from fractions of a micrometer to several micrometers) formed as a result of fretting wear is commensurate with the mean free path of dislocations; therefore, going to the boundaries of the particles, do not form clusters. The resulting network of cracks on wear-resistant surfaces when using these coatings due to the porosity of materials does not lead to wear by peeling or chipping of the surface layer, which probably increases the dissipative properties of the surface.

2. The best results were obtained when using a solid lubricating coating, this, in addition to its high tribotechnical characteristics, is probably due to the increased carbon content on the friction track compared to the original coating, which is typical of the implementation of the selective transfer mechanism.

3. Based on the conducted research, recommendations on the use of the proposed thin-layer coatings for high-loaded parts of mining machines operating in fretting corrosion conditions have been developed.

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***Authors*: Juri Olt,** *Doctor of Engineering Sciences*, *Professor*, *jyri.olt@emu.ee* (*Estonian University of Life Sciences*, *Tartu*, *Estonia*), **Vyacheslav V. Maksarov,** *Doctor of Engineering Sciences*, *Professor*, *maks78.54@mail.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*), **Viktor A. Krasnyy,** *Candidate of Engineering Sciences*, *Associate Professor*, *vikras1955@yandex.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*).

The paper was received on 8 June, 2018.

The paper was accepted for publication on 17 October, 2018.