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REGULARITIES OF DYNAMICS OF CHANGE IN TRIBOTECHNICAL CHARACTERISTICS OF COATINGS FORMED BY TRIBOTECHNOLOGIES OF RESTORATION

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In this paper, the laws of the dynamics of the changes of such tribotechnical characteristics as the moment of friction and the intensity of wear of the formed coatings by tribotechnology of restoration with the use of mixtures of geomodifiers KGMF-1 from natural substances based on the clay of the Katerinovsky deposit in the Kirovograd region of Ukraine are considered. The geomodifier KGMF-1 was added to the engine oil $M10G_{2k}$.

The study of the friction moment was carried out on a friction machine 2070 SMT-1 on various types of tripartite specimens and parts differing in area of the friction zone and the magnitude of its hardness. The processes of friction and wear were investigated by the method of acoustic emission on the Brüel & Kjear instrument with the determination of the intensity of wear.

The results of experimental studies have shown that the dependence of the moment of friction and the intensity of wear on the duration of the test for the strains I and III types are identical. Investigation of the patterns of these characteristics on samples without endurance and endurance of 100 and 300 days revealed the difference: when maintaining the coatings for 100 days tribotechnical characteristics are the best, with the friction moment practically does not change, however, the duration of the time of spin and the intensity of wear decreases.

Key words: technology of tribotechnical renewal, triflection, friction geomodifier, serpentinite, tribotechnical characteristics, friction time, intensity of wear.

Introduction

The increased intensity of use of agricultural, transport and military equipment leads to their failure and significantly reduces operational reliability. Primarily, this is the influence of the following number of factors: non-stationary mode of operation, reverse, vibration, abrasive particles entering into the contact zone of the three-component parts of systems and machine aggregates, a variety of external operating conditions due to variable load and sharp changes in environmental characteristics. The above leads to a significant increase in the intensity of the wear of the friction surfaces of the parts of the three-point ones. One of the ways to increase the durability and reliability of agricultural, transport and military equipment is to improve the tribotechnical parameters of lubricants by adding friction geomodifiers from natural and synthesized materials [1].

The constituents of the geomodifiers, together with the oil, make structural changes in the surface layers of the material of the triangular parts and make their modification in the tribotehnically advantageous direction. The fundamental difference between the friction geomodifiers from other additives is that the substances that initiate the processes of self-organization are introduced in the conjugation of the details [2]. While the rest of the additives are aimed at separating the surfaces of friction with soft metals [3], long hydrocarbon chains, synthesized film, formed composite coatings. They contribute to the formation of optimal surface structure, with the maximum number of free bonds, which provides increased oil-retaining ability and equilibrium roughness. By utilizing the operational properties of the use of geo-modifiers in tribotechnics, one can distinguish the following:

- the ability to form dynamic protective films from fine-grained products of wear and substances of the geomodifactor itself in the form of a quasi-liquefied layer (similar to the sol-gel of the recovery technologies), which reduces the intensity of wear of the three-component parts;
- displacement of friction characteristics closer to the hydrodynamic, substantially reducing mechanical losses;
- chemical and electrical neutrality and ecological purity of materials of geomodifiers and their formed coatings;
- the details of their modified surface layer of the parts of the three-pointers are preserved even until the thermocyclic permanent deterioration.

Literature Review

The effect of reducing compositions containing supplements of geological origin and based on the properties of powder based on serpentine was studied by British scientist Kaeker J. [4]. He also developed theoretical justifications for the application of this type of friction geomodifiers.

Known studies of tribotechnology laboratory of Beijing Tsinghua University [5-7] on the testing of geomodifiers in the form of finely divided mixtures of serpentines. It was shown that geomodifiers contribute to mechanochemical reactions, pyrolysis of the components of oils and tribocatalytic carbonization, graphitization, and the formation of solid carbonaceous compounds from oils. Conditions for the formation of coatings, low coefficient of friction and thermal conductivity, high strength and corrosion resistance of geomodifiers are revealed. The presented materials of the University of Beijing are confirmed by similar studies of the properties of geomodifiers $Mg_6Si_4O_{10}(OH)_8$ in the work of French scientists [8]. It is found that the basis of friction geomodifiers is a large group of minerals having a similar chemical composition, where magnesium can be replaced by iron and nickel. The serpentine breed includes several types of serpentine, magnetite and chromium inclusions, and the variation of chemical elements used as a mixture of geomodification composition [9, 10]. The Institute of Organic and Physical Chemistry of the Kazan Scientific Center of the Russian Academy of Sciences conducted a study of various geomodification compositions and provided recommendations for their effective use in the development of tribotechnologies of recovery [11]. It is determined that with grinding of particles of geomodifiers of friction there is a physical-chemical transformation and activation and abrasive cleaning of friction surfaces with minerals and the formation of juvenile surfaces on details, a mineral stalagmite structure is formed, and on it, with the possible participation of the trifocals, there is tribopolymerization of the components of the composite oil in the molded coating [12]. It was established that the increase of the carbonaceous coating, even in the absence of a friction geomodifier, is the chemisorption of hydrocarbon oils, due to the trio activation of the surfaces of friction, the chemical activity of carbon atoms with no compensated surface bonds. This is supported by studies of the tribological laboratory of Academician I.G. Goryacheva, which deals with the transition in the intensive graft from chemical to physical adsorption, fixed tribopolymerization of molecules of oil and other substances, the participation of radicals, particles of wear, and adsorption from the tribe environment of carbon, sulfur and oxygen [13].

The chemical component of the formation of a metal-ceramic layer from geomodifiers [13] was developed quite thoroughly in [14], which cannot be said about the physical-mechanical and rheological properties of this layer. Such developments are practically absent [15]. The authors of many papers indicate the impact strength and hardness of the processed metal-ceramic surface [16]. Proving the quasi-liquid state of metal-ceramic film on the surface of the friction, in published works absolutely exclude the possibility of an elastohydrodynamic effect, which obviously occurs when the metal-ceramic layer is in operation [17]. Deep metallophysical studies of surface and near-surface layers that formed on friction surfaces during treatment with revitalizes in the open literature were not found [18].

Purpose

The aim of the work is to identify patterns of dynamics of changes in tribotechnical characteristics (at the moment of friction and wear intensity) of coatings formed by tribotechnologies of restoration using mixtures of geomodifiers from natural substances KGMF-1.

Research Methodology

Coverage, with the implementation of tribotechnologies of restoration using a mixture of geomodifiers KGMF-1 from natural substances based on the clay Katerinovsk field of the Kirovograd region of Ukraine, were formed on different types of triangular samples and parts. Examples were samples and details of four types of trifles (Table 1).

Table 1

Types of strains of samples (parts) and their characteristic features

Characteristic features of samples (parts) of three-pointers				
Conjugation type	rolling sample (part)		immovable specimen (part)	
	hardness of material, H_p	area of friction zone, S_p	hardness of material, $H_н$	area of friction zone, $S_н$
I	bigger	bigger	smaller	smaller
II	smaller	bigger	bigger	smaller
III	bigger	smaller	smaller	bigger
IV	smaller	smaller	bigger	bigger

A widespread construction is the tripling of parts of the first type, in which the material of the mobile component has a higher hardness (H_p) and a larger area of the friction zone (S_p), while the fixed - less hardness $(H_н)$ and smaller area of the friction zone $(S_н)$. For the second-order triobs, the characteristic is $H_p < H_н$, $S_p > S_н$, the third - $H_p > H_н$, $S_p < S_н$ and the fourth type - $H_p < H_н$, $S_p < S_н$. The intensity of deterioration of hard and soft materials of parts of the fourth type of triobs is the same.

An example of the first type of conjugation is a conjugation consisting of a steel shaft and a soft liner. It is widely used in systems and aggregates of mobile agricultural and road vehicles, and has proven itself well in operation. The stratification of solid chromium-plated cylindrical specimens and the soft steel drive disk belong to the second type of triplexes. A hydraulic cylinder and a piston made of steel with it, and the cylinder is made of a milder steel, - form the third type of triplexes. The tribulation of the "cylinder-piston shell" refers to the fourth type.

To study the processes of formation of coatings on the working surfaces of conjugated samples after the application of tribotechnologies of restoration, as well as the mechanism of wear and relaxation of the energized energy, we used the circle-ring research scheme on the 2070 SMT-1 friction machine.

In the course of the research, the change in the friction moment, the friction force and the size of the sample, and the intensity of wear, were determined by the amplitude of the acoustic signal from the friction zone.

The lubricating medium used was motor oil M-10G_{2K} (base oil) and motor oil M-10G_{2K} with the addition of tribotechnical reducing mixture: base oil + additive KGMF-1. The research was carried out on a friction machine 2070 SMT-1 under the scheme of "ring-ring", with a coefficient of mutual overlap $K_{mo} = 0{,}5$. Before the tests, the samples were rubbed against each other. The surface roughness in all experimental variants was $R_a = 0{,}2...0{,}3$ μm. The research was carried out at a load of 200 N and a slip rate of 0.7 m/s. The samples had an external diameter of 12 mm, and an internal diameter of 6 mm.

A gear pump through the nozzle fed the base and composition oils in the friction zone. To exclude the influence of wear particles on the parameters of friction and wear in the lubrication system, a filter with fine purification of particles of size 10 microns is installed.

The study of the effectiveness of the additive KHMF-1 was carried out on different types of designs of three-point samples (Table 1). As material of solid materials, steel 45 (HRC52) was used, and as soft - bronze Br.AZH 9-4 (HB95) and gray modified SFM pig iron.

The processes of wearing of triangular samples and details were investigated by the method of acoustic emission. The unique features of the method are limited to the equipment used. The acoustic-emission complex consisting of the Brüel & Kjear serial device was used in this work.

As a sensor, the piezoelectric element of this company was used, which fixed on a fixed sample.

The acoustic emission complex allows removing an acoustic signal from triflections of samples in the course of their testing. It is important during the tribological research to choose the parameters of acoustic emission, which adequately reflects the processes of wear, taking into account the specificity of the formation of the signal. As an information characteristic of acoustic emission, the amplitude of the signal from the region of the friction zone, which correlates with the intensity of wear, was chosen to study the dynamics of the formation and destruction of the wear-resistant layer. To translate the values of the amplitude of the acoustic emission of the signal from the friction zone to the value of the intensity of wear, built tare chart.

To select the frequency interval for the recording of sound signals, the work of a frictionless machine without samples throughout the spectrum of frequencies, and then with prototype samples, was first examined. Analyzing the acoustic signals, the frequency that was most suitable for studying the dynamics of formation and destruction of the formed tribotechnologies of restoration of coating layers was chosen. It was 4 kHz.

Experimental studies of various types of triangular samples were carried out to obtain values of the intensity of wear in the media of the base M-10G_{2K} and composite M-10G_{2K} + KGMF-1 oils. The total duration of the experiment at each repetition was 4 ... 5 hours. In each case, the diagram of the change in the amplitude of the acoustic emission and the friction force on the recorder were recorded, in which at any point of the test the friction moment and the intensity of wear were determined.

The triangulation of samples and parts was worked on both the base M-10G_{2K} and composite M-10G_{2K} + KGMF-1 oils. After the completion of the trimming, disassembly, pouring of oil and degreasing of the surface of the friction. After degradation of the triangular samples, they were re-installed on the friction machine and tested. Moreover, the mode of operation of the three-way, the speed of sliding and loading both during the process of working and for their work after degreasing were the same.

The duration of functioning of the formed protective coating formed by the tribotechnology of the restoration of the working surfaces of samples and parts of various types with the created coating without endurance and coating after a certain time delay was experimentally investigated experimentally.

Results

Experimental studies have shown that the dependence of the friction moment (Fig. 1, a) and the intensity of wear (Fig. 1, b) on the duration of the test for the three-way samples of samples I and III is identical and represented by the same curves.

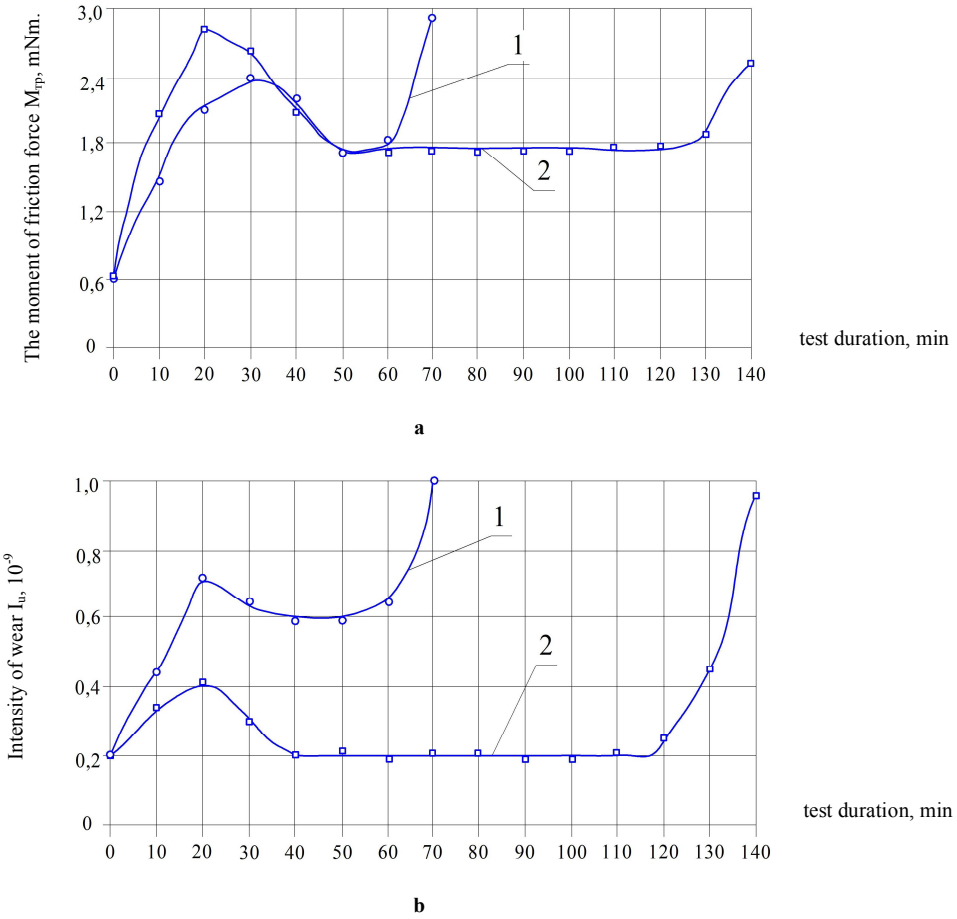
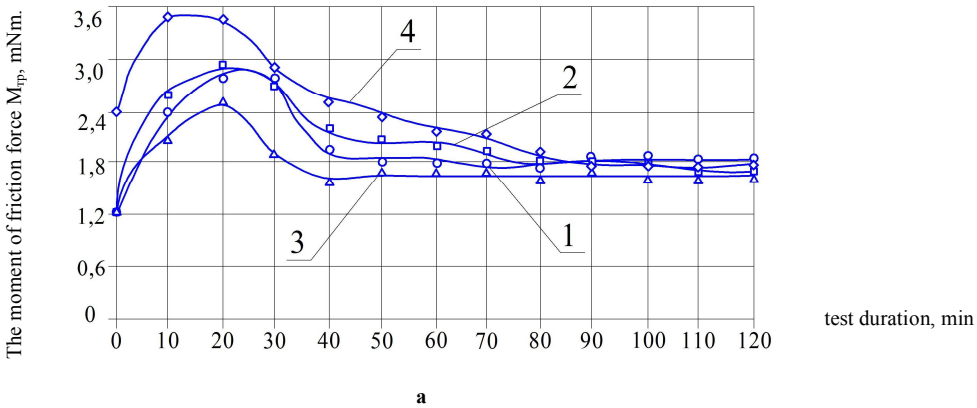
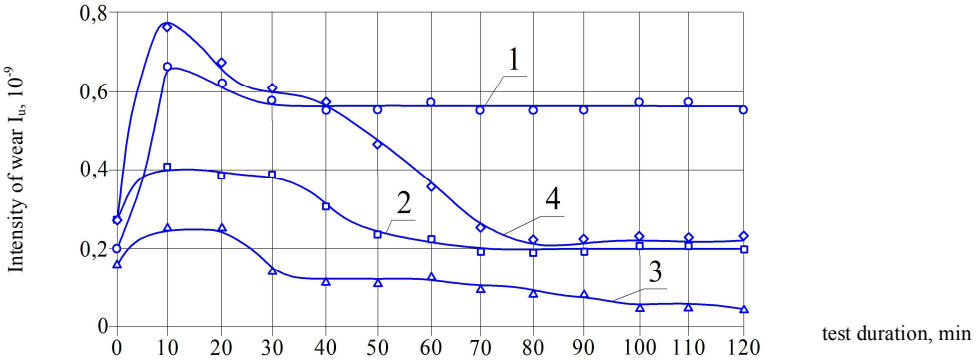


Fig. 1 – Patterns of the change in the moment of friction (a) and the intensity of wear (b) of the threefold of specimens of types I and III in time, in studies of the duration of their existence on the coating of the developed tribotechnology of recovery:
1 – base oil M-10G_{2K};
2 – base oil M-10G_{2K} + KGMF-1

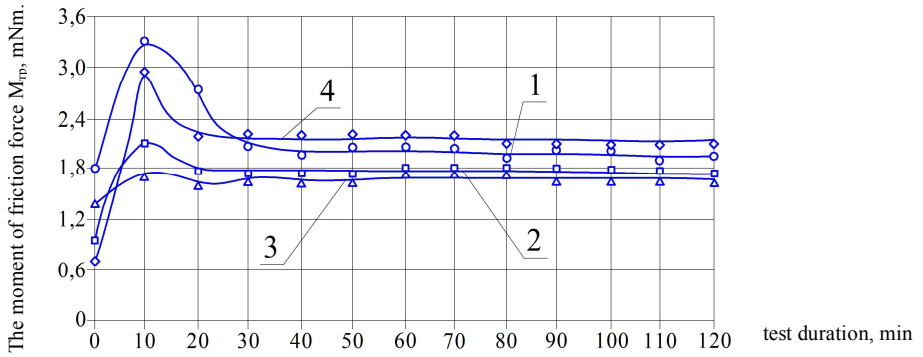
The results of the investigations of the regularities of the change in tribotechnical characteristics of the coatings of the tribotechnology of the restoration and their endurance during 100 and 300 days on the tripartite I and III types are shown in Fig. 2 and rice. 3. As a solid sample material, steel 45 (HRC52) was used.



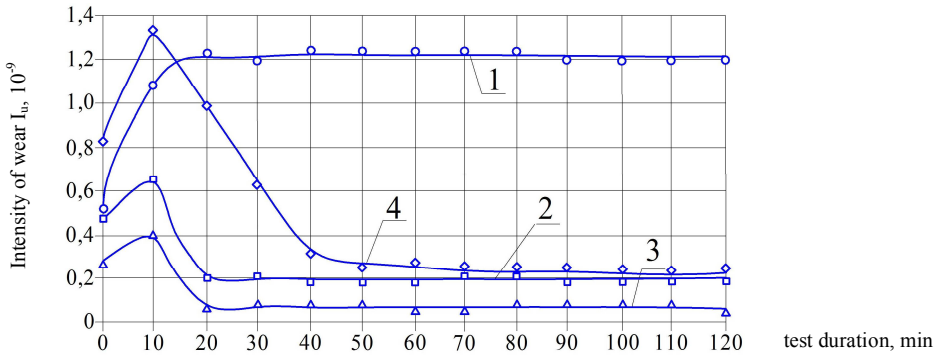


b

Fig. 2 – Patterns of change in moment of friction (a) and intensity of wear (b) of strain of specimens of type I in time:
1 – base oil M-10G_{2K};
2 – created cover without endurance;
3 – coverage after 100 days of exposure;
4 – coverage after 300 days of exposure



a



b

Fig. 3 – Patterns of change in the moment of friction (a) and intensity of wear (b) of three-point samples of type III:
1 – base oil M-10G_{2K};
2 – created cover without endurance;
3 – coverage after 100 days of exposure;
4 – coverage after 300 days of exposure

We substantiate the obtained research results. From the graphic dependencies (Fig. 1), after a degreasing, a rapid and jerk-like growth of the friction moment and the intensity of wear, i.e., strabismus I and III types within 2 minutes, went out to the zander.

A tripod when working on base oil with the addition of tribotechnical reducing compound KGMF-1 indicated the best result. Stratification on base oil worked steadily for 60 minutes, and then observed a rapid in-

crease in the moment of friction and intensity of wear. With the use of tribotechnologies of restoration, the wear-resistant coating formed on friction surfaces for a long time can provide the work of tripling of samples and parts even in the absence of a lubricating medium or in a lubricating starvation mode.

The results of the studies indicate that regardless of the combination of materials in the tripartite samples and parts, on their various types, the rheological properties of the formed coatings in the process of their aging change. It was found out that after a long exposure to the rheological properties of the surface layer of samples and parts deteriorate and in size become equal to those that are in the source material.

It is known that the change in the rheological properties of the surface layers correlates with the tribotechnical characteristics of the triangular samples and parts. Analysis of the presented dependencies (curves 3, Fig. 2, Fig. 3) indicates that tribotechnologies of recovery and which have undergone a process of holding for 100 days have the best tribotechnical characteristics form the coatings. At the same time, the friction did not change, however, the length of the working time and the intensity of wear considerably decreased.

Studies of the same type of tripartite samples in similar conditions after exposure for 300 days are presented in the form of curves 4, Fig. 2 and Fig. 3. You can see that during the first 20 minutes. Work of triflection of samples of type I and 10...15 min. the work of tripling of samples of type III results in intense wear of the coating. This is manifested in the intensive variation of the moment of friction and intensity of wear. It can be assumed that the wear-resistant coating, formed by the tribo technologies of recovery, became fragile and unable to plastically deform, respectively, cracked and torn off the surface of the friction of samples and parts.

Since the engine oil M10G2K contains a tribotechnical reducing compound of the geomodifier KGMF-1, the process of forming a new coating is underway during the test. Because of scratching in the cleaned friction surface of the solid component of the KHMT-1 mixture and the subsequent tribochemical reactions, after 80 min. for type 50 min and I tripping. For a type III strain, the formation on the surface of the friction of the samples and parts of the coating is completed and the tribotechnical characteristics become similar to the created coating without endurance.

Similar dependencies were obtained for the intermixing of samples and parts with materials ratios, where chromium plated steel coatings were used as solid surfaces of friction, and as gray - modified gray pig iron.

Conclusions

1. The mechanism of formation of wear-resistant coatings on friction surfaces of samples and details of different types with the use of tribo-technologies of restoration has been substantiated and experimentally confirmed. It is established that the efficient use of the mixture of geomodifiers KGMF-1 will be on those structures of three-way, where a fixed sample or part is made of a material whose hardness is less than the hardness of the microparticles of the mixture. Conversely, if a stationary sample or part is made of a material which, in hardness, is equal to or greater than the hardness of the microparticles of a mixture, the efficiency of the use of the tribotechnical restoring mixture of the geomodifier KGMF-1 will be negligible.

2. The results of experimental studies of various structures of triangular samples and parts with different ratios of materials allowed to establish that when using a mixture of geomodifiers, in the form of a KGMF-1 additive, the intensity of wear is reduced 3-6 times and practically no loss of friction decreases. It was found out that the wear-resistant coating, formed by tribotechnologies, provides a low intensity of wear in the mode of oily starvation, or a temporary lack of lubricant in the friction zone.

3. Research friction surface structures of different systems and components of vehicles with rheological viewpoint revealed that formed during tribochemical reactions on friction surfaces wear-resistant coating at the initial time of operation has viscous phase is similar to the structure of Zola, and therefore good dissipative properties due to visco-elastic relaxation of stresses. It was established that during the operation there is a change in the structure of the coating, which goes into a solid phase with a slight content of the viscous phase, that is, similar to the structure of the gel. At the same time, the dissipative properties of the protective coating become higher than in the created coating without endurance, and therefore the transition to a non-wearable. It was found that with a longer shelf life (more than 300 days) there is a complete loss of its dissipative properties.

References

1. Aulin V., Hrinkiv A., Dykha A., Chernovol M., Lyashuk O., Lysenko S. (2018). Substantiation of diagnostic parameters for determining the technical condition of transmission assemblies in trucks. Eastern European Journal of Enterprise Technologies, 2 (1-92). P. 4-13.

2. Aulin V., Arifa W., Lysenko S., Kuzyk A. (2016). Improving of the wear resistance of working parts agricultural machinery by the implementation of the effect of self-sharpening. International Journal of Engineering and Technology (UAE), 5 (4), P. 126-130.

3. Ashmarin G. M., Aulin V. V., Golubev M. Yu., Zvonkov S. D. (1986). Grain boundary internal friction of unalloyed copper subjected to continuous laser radiation. Physics and chemistry of materials treatment, 20 (5), P. 476-478.

4. Kaeker J. J. (1990). Three dimensional Elastic Bodies in Rolling Contact. Dordrecht; Boston: Kluwer Academic Publishers. 314 p.

5. Shenghua L., He Y., Yuansheng, J. (2004). Lubrication Chemistry Viewed from DFT-Based Concepts and Electronic Structural Principles. Int. J. Mol. Sci. 5. 13-34.

6. Xiaohao C.; Shenghua L.; Huaihe S. et al. (2003). Tribology Lett. 14. 53-59.

7. Hsu S. M. (2002). Proc. of New Tribological Frontiers and Future Trends, Beijing, China, Oct. 5-20.

8. Yuansheng J., Shenghua L. (2007). Superlubricity of in situ generated protective layer on worn metal surfaces in presence of Mg6Si4O10(OH)8. Superlubricity. Edited by Ali Erdemir. Argonne National Laboratory. Argonne, USA; and Jean-Michel Martin. Ecole Centrale de Lyon.-Lyon, France. P. 445-469.

9. Basu B. (2011). Tribology of Ceramics and Composites: Materials Science Perspective. The American Ceramic Society. P. 522.

10. Tribology of Diamond-Like Carbon Films (2017). Fundamentals and Applications. University Institute of France and University Jean Monnet, Laboratoire Hubert Curien. P. 121.

11. Dounaev A. (2014). Friction Surfaces Modification Using Tribo-Compounds. World Applied Sciences Journal. Vol. 31 (2). P. 272-276.

12. Lyubimov D. N., Dolgopolov K. N. and others. (2009). The structure of lubricant layers formed by friction in the presence of additives of mineral friction modifiers. Friction and wear, № 5 (30). P. 516-521.

13. Goryacheva I. G. (2001). Mechanics of friction interaction. Moscow. Science. 478 p.

14. Dunaev A. V., Sharifullin S. N. (2013). Modernization of worn out equipment using tribological products. Kazan. Edition of Kazan University. 272 p.

15. Vasilkov D. V., Pustovoi I. F., Pustovoi N. I. (2011). Analysis of the layer formed by the mineral modifier of the friction surface. Moscow. Proceedings of GOSNIITI, T. 107, part 2. P. 11-13.

16. Kang E. T. (2000). Surface modification of fluoropolymers via molecular design. Advanced Materials, 12(20). P. 1481-1494.

17. Baskar S., Sriram G., Arumugam S. (2015). Experimental analysis on tribological behaviour of nano based bio-lubricants using four ball tribometer. Tribology in Industry, vol. 37, № 4, P. 449-454.

18. Georgescu C., Solea L.C., Deleanu L. (2015). The influence of degumming process on tribological behaviour of soybean oil. Tribology in Industry, vol. 37, № 3, P. 330-335.

Аулін В.В., Лисенко С.В., Гриньків А.В., Великодний Д.О., Чернай А.Є., Лукашук А.П. **Закономірності динаміки зміни триботехнічних характеристик покриттів, сформованих триботехнологіями відновлення.**

Виконаний аналіз літературних джерел показав, що підвищена інтенсивність використання сільськогосподарської, транспортної та військової техніки обумовлює інтенсивне зношування поверхонь тертя деталей трибоспряжень, їх систем і агрегатів. Виявлено, що одним зі способів підвищення зносостійкості і надійності машин є покращення триботехнічних показників мастильних матеріалів додаванням в них геомодифікаторів тертя. З'ясовано експлуатаційні властивості від використання геомодифікаторів у трибоспряженнях деталей та показано можливість їх відновлення і реалізація процесів самоорганізації.

З наукових робіт вітчизняних та зарубіжних вчених виявлено теоретичну та експериментальну доцільність використання геомодифікаторів у відновлювальних композиціях триботехнологій, особливо порошку на основі серпентину. Визначено, що з подрібненням частинок геомодифікаторів тертя на поверхні відбуваються фізико-хімічні перетворення та спостерігається трибополімеризація компонентів композиційної оливи у сформованому покритті. Зазначене покладено в основу розробки триботехнологій відновлення у різних країнах з використанням різних типів геомодифікаторів.

В даній роботі розглянуто закономірності динаміки зміни таких триботехнічних характеристик, як момент тертя і інтенсивність зношування сформованих покриттів триботехнологією відновлення з використанням сумішей геомодифікатора КГМТ-1 з природних речовин на основі глини Катеринівського родовища Кіровоградської області України. Геомодифікатор КГМТ-1 додавали в моторну оливу М10$Г_{2к.}$

Дослідження моменту тертя проводили на машині тертя 2070 СМТ-1 на різних типів трибоспряження зразків і деталей, що відрізнялися за площею зони тертя і величини її твердості. Процеси тертя та зношування досліджували методом акустичної емісії на приладі фірми Brüel & Kjear з визначенням величини інтенсивності зношування.

Результати експериментальних досліджень показали, що залежність моменту тертя і інтенсивності зношування від тривалості випробування для трибоспряжень I і III типів є ідентичними. Дослідження закономірностей цих характеристик на зразках без витримки і витримці 100 і 300 діб виявили відмінність: при витримуванні покриттів протягом 100 діб триботехнічні характеристики є найкращими, при цьому момент тертя практично не змінюється, однак зменшується тривалість часу

Ключові слова: технології триботехнічного відновлювання, трибоспряження, геомодифікатор тертя, серпентиніт, триботехнічні характеристики, момент тертя, інтенсивність зношування.