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NEW TECHNOLOGY OF MODIFYING A MACHINE ELEMENT SURFACE IN AN ATTEMPT TO OVERCOME THE TRIBOLOGICAL BARRIER

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НОВА ТЕХНОЛОГІЯ МОДИФІКУВАННЯ ПОВЕРХНІ ДЕТАЛЕЙ МАШИН НА ШЛЯХУ ПОДОЛАННЯ ТРИБОЛОГІЧНОГО БАР'ЄРУ

Purpose. The increase in the service life of the main types of mining machines and metallurgical equipment, reduction in their metal consumption, reduction in the number of repair workers and improvement of manufacturing safety substantially depend on a tribological problem, which includes the development of a lubricant, new processing and modification technologies of machine element working surfaces.

Methodology. Maintenance of gears, rolling contact bearings, skid bases, camshaft mechanisms, guide members, sealing elements, junctures, locks and docking devices requires bringing geomodifiers of friction (GMF), special self-lubricating materials, friction modifiers, and methods of their treatment into the friction area.

Findings. For the first time, products of serpentine decomposition have been identified on the basis of fundamental structural research. These products form a protective ceramic-metal layer on the metallic surface. Results of industrial tests prove the high effectiveness of the use of natural minerals as machine elements modifiers. They allowed making the service life of mining and metallurgical equipment 2.5–5 times longer because of the reduction or elimination of repair works and increase in functional properties of engineering products.

Originality. A new scientific direction in the triboenergetics field has been created. It is based on the fundamental research into the mechanochemical influence of the complex of natural materials on the working areas of machine elements. For the first time, it has been proved that in the process of friction, a protection layer with unique wear-resistant characteristics is formed on the contact surfaces. The functional condition of the friction unit surface is recovered as a result of the initialization of self-organizing processes during the plastic deformation.

Practical value. The application of friction modifiers makes it possible to increase the service life and reliability of essential parts of mining and metallurgical equipment, to reduce the quantity of maintenance work and to increase the safety of mining and metallurgical equipment operation.

Keywords: *friction geomodifier, friction pair, surface modification, wear-resistance*

Formulation of the problem. It is well-known fact that the significant part of the expenses related to machinery includes the costs on its service and repair, while the complete overhaul, due to its expensiveness, is often comparable with the cost of a new mechanism. The increase in the service life of the main types of mining machines and equipment and the reduction in their metal consumption depend, among other things, on resolving a tribological problem, i.e. a problem of friction, wear, lubrication, and new technologies of processing and modifying surfaces.

Analysis of recent research. The operational conditions as well as design patterns of tribological units are so diverse and design requirements are so strict that it is difficult to choose the adequate materials and technological ways of enhancing their durability, which nearly always results in a compromising solution. International tribological research is characterized by the tendency to develop functionally oriented methods, which are checked and modified according to the data obtained in the field conditions.

Methods of strengthening machine element surfaces subjected to friction are based on various physical, chemical and mechanical processes, resulting in the increase in wear-resistance, strength, hardness and corrosion resistance, which ensures a specified service life and minimization of energy losses during the friction unit operation.

Ukrainian and foreign authors have outlined the research guidelines and the ways of their practical realization in the area of enhancing the endurance of different types of mechanical equipment.

Since there is no universal way of strengthening tribological units, it is important to consider the factors specific for each single case: for example, the allowable distortion of machine elements, the occurrence and type of residual stresses, the impact of technological environment, ecological and financial parameters. Some strengthening methods are widely known: chemical and thermal treatment, diffusion, surfacing, chemical deposition from gas medium, implantation, thermal vacuum methods, ion-plasma methods and laser methods. A detonation method allows obtaining coatings with enhanced operational properties. Each of the above methods has its advantages, disadvantages and a particular field of application.

The new direction in solving this problem is the mechano-chemisty influence of tribotechnical powder compositions − geomodifiers of friction (GMF) − on the working surfaces of machine elements. GMF represents a complex of grinded natural materials containing minerals of ultrabasic rocks occurring on the boundaries of tectonic plates, and used by nature as materials for a triboprocess. The problem of achieving high-adsorptive potential, which serves as a measure of mechanoactivation, was solved by crushing the serpentine using a vibroimpact method [1].

The total adsorptive potential obtained through this crushing method is 2.5 times higher than that one after grinding the serpentine by grinding balls in a drum-type mill (compare: in the first case $\Delta_{\mu\Sigma 1}$ = 1.52 kJ/mol, in the second case $\Delta_{\mu\Sigma 2}$ = 0.6 kJ/mol).

Review of unresolved issues. High loads, extreme speed, a wide temperature range and the presence of aggressive media determine new requirements for the performance and operation of friction units of modern mining and metallurgical equipment. To ensure the efficient work of gears, rolling contact bearings, skid bases, camshaft mechanisms, guide members, sealing elements, junctures, locks and docking devices, it is necessary to create special self-lubricating materials and coatings, friction modifiers, durable coatings with high chemical resistance and new ways of friction unit treatment.

Statement of purpose. The result of the received mechanoactivation effect became apparent at the following stages of the technological process of friction geomodifier manufacturing. Fine-dispersed powders (0.5−1 μm) having been crushed in a special manner and having passed the mechanoactivation stage, are brought into a friction area with the lubricant, where they make structural modifications in the friction surface in a favourable way for tribotechnics.

The principles of creating nanomaterials on the basis of natural materials have been developed to enhance wear resistance and tribological properties of heavily duty units, in particular in a case of extreme conditions. The article has investigated the technology of activationless slip in the area of surface matching where dispersed micro- and nanoparticles of geomodifiers on the basis of SiO_2, Al_2O_3 are involved. The perfect property of the rolling of spherical nanoparticles with slipping has been found out when there is a relative motion of the surfaces of pairs elements on ceramics in the intermediate layer of ceramic particles. The relevant feature of implementing the effect of the activationless functioning of nanomodifier particles in the area of moveable surface matching is 90% amorphization of components (SiO_2, Al_2O_3). The amorphization is formed at the stage of running-in the surfaces, creating flat-topped microrelief in tribocoupling and achieving sizes of inactivated particles in the process of dispersing nano-quantities. The content of ceramics in nanoparticles in the lubricant comprises 7−10% of the total volume of oil and allows particles not only to penetrate into the dimples of microgeometry of mating pairs surfaces (fig. 1, *a*), but also to continuously migrate in suspension in oil (fig. 1, *b*), acting as bearing microballs. It has been revealed that on the surface of tribocontact, the microrelief with new properties is gradually formed. These properties are completely coordinated with the features of the self-organization of surface matching systems. In extreme conditions of uncontrolled workflow, a quasi-protective layer of residual ceramic nanoparticles contained in geomodifiers provide the short-term antiwear effect in case in case the lubrication is absent.

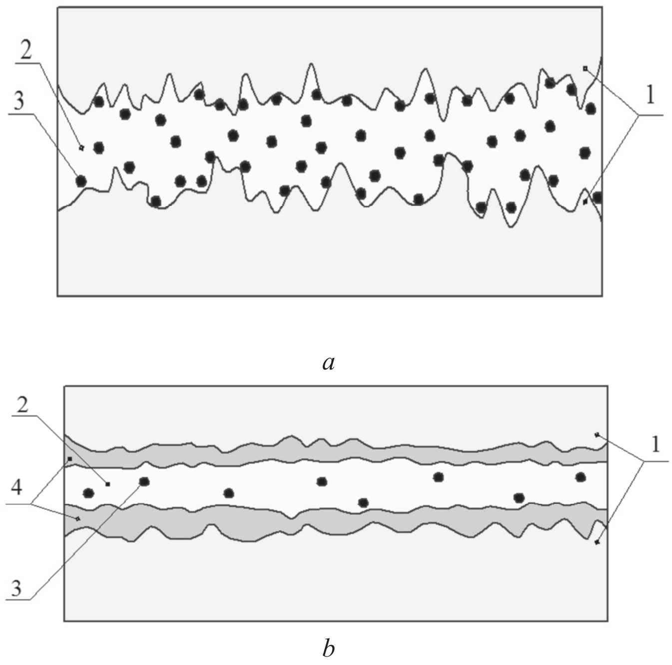

Fig.1. Operation of mating pairs: 1 – mating surfaces; 2 − lubricant; 3 − geomodifier of friction; 4 − wear resistant film

It has been found out that transition silicide layers in carbon steel and cast iron are formed in the process of diffusion and mechanochemical synthesis of components of geomodifier reaction mixture. Based on experimental results and acquired practical experience in commercial operation, it has been confirmed that, to obtain the corresponding coating layer on cast iron, used for the manufacture of heavy duty precision parts, geomodifier reaction mixture should contain at least 60% of components containing silicon.

We used scanning tunneling electron microscopy, computer technology to measure the surface topography of friction, wear, adhesion, the composition of modified nanoscale layers, which made it possible to determine the conditions that lead to extremely low friction and wear values (fig. 2).

Basic material. While manufacturing and during the subsequent work of the unit of friction, the defective layer of metal is formed on the surfaces of friction. The particles of GMF, brought into a zone of friction and having weak abrasive properties, delete this layer, simultaneously getting grinded between mating surfaces, losing its abrasiveness. Then during the friction, micro-hardening of surfaces and further splitting of GMF particles on cleavage planes occur. At this stage, in points of physical contact, the micro-metallurgical processes take place. When this happens, the free ions are *allocated* from the structure of GMF, which *diffuse* into superficial layers of substrate material and form there firm solutions. A layer of metal ceramics is formed on the surface. It consists of initial tribounit material and material of fine-dispersion natural mineral. The process of self-organization consists in a hereditary "memory" of material. Included in the structure of a powder, *A1* and *Fe* are catalysts of pyrolytic carbon formation along the borders of grains up to a subsurface layer, and the basic composition of GMF modifies the boundary layer with a high degree of available bonds attaching the "lost" material from the dispersion environment.

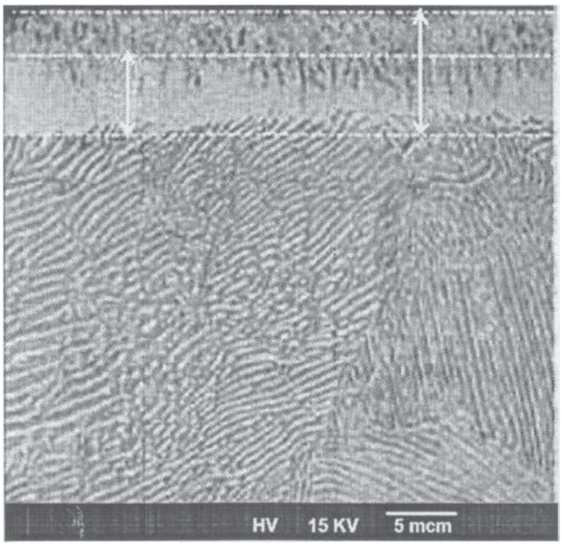

Fig. 2 Micrograph of a cross-thin section of a friction surface of the sample of gray cast iron run-in with GMF, x 4000

The distinctive feature of the process is its ability for self-regulation, which is conditioned by the fact that the process occurs simultaneously in both contacting surfaces under the influence of the same load. Moreover, diffusion of GMF into a firmer surface occurs more slowly, that results in complete smoothing of microhardness of the superficial layers of contacting elements. The changes taking place lead to a significant increase in the linear sizes of elements.

Simultaneously the process of mating surfaces microgrinding occurs, resulting in essential reduction in their roughness. A typical grain-oriented microrelief is formed on the surface of friction. This microrelief has micro-dimples good at retaining oil.

Equal micro-hardness in combination with low roughness of surfaces leads to unique antifriction effect.

The following examples prove the efficiency in recuperating friction surfaces by geoactivators. Geoactivators were used to treat roller bearings of the PS-150-1 rolling mill at the Kryvorizhstal Metallurgical Plant, which resulted in the growth of rolled metal quantity during the bearing service time. The comparative analysis showed that the service time became 2 ... 5 times longer after implementation of geoactivators.

Grinder gearboxes were subjected to geoactivator treatment at the Nikopol FerroAlloy Plant. As a result of experiment, we could observe the significant reduction in the noise accompanying gear operation, reduction in current load by 12%, increase in contact area from 60 to 90%, disappearance of pitting on the surface of pinions, decrease in bearing temperature from 45 to 24°C.

During long-term endurance testing of friction units run-in with geoactivators, we observed further gradual reduction in friction coefficient in time. This can be explained by formation of the surface structure still going on after the treatment is over. The total service life of friction units treated by geoactivators increased 3–5-fold.

The putter open gearing transmission of the ESh-15/90 walking excavator was treated at Basanskyi Open-pit Mine of Marganets Ore Mining and Processing Enterprise. The gauging of teeth after two months of processing showed a gain of 0.14 mm tooth thickness (from 31.64 to 31.78 mm), whereas the two-month deterioration of the teeth of untreated wheels was 0.4 mm.

The process of linear size increase is self-regulated as it lasts until existing gaps are chosen. Self-regulation ability gives wide opportunities in geomodifier application. Its use allows recovering worn-out gearing transmissions, bearing and sliding rollers, pump elements. The high antifriction properties of the formed surfaces make it possible to lower considerably power consumption, to raise the efficiency of machines and mechanisms.

Thus, the basic advantages of geomodifiers of friction are the ability to create a dynamic protective film in the friction area from fine-dispersion deterioration products and GMF itself; to strengthen a surface of friction evenly in the process of running-in a tribounit; to considerably reduce a factor of friction (4–6-fold), and hence mechanical losses; to repeatedly reduce the speed of wear process of friction surfaces; to increase allowable load limit in a tribounit.

Surface modification aimed at decreasing roughness and increasing essentially operational characteristics of machine elements has been achieved due to the simultaneous use of high-energy dimension ultrasonic element treatment and geomodifiers of friction brought into superficial layers of metal.

In the course of processing, the cold-hardening of the surface and friction geomodifier particles being in the dimples of surface microroughnesses takes place under ultrasonic influence [2]. When the cold-hardening of firm constituents of a friction geomodifier on the basis of serpentine occurs, their partial disintegration takes place, as a result of which the fine parts of new structural formations are allocated, which, having hit a sliding surface, block the evolution of destructions. It results in an essential increase in disposition density, crushing crystals into fragments and blocks, an increase in a degree of cold-hardening and, as a consequence, in substantial growth of surface hardness. Structural changes, which occur in the near-surface layers of work-pieces treated in an offered way, lead to a considerable increase in their operational characteristics, such as contact stability, wear resistance, durability, etc.

The measurements of the microstructure of the surface taken with the "TAIYSURE-5" profilograph have given the following results: the roughness of shaft area after ultrasonic treatment has decreased 3.5-fold, after the simultaneous treatment by ultrasound and geomodifier, the roughness of the surface has decreased 6-fold.

The results of the roughness research are illustrated in the table and in fig. 3.

Table

Results of the Study of Roughnesses of 30 KhHSA Steel

№	Type of treatment	Surface roughness, μm
1	Turning	3.7
2	Ultrasonic treatment	0.97
3	Ultrasonic treatment combined with friction geomodifier	0.6

Samples used for tests on the SMTs-2 friction machine have been separately processed.

The following samples of 40Kh steel have been tested:
- normalized ground steel (HB 180)
- improved ground steel (HB 350)
- normalized steel (HB 180) treated by ultrasound, (HB 320)
- normalized steel (HB 180) treated by ultrasound together with geomodifier (HB 360).

The results of wear resistance comparative tests, carried out by the SMTs-2 friction machine are shown in fig. 4.

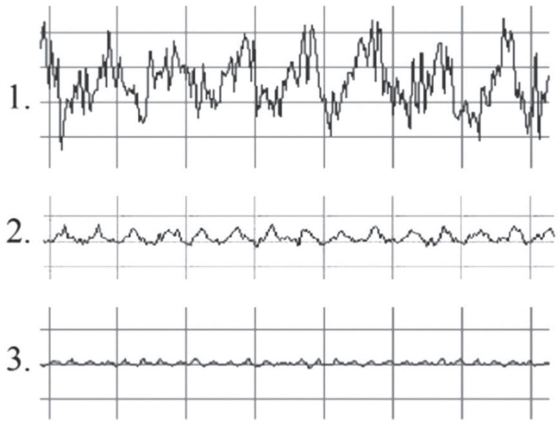

Fig. 3. Profilogram of shaft surfaces (vertical magnification is 1000, horizontal magnification is 50000): 1 − initial profilogram (after turning); 2 − profilogram after ultrasonic treatment; 3 − profilogram after cotreatment by ultrasound and geomodifier of friction

The deterioration tests have been carried out according to the scheme "roller-to-roller", N_u=600000:
- deterioration of sample 1 made up 24.2 mg
- deterioration of sample 2 made up11.0 mg
- deterioration of sample 3 made up 8.9 mg
- deterioration of sample 4 made up 5.7 mg.

A new scientific trend in the field of tribology has been developed, which is based on the fundamental research into mechanical and chemical processes occurring in the area of machine element working surfaces under the influence of the complex of natural materials crushed in the contact point into nanolevel particles − geomodifiers of friction. We have pioneered to prove that in the process of friction, a specific protecting layer is formed on the contact surfaces. This layer is characterized by unique tribotechnical properties of anti-friction, wear-resistance and scuff-resistance. Friction unit performance is recovered due to initiating self-organizing triboprocesses.

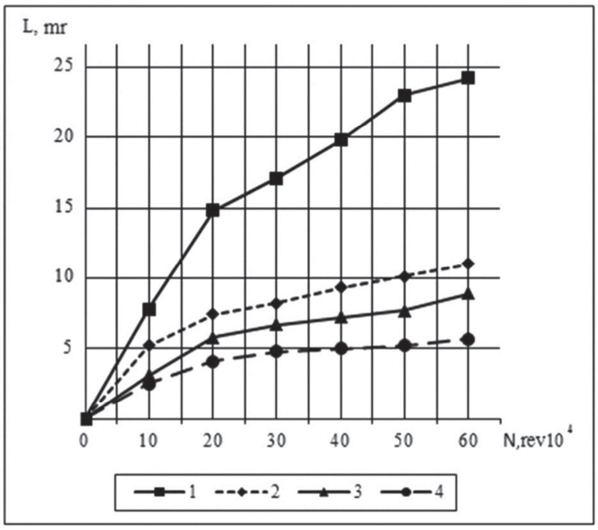

Fig. 4. Comparative analysis of deterioration parameters for different ways of treating samples of 40 Kh steel: 1− normalized ground steel (180 HB); 2 − improved gro-und steel (350 HB); 3 − normalized steel (180 HB) treated by ultrasound, (320 HB); 4 − normalized steel (180HB) treated by ultrasound together with geomodifier (360HB)

Conclusions and prospects for development. The use of GMF as the compositions for worn-out friction units' recovery, without operating equipment being shut down, allows essential reduction in maintenance costs related to machinery and equipment repair, reduction in power consumption, an increase in a service life of machinery and mechanisms.

Combined dimensional final processing with the simultaneous use of ultrasound strong sources and friction geomodificators brought into the processed surface, allows modification of the working surface with high operational characteristics in local element areas (which is very important).

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Мета. Збільшення терміну служби основних видів гірських машин і металургійного устаткування, зниження їх металоємності, скорочення чисельності робітників, зайнятих ремонтом, підвищення продуктивності та безпеки залежать, значною мірою, від трибологічної проблеми, що включає розробку мастила та нових технологій обробки й модифікування робочих поверхонь деталей машин.

Методика. Забезпечення нормальної роботи зубчастих передач, опор кочення та ковзання, кулачкових механізмів, напрямних, ущільнюючих елементів, шарнірів, замків, стикувальних вузлів шляхом уведення в область тертя геомодифікаторів тертя (ГМТ), спеціальних самозмащувальних матеріалів, модифікаторів вузлів тертя, способів їх обробки.

Результати. Уперше на підставі фундаментальних структурних досліджень ідентифіковані продукти розкладання серпентину, що утворюють захисний металокерамічний шар на металевій поверхні. Наведені результати промислових випробувань, що підтверджують високу ефективність застосування природних мінералів в якості модифікаторів поверхонь деталей машин, які дозволили в 2,5−5 разів підвищити ресурс гірничо-металургійного устаткування за рахунок зниження, а іноді виключення, ремонтних робіт і підвищення функціональних властивостей машинобудівних виробів .

Наукова новизна. Створено новий науковий напрям в області геотрібоенергетики, що заснований на фундаментальних дослідженнях механохімічного впливу на робочі поверхні деталей машин комплексу природних матеріалів. Уперше доведено, що у процесі тертя на контактних поверхнях формується захисний шар, що має унікальні протизношувальні характеристики. Відбувається відновлення функціонального стану поверхні вузла тертя за рахунок ініціювання самоорганізованих процесів у пластичній деформації.

Практична значимість. Застосування геомодифікатора тертя дозволяє підвищити ресурс і надійність відповідальних деталей гірничо-металургійного устаткування, знизити кількість ремонтів і підвищити безпеку роботи гірничо-металургійного устаткування.

Ключові слова: *геомодифікатор тертя, пара тертя, модифікування поверхні, зносостійкість*

Цель. Увеличение срока службы основных видов горных машин и металлургического оборудования, снижение их металлоемкости, сокращение численности рабочих, занятых ремонтом, повышение производительности и безопасности зависят, в значительной степени, от трибологической проблемы, включающей разработку смазки, новых технологий обработки и модифицирования рабочих поверхностей деталей машин.

Методика. Обеспечение нормальной работы зубчатых передач, опор качения и скольжения, кулачковых механизмов, направляющих, уплотнительных элементов, шарниров, замков, стыковочных узлов путем введения в область трения геомодификаторов трения (ГМТ), специальных самосмазывающих материалов, модификаторов узлов трения, способов их обработки.

Результаты. Впервые на основании фундаментальных структурных исследований идентифицированы продукты разложения серпентина, образующие защитный металлокерамический слой на металлической поверхности. Приведены результаты промышленных испытаний, подтверждающие высокую эффективность применения природных минералов в качестве модификаторов поверхностей деталей машин, которые позволили в 2,5–5 раз повысить ресурс горно-металлургического оборудования за счет снижения, а иногда исключения, ремонтных работ и повышения функциональных свойств машиностроительных изделий.

Научная новизна. Создано новое научное направление в области геотрибоэнергетики, которое основано на фундаментальных исследованиях механохимического воздействия на рабочие поверхности деталей машин комплекса природных материалов. Впервые доказано, что в процессе трения на контактных поверхностях формируется защитный слой, обладающий уникальными противоизносными характеристиками. Происходит восстановление функционального состояния поверхности узла трения за счет инициирования самоорганизующихся процессов в пластической деформации.

Практическая значимость. Применение геомодификаторов трения позволяет повысить ресурс и надежность ответственных деталей горно-металлургического оборудования, снизить количество ремонтов и повысить безопасность работы горно-металлургического оборудования.

Ключевые слова: *геомодификатор трения, пара трения, модифицирование поверхности, износостойкость*

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