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MULTILAYERED ANTIFRICTION NANOSTRACTION COVERING FOR LUBRICATION IN THE TRIBOCOUPLING "WHEEL-RAIL"

Summary. In article principles of creation of a new way of the lubrication a wheel-rail tribosystem by drawing on a lateral side of a rail head of a multilayered antifriction nanostructurial covering possessing property of blocking negative segregation phenomena in metals of a wheel and a rail are considered.

МНОГОСЛОЙНОЕ АНТИФРИКЦИОННОЕ НАНОСТРУКТУРНОЕ ПОКРЫТИЕ ДЛЯ ЛУБРИКАЦИИ В ТРИБОСОПРЯЖЕНИИ «КОЛЕСО-РЕЛЬС»

Аннотация. В статье рассмотрены принципы создания нового способа лубрикации трибосистемы колесо-рельс путем нанесения на боковую грань головки рельса многослойного антифрикционного наноструктурированного покрытия, обладающего свойством блокировки негативных сегрегационных явлений в металлах колеса и рельса.

1. INTRODUCTION

One of the basic conditions of high efficiency of a rolling stock operation of a railway transport is reliability of friction knots and increase of their technical and economic parameters. On a share of these knots now it is necessary to 85% of all refusals.

World operating experience and researches of a wheel-rail tribosystem work shows, that to this system in different degree influences about 60 factors. They can be united in five basic groups: dynamics of a wheel-rail system, mechanics of contact interaction, materials of wheels and rails, a friction management, defects of wheels and rails. Improvement of quality of wheel and rail steels, and also products from them is one of the major directions of researches and workings out. The account of communications with other groups of factors allows developing the strategy of optimization of a wheel-rail system, to raise term of its service and to reduce the expenses.

The basic researches results in the field of a friction have found the reflection in the practice for creation of a various metal-polymer interfaces and the sliding pairs applied on the railway transportation owing to variety of advantages. Their wide use is limited; however, to insufficient understanding of the wear processes laws of polymer and influence of destruction products on mechanical characteristics of a metal counter body at micro chemical level. The effective decision of such problems probably only on the basis of fundamental science achievements. The science about materials should be based on researches of laws of the systems development consisting from the molecular and nuclear levels objects. They define the processes proceeding on a surface tribocontact.

Thereupon finding-out of a behavior features of tribocontact surface layers - one of the central problems in tribotechnical as thin blankets of the tribocoupling in many respects define wear resistance of a friction knot. In the surface layers participating in a friction there is an essential reorganization of a material structure, there are «secondary structures» as result of self-organizing at a friction. Therefore to research of a friction surface we pay special attention.

Use of modern methods of the surface research (electronic spectroscopy for the chemical analysis, Auger-electronic spectroscopy and infra-red Fure spectroscopy), and also quantum-chemical methods of calculation allows to consider in details interaction tribocoupling surfaces and to study the processes occurring with substances in the friction course [1-3].

2. THE LUBRICATION WAYS IN A WHEEL-RAIL TRIBOSYSTEM

To reduce an intense condition in near surface areas of rubbing firm bodies, it is necessary to create steady layers between friction surfaces. When the sliding pairs with a lubricant functions, a role of the uncoupling layer is being fulfilled by the lubricating film which form, entering in structure of a lubricant composition the nanocluster additives, capable to function in a tribocoupling for a long time, constantly reappearing in a film due to the chemical reactions at a friction. At metal polymer tribocoupling a role of such dividing layer the frictional carrying film over which also can be formed, optimizing structure and ways nano-modified carries out a component of an antifriction composite. These layers, separating and interfering with rapprochement of a friction surfaces, can lower considerably a friction force, and thereof also the wear process [4].

Recently we spend works on creation of essentially new way lubrication the wheel-rail tribosystem by drawing multilayered antifriction nanostraction covering on the lateral side of a rail head. This way essentially differs from the lubrication by method of drawing of plastic (semi-fluid) lubricant compositions. That the durability of a covering essentially increases concerns advantages of this system and the quantity of repeated drawings of a material is reduced, the volume and weight of a put material is much less, than in case of plastic lubricant compositions. The quantity of technological "windows" in a train schedule, intended for operation performance lubrication by mobile rail lubricator besides, decreases, environmental contamination by mineral oil is eliminated. The multilayered covering on a rail formed at drawing of the basic material (power skeleton) with an antifriction layer, should keep antifriction properties in 10 times longer, than it is provided by technical requirements on lubricant compositions for contact zones of wheels and rails. The antifriction component of covering contains nanostraction additives, blocking the negative segregative process in wheel and rail metal and raises operational firmness of a wheel and a rail that leads to economy of material resources and reduction of repair work volume.

Research diffusive and segregation processes at metal polymer tribocoupling demands steadfast attention [5, 6]. As a rule, the role the impurity and the alloying elements which are usually being in a polycrystalline material of metal and also chemical compounds and elements polymeric components of this knot is underestimated. In railway transportation this problem only was designated [7, 8]. There are no direct experimental data, allowing to estimate real degree segregation processes and their influence on deterioration and defect formation on the working surfaces of a wheel and a rail while in service.

3. SEGREGATIVE PROCESSES AND DIFFUSION PHENOMENA ON RUBBING SURFACES

Principal causes of a conclusion from operation of wheels on railway transportation are the general deterioration, defects of a contact-fatigue origin and breakaways. Most often on a surface of wheels observe crumbling by light spots and sliders. Rails also have contact-fatigue damages, besides on a surface of driving there are the defects connected with accumulation of nonmetallic inclusions. These phenomena are caused by that properties of used steels far not always correspond to the extreme loadings arising at operation. Wheel steels developers now make greater efforts on creation of the new technological receptions, allowing improving quality of steels. The listed facts show, that the problem of deterioration and contact weariness of materials now is far from the decision.

It is known, that separate grains of alloys (single crystal) on the order the best wear resistance, than polycrystalline materials, as a rule, possess. The reason of mechanical properties down turning of these materials consists in existence intercrystalline borders, which durability considerably below, than durability of grains. Force of connection on intercrystalline borders is determined by their structural imperfection and element structure of thin layers on borders. As have shown ours X-Ray photoelectron and Auger-electron spectroscopy researches (depth of the analysis makes from 5Å up to 40 Å) of a surface, the concentration of atoms on borders can change from shares of a monolayer up to several monolayers. Element structure of layers intercrystalline borders and concentration of atoms do not remain constants. Some segregation processes are one of the reasons of it. There are researches segregation the phenomena are carried out by us alloying and impurity elements in tribosystem a wheel-rail-wheel chock and a wheel-rail with a multilayered antifrictional covering. Methods nanostructural diagnostics of elements of these systems [9, 10] are developed.

The atoms dissolved in a body of crystal grain, in due course are displaced and collect on borders of grains, on a free surface or other interfaces. The size of connection between crystal purposefully can be changed, forming on borders of grains monolayer from those or other elements. Thus it is necessary to know, what elements and in what degree strengthen or, on the contrary, weak borders of grains in the given material [11]. Duly detection of the elements capable to be fragile of border of metal grains will allow to develop concrete actions and ways of timely certification of tribosystem elements, the traffic safety directed on increase and maintenance of efficiency of a wheel-rail tribosystem action.

Researches of element structure on borders of steel grains of a railway wheel have been carried out by us using modern methods of a surface research [12] (X-Ray photoelectron and Auger-spectroscopy). In figure 1 Auger -spectra for surfaces of destruction (jag type of defects), located on surfaces of driving of a wheel and a bandage are brought. According to the received data, the top layers of metal of defects of a wheel contain, except for iron, sulfur, phosphorus and zinc. In a layer of a bandage the maintenance of such elements as sulfur and phosphorus is, much less, and it corresponds to their volumetric contents.

The maintenance of phosphorus and sulfur on a surface of wheel jag achieves 2,2 and 3,15 nuclear % accordingly, that exceeds the volumetric contents of these elements more than in 30 and 300 times. This effect decreases with depth and fixed concentration of sulfur and phosphorus on distance of 8 mm from a surface approximately in 10 times more, than in volume. In other defective places of a surface of driving of a wheel and on depth the method of Auger -electronic spectroscopy finds out such elements as barium, zinc and potassium, a part composite brake shoe. Sulfur also is a part composite shoe. The occurrence of a line of calcium (a spectrum 4, figure 1) can be carried on diffusion-exchange processes with an environment. All these elements which are being on borders of grains, are fragile them.

4. WAYS OF BLOCKING OF NEGATIVE SEGREGATIVE PHENOMENA IN WHEEL AND RAIL STEELS

There were quantum-chemical calculations of multinuclear clusters modeling borders between grains in a superficial layer of steel are lead. Alongside with iron atoms clusters contain atoms alloying and dashing elements, left on border as a result of grain border segregation. That investigated effects have been reproduced precisely enough, the quantity of atoms in clusters should be the order 20 and more. We investigate influence of a chemical compound members of segregation on durability of connection between grains and, finally, on wear resistance of steel. With this purpose we determined full clusters energy of connection (it is that energy, which is necessary for giving to the cluster to divide it into separate atoms) and energy of connection between grains. Atoms of a boron, carbon, nitrogen, molybdenum strongly "sew" grains of iron as cluster energy of connection, containing these atoms, appears below, than cluster energy of connection the same size consisting of pure iron. On the other hand, atoms of lithium, silicon, phosphorus, sulfur, copper and nickel though enter chemical connection with iron, weaken communication between grains as energy of connection corresponding clusters is less, than cluster energy of connection from pure iron. It is obvious, that easing of communication between grains in a superficial layer reduces wear resistance of steel.

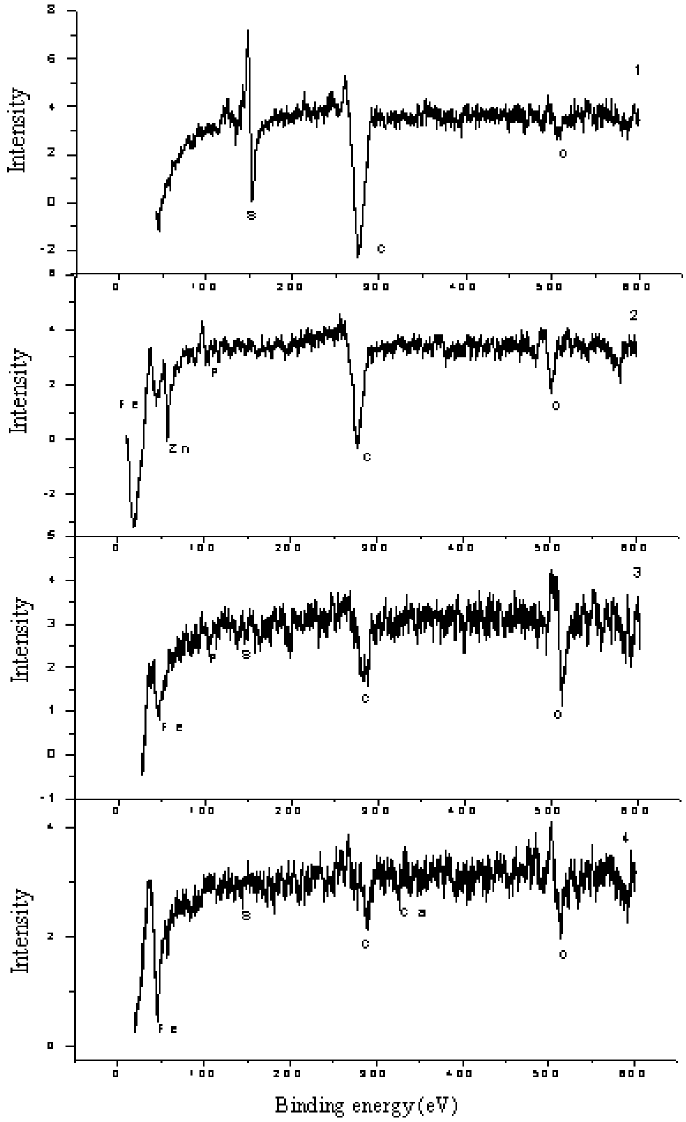

Fig. 1. Auger-spectroscopy of a wheel driving (1, 2) and a bandage (3, 4) surface
Рис. 1. Оже-спектроскопия поверхностей колеса (1, 2) и бандажа (3, 4)

The received results will be agreed with experimental data about influence of various elements on wear resistance of polycrystalline materials. However, it is important to emphasize, that our researches show a principal cause of such influence is a degree of durability of chemical connection of the segregated atoms with atoms of iron on grain border surfaces. Similar hypotheses expressed in the literature and earlier, but our calculations have confirmed this fact at a strict level [11].

Basing on the received results, it is possible to put a following problem - how to reduce harmful influence of atoms of strength reducing elements (SRE) on wear resistance of steel. One of ways of the decision of this problem - introduction in metal structure of the atoms increasing energy of connection between grains and by that the action of atoms of SRE was neutralized. Such additional atoms, depending on their activity, could supersede in full or in part atoms of SRE with grainborder surfaces, that is block an output of atoms of one element on a grainborder surface by means of atoms of other elements. That such a blocking was possible, it is necessary, that full energy of connection of the cluster in which blocked atoms are on a surface, was above energy of connection of the cluster in which blocked atoms are inside of grains (fig. 2).

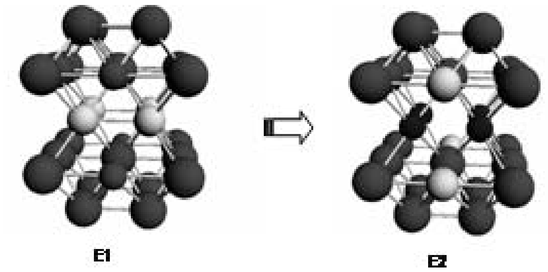

Fig. 2. The blocking of SRE in volume of grains. The boron takes a place of the sulfur on border between grains (E1> E2)

Рис. 2. Блокирование ослабляющих элементов в объеме зерен. Бор занимает место серы на границе между зернами (E1> E2)

It is follows from calculations, that atoms of boron can block an output of atoms of sulfur and phosphorus on grainborder a surface. Atoms of carbon and nitrogen can block an output of atoms of sulfur. From all aforesaid it becomes clear, what additives should enter in antifriction to a component of a multilayered covering for blocking negative segregating phenomena in metal of a wheel.

5. FORMATION OF THE MULTILAYERED ANTIFRICTION COVERING POSSESSING PROPERTIES OF BLOCKING NEGATIVE OF THE SEGREGATING PHENOMENA

As a result of the analysis of literary data [13, 14] and the leading of a tribologic laboratory and modeling tests of the big number of samples with various coverings and their subsequent researches physic mechanical and spectral characteristics the multilayered coverings, consisting of the strong power skeleton maintaining operational loadings, and antifriction nanomaterial. Such coverings provide essential decrease of factor of friction and possess blocking properties of negative segregating the phenomena in metal of a wheel and a rail.

At a stage of preliminary selection of methods of drawing of coverings it has been established, that the coverings generated by a method supersonic gas-thermal sputtering and a plasma method, do not provide a sufficient resource of work in conditions of carrying out preliminary tribologic tests. Technologies of detonation and plasma drawing of coverings with the subsequent reflow can be recommended for stationary conditions, but cannot be recommended for drawing coverings for rails in operational conditions. By results of tribologic tests as a way of drawing of a power skeleton the method of electrospark drawing of coverings has been chosen.

At drawing on a metal substrate of a power skeleton the method electrospark alloying (ESA) on a surface forms a new layer the changed superficial layer (CSL), by thickness from 20 up to 200 microns which quantitative structure does not coincide neither with structure of a substrate, nor with structure of a material of the initial anode. Consecutive application at electrospark alloying of two different working electrodes materials, as a rule, leads to a two-layer CSL, and in some cases and to the CSL with a lot of layers. Materials of a substrate and a covering it is deep enough (from 6 microns up to 25 microns) mutually diffuse each other, creating strong transitive a layer. Thus, superficial the layer has a wide transitive zone between a substrate and actually a covering into which structure enter, both elements of a substrate, and elements of the new materials entering into the anode. In the superficial layer of a covering generated as a result of nonequilibrium crystallization and thermomechanical pressure, there are micro defects, times, cracks, microcristal which provide surfaces other mechanical characteristics, than in an initial substrate. From the materials chosen as a power skeleton, on physicomechanical properties the best recognizes material VK-6, however, by results of tribology tests (on deterioration of a wheel roller) and to economic reasons optimum it is possible to consider a power skeleton from a steel 65G.

Drawing of various antifriction coverings on the generated power skeleton has allowed after carrying out comparative tribology tests, physicomechanical and X-ray spectrometric researches to stop on two antifriction nanomaterial with the additives blocking negative segregation phenomena. These antifriction layers were put on a power skeleton by a plasma method. It is probably also use of technology of a gas-flame dusting of the same materials.

For formation of power skeleton materials according to table 1 were used.

Table 1

The list of samples

Number of the sample	Structure of the covering put on the sample from a rail steel	Way of drawing
11	Copper M1	ESA
12	Bronze -9-4	ESA
19	VK-6 + F4 MB	ESA +HVOF
20	steel 65G + F4 MB	ESA +HVOF
28	VK-6 + «REX»	ESA +HVOF
44	Rail steel	ESA

Research of process of frictional interaction of samples of wheel steel with the rail steel having on surface investigated coverings, were spent under the scheme "roller-roller" realizing a method "hole". This method appreciated a degree of influence of various coverings on samples from rail steel on deterioration of wheel steel at its frictional interaction with rail steel in conditions of 100% slipping, and the top roller (from wheel steel) is fixed, and bottom (from rail steel) rotates with the set speed. Tests were spent without a supply of external a lubricant composition to a zone of frictional interaction at loading 1500 H and speeds of rotation of a rail roller of 20 turns in a minute for decrease in influence of temperature in a zone of frictional interaction).

As a result of tests dependences of deterioration of a wheel roller on time of tests (number of turns of the bottom roller), intensity of wear process of a wheel roller from specific pressure in a zone of frictional contact, dependence of factors of friction on time of tests and deterioration of a rail roller with various coverings have been received. In figures 3,4 dependences of factors of friction on time of tests for the sample from rail steel with a covering from steel 65G, the put method electrospark alloying and the sample from a rail steel with an antifriction covering from material F4-MB, generated on a power skeleton from a steel 65G are presented.

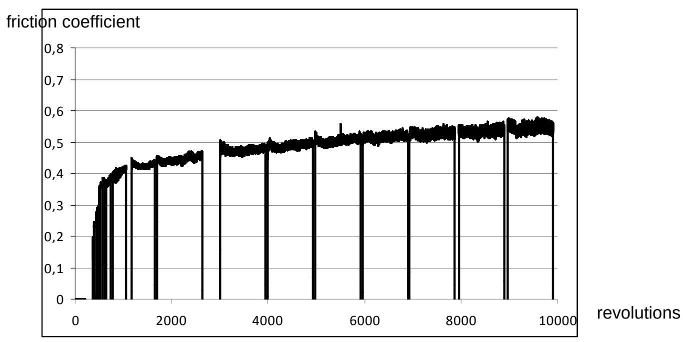

Fig. 3. Dependence of the friction coefficient of the sample from rail steel with a covering from steel 65G, put by electrospark alloying method

Рис. 3. Зависимость коэффициента трения образца из рельсовой стали с покрытием из стали 65Г, нанесенным методом электроискрового легирования

It is necessary to note, that carrying out comparative tribologic tests of all lubricant compositions admitted to application on a rail-way network of Russia, have shown, that the best lubricant composition keeps the antiburrage properties no more than 6000 turns of the sample from rail steel with absolute slipping. Resource tests of multilayered coverings have shown their high efficiency up to 50000 turns (fig. 4).

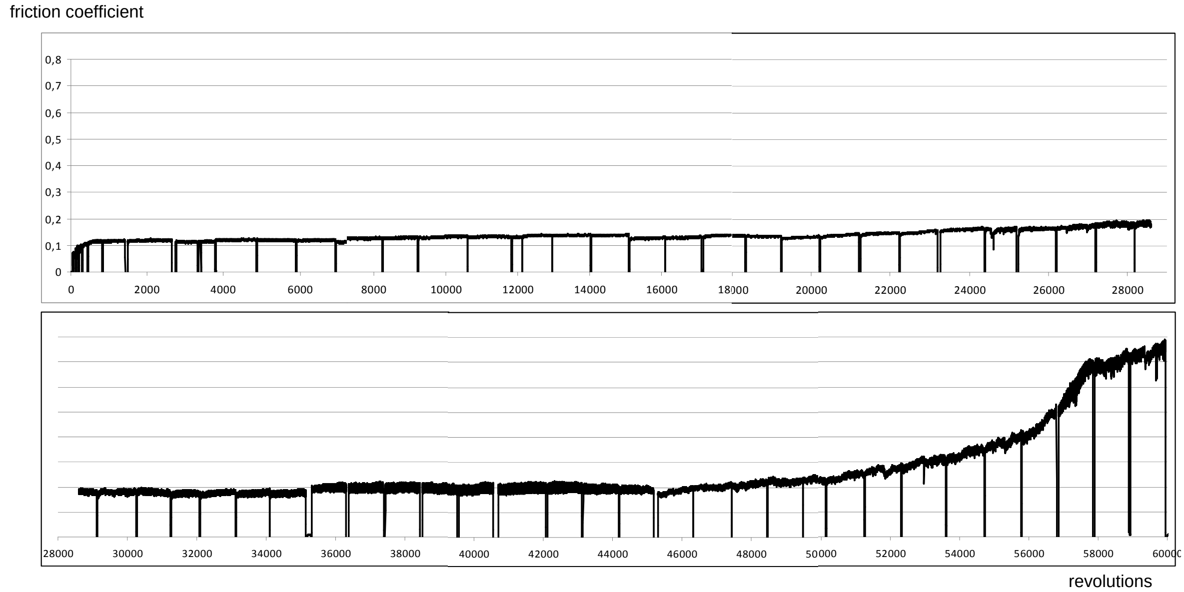

Fig. 4. Dependence of factor of friction of the sample from a rail steel with an antifriction covering from material F4-MB, generated on a power skeleton from a steel 65G

Рис. 4. Зависимость коэффициента трения образца из рельсовой стали с антифрикционным покрытием из материала Ф4-МБ, сформированным на силовом каркасе из стали 65Г

In drawings 5-6 sizes of the intensity of rollers wear on the basis of 10000 turns of a rail roller are resulted.

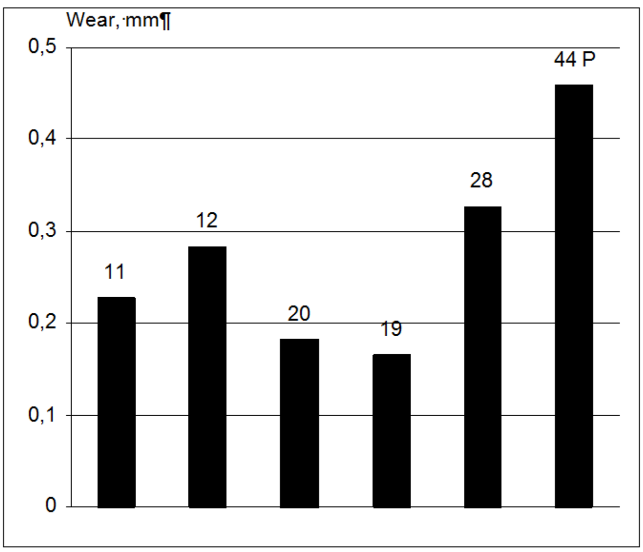

Fig. 5. The intensity of rollers wear samples from a rail steel on the basis of 10000 turns

Рис. 5. Величины износов образцов из рельсовой стали на базе 10000 оборотов

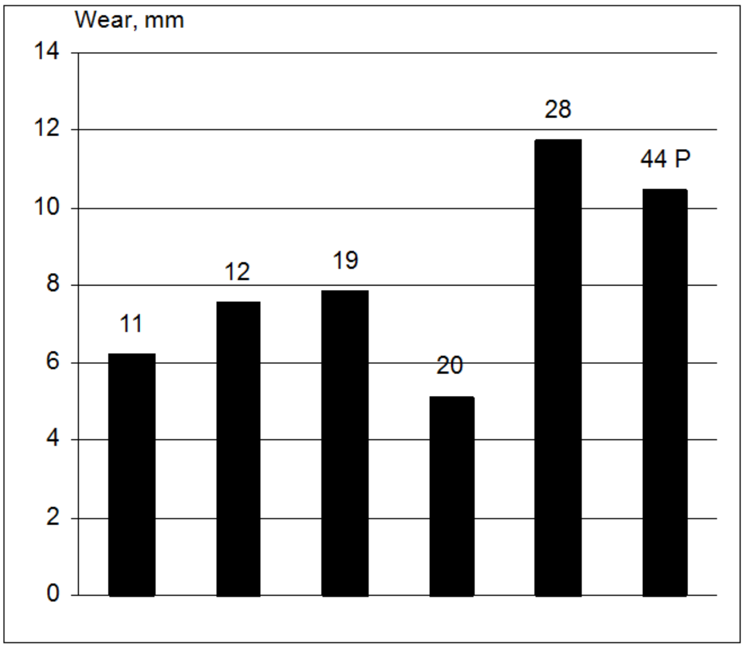

Fig. 6. The intensity of samples wear from a wheel steel after carrying out of tests of samples from a rail steel on the basis of 10000 turns

Рис. 6. Величины износов образцов из колесной стали после проведения испытаний образцов из рельсовой стали на базе 10000 оборотов

The lowest the intensity of wear is inherent in samples with a covering from thermoplastic fluorine polymer F4 MB.

6. CONCLUSION

Essentially new way of lubrication of wheel-rail system by drawing on a lateral side of a head of a rail multilayered antifrictional nanostructurial coverings is developed. At use of this way of lubrication the quantity of repeated drawings of a material is essentially reduced. The volume of bringing material and quantity of technological "windows" in a train schedule, intended for performance of lubrication operation bu mobile rail-lubricator decreases. It is eliminated of environmental contamination by mineral oil.

The put covering has high adhesion with a substrate as wide diffusion the zone between a substrate and a covering provides so good coupling, what even after friction on border a substrate-covering there is no crack.

The carrying out of quantum-chemical calculations and X-ray-electron researches of a surface tribocoupling the most proof antifrictional components have allowed to choose and to develop nanostructurial the antifrictional covering possessing property of blocking of negative segregation phenomena in metal of a wheel.

Laboratory tribologic tests lead by the "roller-roller" scheme with absolute slipping, have confirmed efficiency of multilayered coverings. The factor of friction keeps stable value ~0,15 up to 50000 turns, deterioration of a wheel roller decreases at 2,5-3 time, rail at 3-10 time.

Operational tests of the skilled coverings put on a lateral side of a head of a rail in curves of small radius, are spent now. Covering destructions is not observed.

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