MECHANICAL LOADING SYSTEMS SAFETY
PROCESSES MODELING

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Abstract. Mechanical means which are directly related to the information support path (locators,
observeration stations, accompaniment, detection, localization, etc.) require special attention
within the framework of the technical channels of receiving information. Their accurate and
stable performance is of the utmost importance. Loss of the mechanical properties occurs during
operation, that is material wear. To improve the quality of mechanisms and to ensure the stability
of the radio-electronic means, the authors of the paper consider the possible mode of friction
geoactivators in the friction unit parts of machines. The studies of the rubbing surfaces chemical
composition after being processed by the geoactivator demonstrate that the components of the
geoactivator diffuse into the surface layers of the material and form glass-crystalline layers,
which are the solutions of the geoactivator components in the phase components of the surfaces
steels and cast irons. The studies of mechanical properties have shown that the hardness and
wear resistance of the surface layer increases and the roughness of contacting surfaces gets
reduced.

1. Introduction
Mechanical means which are directly related to the information support path (locators, observation
stations, accompaniment, detection, localization, etc.) require special attention within the framework of
the technical channels of receiving information. Their accurate and stable performance is of the utmost
importance. Loss of the mechanical properties occurs during operation, that is material wear. An
essential obstacle to the increase of machines’ and mechanisms’ durability is the wear of their nodes
during friction. The loss due to wear and the importance of the problem of increasing wear resistance
and durability of machines can be demonstrated as follows: 80-90% of the machines failures are due to
the nodes wear and the loss of funds in mechanical engineering reaches up to 5% of the national income.

To prevent the machines and mechanisms parts wear, a method of regenerating rubbing nodes, using
friction geoactivators, was developed. This method is completely different from the current ones due to
the fact that it not only reduced the friction coefficient but also allows to partially restore the functional condition of the worn surface on-the-job. Geoactivator is a powder material, made on the basis of the domestic natural material – serpentinite, which contains a lot of chemical elements (32), with the highest of Mg (≈ 23%), Si (18 - 21%), and their oxides SiO2 (33.4 – 44.5%), MgO (25.6 – 38.0%).

Silicates play a key role in the processes which occur in the friction units. Silicates are sulfuric chemical compounds containing silica SiO2, which can create silicatic acid complexes of various forms (chains, hexagons, ribbons, etc.).

The properties of silicates are defined by their composition, the type of forces among the ions, the structure of crystalline lattices, and their defectiveness. Silicate hardness ranges from 1 (talc) to 6 ... 7 (forsterite) units on the Moos scale.

2. The main part of the article

The basis of silicates with small cations is a tetrahedral orthogroup [SiO4]4 with Si4 in the middle and 4O2 at the top of the tetrahedron with the ribs length of approximately 2.6 Å. Tetrahedrons in silicates can interconnect by common oxygen vertices to silica acid complexes. Every two neighboring tetrahedrons have a common vertex. At the decrease of the O/Si atomic ratio in the silicates, the number of tetrahedrons increases.

The geoactivators comprise of different forms of the magnesium silicates with a common formula of nMgO-mSiO2 or with the substitution Mg2+ ↔ Fe2+ (3Mg2+ ↔ 2Fe3+), (Mg, Fe)2[SiO4] (to be more precise, considering constitutional or crystallization water n(Mg, Fe)O·mSiO2 kH2O).

These silicates can form solid solutions of limited and unlimited solubility, as the result of substitutions of the Mg2+ lattice cations by other cations engaged in similar packaging spaces from large ions O2-. It is also possible to replace the Mg2+ cations with cations of greater valence (Al3+, Fe3+) with the occurrence of cationic vacancies. Vacancies, distortions in lattices due to differences between the ion radii of mutually replaced cations, the location of the portion of the latter in the interstices of the lattice, dislocations are the defects of silicate lattices which can change the diffusion rate, accelerate chemical reactions, increase sintering and other physicochemical characteristics.

Natural silicates which are the components of the geoactivators contain all possible phases in one way or another. Of these, forsterite and enstatite at about 50% concentration. Forsterite has a rhombic crystal lattice with the following parameters a = 4,770 Å, b = 10,260 Å, c = 5,990 Å. Forsterite is stable within the entire temperature range with the hardness of 7 units on the Moos scale. The most important quality of the forsterite is the ability to form solid solutions.

Enstatite has a structure consisting of infinite chains of various types with a general formula of Mg2[Si2O6]. Enstatite has two polymorphic forms - enstatite and clinoenstatite. The structure of main construction materials – steels and cast irons, has carbon in the form of cementite (chemical compound Fe – Fe3C) practically at any concentration, according to the Fe – C (Fe – Fe3C) state diagram. When the carbon is less than or equal to 0.8%, cementite is part of perlite, when carbon is more than 0.8% - cementite is also observed in free form.

Pic. 1 demonstrates cementite lattice. Cementite has rhombic lattice with the following parameters: a = 5,077 Å, b = 6,776 Å, c = 4,515 Å. The comparison of the cementite and forsterite lattices (table 1) showed almost complete parameters coincidence over two axes.

Geoactivator particles that lubricated in the friction zone are exposed to contact pressure, which in the micro-block of the contact spot may reach up to 1000 MPa. As a result, the destruction of geoactivator crystals and the formation of active radicals occurs. The similarity of cementite and forsterite lattices allows silicate compounds to be formed on the steel surface at no significant distortion of their lattices, which is very important for the diffusion processes.

At the same time, geoactivator crystals having higher hardness than the material of the part, micro polish the friction surfaces and remove oxide films, preparing the contacting surfaces to be processed by the geoactivators. At the same time, the roughness of the surface decreases along with its activation.
Under the contact loads (at the material flow limit level), the substitution of Mg crystals cations in the geoactivator crystals to the Fe cations to form solid solutions takes place. As a result of these processes, a glass-crystalline layer is formed at the friction surface, firmly merged to the surface of the part, and consisting of various compounds (from endless layers and chains to the amorphous phase), interconnected and capable of further phase transformations. This process continues until the entire surface of the metal is saturated with a geoactivator. The process ends with the formation of the stable crystal structure of the surface layer and adjacent to the surface layers of the metal. The completion of the surface saturation process with the geoactivator is accompanied by a sharp decrease of the friction coefficient and the temperature of the friction node. Thus, the processes occurring in the friction zone during processed by the geoactivator can be divided into four stages:

- surface activation;
- absorption of the geoactivators by the top layers of the metal;
- diffusion of the geoactivator from the top layer into the metal;
- regeneration of the friction surfaces and roughness decrease.

The studies of the chemical composition of the friction surfaces made of 45 and 45 XH steel after processing with a geoactivator for 15, 20, and 40 hours of uninterrupted operation have been conducted. Metallographic oblique grinds were made for the study.

| Table 1 – Cementite and forsterite latices parameters | The parameter value, Å |
|------------------------------------------------------|------------------------|
| Forsterite                                           | a = 4,770              |
|                                                     | b = 10,260             |
|                                                     | c = 5,990              |
| Cementite                                           | c = 4,515              |
|                                                     | 2 a = 10,154           |
|                                                     | b = 6,726              |
| Parameters deviation, Å                             | 0,255                  |
|                                                     | 0,106                  |
|                                                     | 0,736                  |
| Parameters deviation, %                             | 5                      |
|                                                     | 1                      |
|                                                     | 11                     |

The study of the friction surfaces chemical composition processing by the geoactivator showed that the components of the geoactivator diffuse into the surface layers of the material and form glass-crystal layers, which are the solutions of the geoactivator components in the phase components of steels and cast irons. The penetration depth is 0,1…0,2 mm.

The mechanical properties of contacting surfaces are investigated: microhardness, roughness, wear resistance. Microhardness was measured with help of the PMT-3 tool according to GOST 9450-76 at the load of 50 and 100 kg/mm2. The microhardness study at different depths of the metal surfaces treated with geoactivators allowed us to establish a certain dependency. The hardness of the surface layer revealed on the micro slice in the form of a light strip, differs from the initial hardness of the processed material and, as a rule, significantly exceeds it (Pic. 1).

The microhardness of the metal equals the initial microhardness of the metal at the depth of 0,2 mm and above. This can be seen by the microhardness and layer depth dependency curves, presented on the Pic. 2. Consideration of these curves shows that the maximum increase in hardness is observed at the depth (up to 0.04 mm), where the lower part of the modified layer ends and the subsurface layer begins.
The mechanical properties studies demonstrated that the hardness of the surface layer gets increased by 1.5…3.5 times, wear resistance gets increased 4…5 times, roughness of the contacting surfaces decreases 2.5…10 times (table 2).

Thus, the effect of geomodifiers leads to the occurrence of a unique tribological effect.

3. Conclusions

The results of the conducted studies demonstrated that adding geomodifiers based on the natural material – serpentine leads to the increase of reliability and durability of the treated friction nodes by 2…3 times, the hardness of the surface layer gets increased by 1.5…3.5 times, wear resistance gets increased 4…5 times, roughness of the contacting surfaces decreases 2.5…10 times.

The obtained results allowed us to establish the nature of the wear and disclose the mechanism of the wear-resistant layer formation with applied friction geoactivators, a change in the mechanical properties of materials, the geometric characteristics of the friction surfaces, and the operation modes of mechanisms on the wear and restoration of parts with applied geoactivators.

Table 2 – Mechanical properties of steels

| Material                          | Mechanical properties                                      |
|-----------------------------------|-----------------------------------------------------------|
|                                  | Hardness HB, kg/mm² | Roughness Rₐ, mcm | Wear resistance |
| Steel 45, initial state           | 179               | 2.5              | 2.1·10⁻¹¹       |
| Steel 45, processed by the geoactivator | 550           | 0.8              | 0.6·10⁻¹¹       |
| Steel 40XH, initial state         | 200               | 1.25             | 1.5·10⁻¹¹       |
| Steel 40XH, processed by the geoactivator | 585           | 0.2              | 0.4·10⁻¹¹       |

The approach proposed by the authors will improve the quality of the radio-electronic equipment mechanical products manufacturing, will increase its durability, reduce the level of lateral deviations and ensure the reliability of the information transmission channels.

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