The use of boehmite in tribology

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Abstract. The analysis of the results of the use of nanostructure boehmite as a break-in and prophylactic tribological preparations is carried out. The mechanism of boehmite action during the running-in of a diesel engine and a drilling rig gearbox is considered. A boehmite-based product reduces break-in time, reduces the friction coefficient and wear of tribological couplings. A scheme of the effect of boehmite on increasing the life of tribological compounds is developed. Justified its use as a repair and recovery tribological product.

1. Introduction
Losses of financial resources from friction and wear in developed countries reach 4-5% of national income, and overcoming friction resistance absorbs 20-25% of the energy generated per year around the world. For the full cycle of operation of machines (in transport, energy, engineering, etc.), operating costs, repair costs and spare parts are several times higher than the cost of manufacturing new equipment [1-3]. Therefore, research and the search for new tribological compositions that can reduce friction, wear, and operating costs continue. And nanostructure boehmite may be one of such materials [4].

2. The goals and objectives of the study
Evaluation of the effectiveness of boehmite in tribotechnics: when running in engines and transmission units, as a preventive measure when introduced into oils and greases.

3. Materials and research methods
We used boehmite powder obtained by hydrothermal oxidation of aluminum powder [5]. A distinctive feature of this boehmite is its high degree of homogeneity, the stability of the composition and structure. According to x-ray structural and petrographic analyzes, the material is well crystallized and consists entirely of aluminum monohydroxide (boehmite) AlOOH. (figure 1 (a)). The coherent scattering region characterizing the crystal size of the initial powder is 20–40 nm for different batches of the powder and does not exceed 80 nm. The boehmite of hydrothermal synthesis can be characterized as a nanostructured material. Losses on ignition correspond to stoichiometric 15 wt. % Using a scanning microscope, it was possible to observe both individual particles and particle aggregates predominantly 2-3 microns in size, up to a maximum of 10 microns (figure 1 (b)). Individual particles of irregular shape, consisting of smaller nanocrystallites, are combined into large aggregates.
Figure 1. X-ray powder of boehmite (a) and a scan of the aggregates of its particles (b).

As you know, a common drawback of nanoparticles is the tendency to aggregation, which eliminates their valuable properties. Therefore, nanostructure boehmite powder or its composition with other mineral components was mixed with a surfactant, introduced into oil, and sonicated. This ensured the disaggregation of powder particles, the aggregative and sedimentation stability of the suspension.

Comparative tests of 12 tribotechnical materials, including those containing serpentine additives, were carried out according to the “roller-block” scheme (block — cast iron of cylinder liner D-240 diesel, roller — steel 40Cr) on a friction machine 2070 SMT-1M with a rotational character of movement test samples. The coefficient of friction and the temperature in the mating zone of the parts were determined.

Comparative wear tests were carried out on a modernized 77MT-1M friction machine with a smaller sample (a fragment of a piston ring) reciprocating along a larger one (a fragment of a cylinder liner D-240), at a load of 300 N and a sliding speed of 3.2 ms⁻¹. Accelerated tests were carried out in conditions of physical modeling of the real friction process (identical materials and kinematics of the translational movement of the piston along the surface of the cylinder). Pressure was the accelerating factor.

The effect of boehmite on the run-in was studied on a D-243 diesel engine at the upgraded break-in brake stand KI-5540-GOSNITI and a drilling rig gearbox. In the second case, kaolin and talc were introduced with boehmite. We used kaolin of the Prosyanovskoye deposit according to TU 421-533-2001, talc of the Shabrovskoye deposit of TMK-28 grade. Run-in of aggregates was carried out according to standard methods.

The surface roughness was checked before and after running-in by a Surtronic-ZR profilometer from Taylor-Hobson (England). The wear of the mating parts of a diesel engine at various stages of running-in was evaluated by the mass fraction of solids in oil.

4. Results and its discussion
On a friction machine 2070 SMT-1M tribostructure with boehmite showed the lowest (0.045) coefficient of friction in a wide range of loads (150 - 600 N, up to 150 MPa). He increased the load capacity of the tribocouple in comparison with pure oil almost 2 times. At constant load the temperature did not exceed 60 °C, and with pure oil it rose to 90 - 100°C.

On the friction machine 77MT-1M, the composition containing boehmite showed the smallest wear (wear spot length decreased from 2.45 mm for pure oil to 1.35 mm, i.e., 1.81 times). The wear rate calculated as the ratio of the wear value (spot length) in m to the friction path in m was 1.06 · 10⁻⁷ for pure oil, and the inverse value, wear resistance, was approximately 0.94 · 10⁷. For tribostructure with boehmite, respectively 0.60 · 10⁻⁷ and 1.70 · 10⁷. The cylinder-piston group of the car spot length corresponds to the 11-12 wear resistance class or 10¹¹ - 10¹², which corresponds to the wear rate of
The wear value obtained in the experiments is greater by 4-5 orders of magnitude. This manifests the effect of accelerated testing under accepted conditions on a friction machine 77MT-1M.

In addition to tests on a friction machine 77MT-1M, we studied the effect of boehmite on wear on the four ball friction machine (FBFM) and on the MTU friction machine. Boehmite was introduced into motor, industrial, rapeseed oil and solid oil. Depreciation was estimated by the size of the wear spot and weight loss of the mating parts. Tests have shown that the addition of boehmite reduces the size of the wear spot at (FBFM) to 34%, the weight loss of parts (MTU machine) decreased by 2 and 6 times, respectively, for grease (solid oil) and I I20 oil.

Run-in tests have shown that introducing boehmite powder and surfactant into M-10G2K engine oil reduces the time to reach maximum compression (P) by 2 times, ensures quick achievement of rated power values (W), reduces fuel consumption (G) and oil temperature (T), the roughness of the bearing shells and piston rings decreases by 1.4 and 1.7 times, respectively (table 1). In general, the addition of boehmite accelerates and improves the quality of running-in, reduces running-in wear by up to 2.5 times, which increases the operational life of a diesel engine.

| Time, min | P, MPa | W, kW | G, g/h.p. | T, °C |
|-----------|--------|-------|-----------|-------|
| 40        | 3.0    | 2.93  | 30        | 40    |
| 80        | 3.0    | 2.93  | 60        | 80    |
| 90        |        | 52.5  | 45.0      | 257   | 270   |

Lapping additive on the basis of boehmite showed itself well in terms of running-in of engine parts of grade 10-11 of cleanliness and hardness of 52-56 HRC. The teeth of the gear wheels (steel type 18HGT) and rolling bearings (steel type SHX-15) have a hardness of 61-63 HRC or 179 - 207 MPa with a cleanliness class of 7-8 with a roughness of Rz 3.2-6.0 microns. The nanoscale of boehmite particles (crystal size less than 100 nm, aggregates less than 1 μm) leads to their indentation into the hollows of the roughness of the rough surfaces of the teeth and, obviously, therefore, the abrasiveness of boehmite powder in the transmission units was weak. In addition, during friction at elevated temperatures in the contact of mates, disintegration of boehmite particles and its decomposition with the release of water and the formation of aluminum oxides can occur. In this case, the grinding of the starting aggregates and individual particles occurs, which further reduces their size [6].

Also the additive, contained of nanostructure boehmite, surfactant, talc and kaolin and which is used in running transmission units, was developed. Its tests were carried out on the gearbox of a mobile drilling rig mounted on the chassis of a KamAZ car. A feature of the gearbox is the presence of high hard gears and bearing parts, the absence of non-ferrous metals and soft alloys.

Compared with the run-in on a standard gear oil TM-3, a reduction in the duration of the run-in of the gearbox from 8 hours (working shift) to 3.0-3.2 hours, i.e. 2.5 times, was obtained; decrease in oil temperature from 75 to 61°C; 2.5 times increase in the running-in surface area. At the same time, after draining the break-in oil and refueling, the noise and the temperature of heating the parts decreased, and an increase in the resource of the critical unit of the drilling rig is predicted.

The positive effect of kaolin and talc additives is due to their physicomechanical properties and particle sizes (units μm), suitable for running gears, comparable with the surface roughness of gear parts. Kaolin and talc are thermally more stable and do not decompose at temperatures of 400-600°C, like boehmite, with the formation of smaller particles. Particles of talc and kaolin abrade microroughnesses in the surfaces of parts, increasing the area of the contact contact surface, reducing unit loads and, thus, preventing the formation of a scuff. Once in the friction zone, leveling the surface, these particles can adsorb resins and oxidation products of the lubricating medium. Kaolin with larger particles is more actively involved in abrasive grinding, opens juvenile surfaces and promotes a more active effect of surfactants according to the acad effect P.A. Rebinder. Talc, as a plastic material, serves as an intermediate material between kaolin particles and, together with
boehmite, promotes a more uniform distribution of kaolin particles in the lapping composition and in the running oil. Thus, the running-in efficiency depends not only on the physicomechanical properties of the components of the additive, but also on the ratio of the particle size of the components and the surface roughness of the parts being worked on. For details of greater roughness and hardness, compositions of boehmite with minerals are effective larger components.

Taking into account the provisions of tribology, the role of boehmite in tribotechnology can be reduced to the following:

- abrasive wear and grinding of areas of increased roughness of friction joints, increasing the purity of their surfaces, reducing the mechanical component of the coefficient of friction;
- cleaning of friction surfaces from deposits, oxide films and defective structures, which ensures access of tribomedia substances to juvenile surfaces of metals and accelerates the formation of antifriction coatings;
- some subsequent adsorption on the surfaces of boehmite particles of resinous substances creating a “third body” in the tribopair, which also reduces the coefficient of friction;
- dispersion and decomposition of boehmite (with the release of water), which reduces the overheating of contact surfaces;
- lamination and hydration shells on the surface of the particles also contribute to a decrease in the coefficient of friction [7];
- a catalytic effect on chemism in the friction zone is possible;
- nanostructured ceramicization of local defects with the formation of a layer of high heat resistance, wear resistance and high electrical resistance.

Each of the listed properties can manifest itself under different friction conditions, at different stages of the transformation of boehmite particles: at the beginning, some properties play an important role, and later on others. With this in mind, a scheme has been developed that explains the increase in the resource of friction units by reducing their wear rate (figure 2), running-in wear, and shortening the break-in time.

![Figure 2. Wear of the interfaces before (1) and after (2) the introduction of tribostructure.](image)

$U_{\text{red}}$ - reduced initial clearance (wear) with the introduction of tribostructure; $U_{\text{in.}}$ - the initial clearance of the interface during run-in; $U_{\text{ul.}}$ - ultimate clearance; $t_{\text{red.}}$ - reduced run-in time of the unit with the introduction of tribostructure; $t_{\text{run.}}$ - run-in time of the unit; $t_{\text{reg. res.}}$ - regulatory resource; $t_{\text{ad. res.}}$ - an additional resource due to the use of tribostructure.

It is known that with significant wear and tear to extend the service life of the units can provide repair and restoration compounds. [2, 3]. Especially effective of them are serpentine. In this regard, it is interesting to compare the physicochemical properties of serpentine minerals and boehmite (table 2).
Table 2. Some properties of serpentine and boehmite powders.

| Properties                              | Serpentine | Boehmite |
|-----------------------------------------|------------|----------|
| The water content, %                    | 13         | 15       |
| Decomposition temperature, °C           | 650 - 750  | 500 - 600 |
| Mohs hardness                           | 2.5-4.0    | 3.5      |
| Compounds with FeO, Fe₂O₃                | FeO·Al₂O₃, Fe₂O₃·Al₃O₅ | 2FeO·SiO₂, MgO·Fe₂O₃ |
| Energy density, J·cm⁻³                   | 82.78      | 104.31   |
| Catalytic effect                        | +          | +        |

Mohs hardness of serpentine minerals 2.5-4.0, boehmite - 3.5. The total amount of constitutional water is 13% for serpentine, 15% for boehmite. The final decomposition products of serpentine are members of a continuous isomorphic series of olivines containing iron oxide and silica, and in boehmite – alumina.

The end product of boehmite decomposition, alumina, can also form chemical compounds with iron oxides, as well as serpentine decomposition products, including solid solutions. The Fe₂O₃ – Al₂O₃ system was studied by various authors [8, 9]. The crystalline phases present in the system are: hematite with corundum in solid solution, corundum with hematite in solid solution, phase 1: 1 = Fe₂O₃ · Al₂O₃ (solid solution), spinel phase, which is mainly a solid solution between magnetite (FeO · Fe₂O₃) and hercinitis (FeO · Al₂O₃) with some excess of Fe₂O₃ or Al₂O₃, or both at the same time. The formation of a solid solution of Fe₂O₃ · Al₂O₃ is promoted by the same structure and close parameters of the unit cell of oxides. Thus, both the decomposition products of serpentine and aluminum oxides, which are the decomposition products of boehmite, can enter into chemical interaction with iron oxides always present on the surface of steel parts with the formation of new phases.

The energy density of boehmite is higher than that of serpentine, which can contribute to the formation of repair and restoration tribo-coating [10].

The use of serpentine tribo compounds leads to the formation of tribocover containing mainly carbon [11]. Under conditions of friction, oil is pyrolyzed with carbon evolution, and serpentine decomposition products can be catalysts for this process. But it is also known that boehmite is widely used for the manufacture of catalyst supports and catalysts themselves. Therefore, we can assume the formation of carbon tribocovering, as a result of the catalytic action of boehmite, as boehmite in many physicochemical properties (water content, dehydration temperature, hardness, energy density, ability to form chemical compounds and solid solutions with iron oxides, catalytic effect) has properties similar to serpentine. The above suggests that boehmite can be not only run-in, but also repair-restoration composition, which of course requires additional tribological confirmation.

Alpha-alumina or corundum is the most stable form of alumina - the last phase in the process of boehmite transformations. Corundum is chemically resistant to many reagents and melts, has insulating properties, high hardness (9 on the Mohs scale), and is practically not hygroscopic. High hardness of corundum is not a negative factor. More important is the particle size. For example, many tribological compositions include nanodiamond particles (KARAT-5, KARAT-M, Formula «AB», Renom Engine Lubrifilm, Diamond Run In, Nanodiamond Green Run, etc.) [11]. These compounds have proven themselves as preventive, and KARAT-5 and KARAT-M - and as repair and restoration. In running-in, they reduce running-in wear, accelerate running-in, and realize equilibrium surface roughness. As a result, wear resistance is increased, mechanical losses are reduced, and the operational qualities of the units are improved. The "nanodiamonds" that make up the structure of the oil film, increasing its dynamic strength, form new friction surfaces, and reduce (especially at high loads and lubricant deficiency) friction and wear.

5. Conclusion
The introduction of nanostructure boehmite and surfactant into the oil up to 2 times accelerates and improves the quality of running-in of internal combustion engines, ensures the rapid achievement of passport values of power and fuel consumption. Running-in composition for running in gearboxes...
containing boehmite, kaolin, tale and surfactant provides a 2.5-fold reduction in running time and temperature, an increase in the running-in surface area. The running-in efficiency depends not only on the physicomechanical properties of the components of the additive, but also on the ratio of the particle size of the components and the surface roughness of the worked-in parts. Compositions based on nanostructure boehmite can be promising running-in and prophylactic tribological compositions that provide savings in material and energy costs.

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