Study of the wear resistance of alloyed powder-based hybrid materials manufactured using "KARBUL" technology

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Abstract. This research paper presents the results of studies of the tribological properties of materials manufactured using the "KARBUL" technology, modified with powders of various compositions. The tests were carried out according to the "disk-disk" friction pair on a modern friction machine SMT-1. The structure and wear mechanism of materials manufactured using the Karbul technology have been investigated.

1. Introduction
Carbon composites based on "KARBUL" technology have several advantages, such as corrosion and chemical resistance, low specific gravity, high working heat resistance [1-2]. These and other properties can be used, for example, in the manufacture of pump stages of submersible centrifugal pumps operating in conditions of extreme scaling. Preliminary operating results showed low adhesion properties of carbon materials and formation fluid, in contrast to the applied metal materials under these conditions. Currently, work is underway to introduce "KARBUL" materials into industry.

The aim of the work is to study the tribological properties of materials manufactured using the "KARBUL" technology, depending on the technological parameters and type of filler.

2. Materials and test procedure
Materials for the research were developed and manufactured using the "KARBUL" technology, which differ in the type of filler and technological conditions.

The "KARBUL" technology includes the following steps:
1. Preparation of the vulcanizable elastomeric mixture;
2. The manufacture of the workpiece from the elastomeric mixture;
3. Precursor fabrication;
4. Curing of the precursor in the product;
5. Product control: geometry (dimensions), hardness.

As an elastomeric binder, synthetic rubbers of the BNKS-18AMN and SKD SN brands were used, as well as organic Peroxide 14/40.
Table 1 presents the names of materials manufactured using the "KARBUL" technology and the composition of discrete powders used in their manufacture.

To study the mechanical properties of materials and surfaces the following equipment was used:
1. Hitachi TM1000 Tabletop Scanning Electron Microscope
2. Micro-Hardness Tester (CSM Instruments, Switzerland)
3. Shore A and Shore D hardness testers.

Wear tests according to the “plane-plane” friction pair were carried out on a modern friction machine SMT-1 (Tochpribor, Russia), the kinematic diagram of which is shown in figure 1.

| Sample # | Material                     | Powders                                                        |
|---------|------------------------------|----------------------------------------------------------------|
| 1       | KARBUL SiC PC KK-40Sh        | Silicon carbide, shungite                                      |
| 2       | KARBUL SiC PC KKO-60         | Silicon carbide (2 sizes), artificial graphite, white carbon   |
| 3       | KARBUL SiC PC KKO-36 RS      | Silicon carbide (2 sizes), white carbon                        |
| 4       | KARBUL SiC PC KK-40          | Silicon carbide (2 sizes)                                     |
| 5       | KARBUL SiC PC KK-60          | Silicon carbide (2 sizes), artificial graphite                |

Figure 1. Kinematic diagram of the modern friction machine SMT-1 (1 - specimen, 2 - spindle unit, 3 - engine, 4 - drive belting, 5 - counter-sample, 6 - clip, 7 - strain indicator, 8 - dowel handle, 9 - test chamber, 10 - neck bearing, 11 - lever kit, 12 - ball screw motor, 13 - axial bearing).

The signals from the sensors were recorded using the National Instruments PCI 6023E multifunction ADC card. The signal processing software was developed using the LabVIEW 2009 graphical environment. Before each experiment, the samples were washed in an ultrasonic bath in Nefras C2 80/120 solution, after which they were kept in a heat chamber for 30 minutes at a temperature of 100°C. Then the samples were weighed using an Ohaus Adventurer balance having a measurement error of 0.0001 g. After the tests, the cleaning and weighing procedure was repeated to calculate the weight loss.

As a criterion for the wear resistance of coatings, we used the value of the volumetric wear rate $I_V$, [mm$^3$·min$^{-1}$], formula 1.
where \( W \) – volume of lost material, mm\(^3\)
\( T \) – testing time, min.

Friction and wear tests of materials were carried out under the following conditions:

- disk pressing force – 100 Н;
- specific pressure – 0.066 MPa;
- shaft rotation speed - 275 rpm;
- sliding speed (average diameter) - 0.5 m \cdot s^{-1};
- the experiment duration is 10 minutes.

3. Results and discussion

Figures 2 and 3 show the results of tests of materials for friction and wear. It can be seen from figure 3 that sample No. 2, made using the "KARBUL" technology with the addition of powders of silicon carbide, artificial graphite, and white soot, has the lowest coefficient of friction. During the tests, a smooth decrease in the coefficient of friction. It is worth noting that the same material is significantly superior in wear resistance to materials containing, in addition to silicon carbide, white soot (sample No. 3), artificial graphite (sample No. 5) and two types of silicon carbide powder (sample No. 4).

![Figure 2. The coefficient of materials’ friction manufactured using the technology "KARBUL".](image)
Figure 3. Wear rate of materials manufactured using the KARBUL technology.

In figure 4 (a), the structure of the KARBUL SiC RS KKO-60 material is presented, which contains two types of silicon carbide powder, artificial graphite, and white soot, figure 4 (b) is the surface of this material after friction and wear tests. Analysis of the surface shows that the main wear mechanism is the chipping of solid particles of silicon carbide from the matrix. On the surface are visible recesses, which were formed after removal of solid particles.

Figure 4. The surface of the sample KARBUL RS KKO-60 before (a) and after (b) tribotest.

This wear mechanism is present to one degree or another in other studied materials.

The following trend is also observed. The materials with the lowest coefficient of friction are characterized by the least wear. The material with the filler of two types of silicon carbide powder, artificial graphite and soot has the highest wear resistance.

Wear tests were carried out at relatively low load levels (0.066 MPa), typical for radial mating of pump stages of centrifugal submersible pumps. The main requirements for them are abrasive wear resistance of mates and low adhesion of formation fluid salts to the material. In this sense, materials based on the "KARBUL" technology are promising for use in the pumping stages of submersible centrifugal pumps.

Furthertribological studies should be aimed at optimizing the size, shape of powder fillers and the study of the wear mechanism.
4. References

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