Tribological studies of carbon seal materials at cryogenic temperatures

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Abstract. The results of the tribological properties studies of composite materials at cryogenic temperatures are presented in the present paper. Test equipment has been developed, friction and wear tests have been carried out at a temperature of \( T = -196 \, ^\circ C \). The test results showed a significant dependence of the composite material wear rate on the load.

1. Introduction

Composite materials based on epoxy resins are applied in details of tribo-couplings due to the good adhesion of epoxy polymers to metals and other materials, high mechanical strength, low shrinkage and water absorption. The most widely used composite materials in Russia are AMS-1, AMS-3, AMS-5M, which feature higher mechanical strength, wear resistance, heat resistance and low coefficient of friction [1]. These materials are used to manufacture piston rings of compressors operating without lubrication, mechanical seals, sliding bearings for dry friction units with normal humidity at elevated temperatures, blades of rotary air pumps, parts of turbo pump units. Composite materials have proven themselves to be good when working at cryogenic temperatures [2]. To increase the resource of devices operating in cryogenic conditions, it is necessary to increase the wear resistance of resource-determining units, which are made of composite materials.

The purpose of this work is to assess the wear resistance of composite materials when operating in cryogenic conditions. To achieve this goal, it was necessary to develop test equipment, elaborate the test methodology and carry out experiments on friction and wear.

2. Materials and test procedure

2.1. Samples for testing

An antifriction self-lubricating composite material based on carbon fabric with epoxy resin as a binder (analogue of AMS-5M) was used as a test object. The counter sample was made of chrome-plated steel 07Kh21G7AKh5 (\( C < 0.07\% \); \( Si < 0.7\% \); \( Mn = 6...7.5\% \); \( Ni = 5...6\% \); \( Cr=19.5...21\% \); \( N=0.15...0.25\% \)) with chrome coating or from a WC/Co8 hard alloy. The kinematic scheme "ring - ring", figures 1, 2, was used for the tests.
2.2. Test equipment
To carry out tests on friction and wear under cryogenic temperatures, a new stand for experiments based on the UMT friction machine was developed at IMASH RAN (Mechanical Engineering Research Institute of the Russian Academy of Sciences), figure 3. On the bed of the UMT friction machine are mounted:
- cryogenic chamber;
- drive unit with a frequency converter;
- support-loading unit;
- sensors for measuring friction force, axial force, temperature and wear.

The axial force $N$ was measured using an M50 membrane compression strain gauge (manufactured by Tenzo-M), the friction force was determined by a T24A beam-type force transducer (Tenzo-M). To measure wear during the experiment, an inductive sensor IWRM 08I9501 manufactured by Baumer was used. The temperature was measured with a Pt100 thermal resistance sensor. To collect data from the sensors, we used an NI DAQ-9184 chassis with an NI DAQ-9219 module. The program for data processing was written in the NI LabVIEW 2017 graphical environment. The post-processing of the data was carried out in the NI DIAdem 2017 program. During the tests, the temperature in the chamber, axial force, coefficient of friction, and wear were continuously recorded.

2.3. Experimental technique
After assembling the test unit, liquid nitrogen was poured into the neck until the moment of moderate evaporation and the temperature of the samples $T = -196^\circ C$, figure 4. During the experiment, liquid nitrogen was added. After cooling the samples, the drive unit was switched on, which ensured rotation of the sample with a given frequency, and the samples were loaded with an axial force $N$ of a given value. The loading was provided by excess air pressure in the pneumatic piston by means of a pressure...
regulator. Built into the disk of the support-loading unit 2 an inductive displacement sensor recorded the wear of the sample during the test, figure 4.

![Figure 4. General view of the friction machine test unit (1 - temperature sensor; 2 - disk of the support-loading unit; 3 - shaft of the drive unit; 4 - neck for filling liquid nitrogen).](image)

Loading conditions:
- sliding speed \( V = 1 \text{ m}\cdot\text{s}^{-1} \);
- contact pressure \( p < 10 \text{ MPa} \);
- ring temperature \( T = -196 \ldots +25^\circ\text{C} \);
- test environment - air atmosphere.

3. Results

Tests at high levels of contact stresses (\( p = 10 \text{ MPa} \)) showed that there is intense wear of the composite material. In addition, the hard chrome coating on the counter sample wears out to the substrate, figure 5, 6, 7.

![Figure 5. Wear track of composite sample.](image)

![Figure 6. Wear track of the chrome-plated steel.](image)

Subsequently, the value of the load was reduced, and rings made of WC/Co8 hard alloy were used as a counter-sample. The working surface was polished and lapped before each experiment.
A stable value of the friction coefficient $f = 0.15$ after the running-in stage was observed only at the value of the axial force $N = 1000$ N. At a higher load, the nature of the friction coefficient graph is unstable, and the value fluctuates in the range $f = 0.2...0.3$. As a result of the experiments, the dependence of the friction coefficient on the value of the axial load was obtained, figure 8.

Figure 9 shows the wear rate of the coupling when testing the Composite-Chrome coating pair. It can be seen that the wear resistance of the material significantly (around 22 times) decreases with an increase in the axial force from 1000 N to 2000 N. During the tests, it was found that wear changes step by step. Figure 10 shows a record of pair wear at an 1500 N axial force. The graph shows recurring flatter and steeper sections, which indicate different wear rates at the boundaries between the carbon fiber layers. The steeper parts of the wear curve are accompanied by a slight increase in frictional force.
Figure 9. Wear rate of coupling when testing a composite paired with a chrome coating.

Figure 10. Wear of coupling when testing a composite paired with a chrome coating (axial force 1500 N).

4. Conclusions
1. A stand for testing based on the UMT friction machine has been developed, which allows reliable testing of materials at a temperature of $T = -196^\circ C$.
2. The investigated material is satisfactorily efficient up to 2 MPa: wear rate - 0.031 mm·min$^{-1}$; friction coefficient - 0.15.
3. It is noted that the friction force and wear rate change at the boundary of the carbon fabric layers.

References
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