Increasing the anti-friction properties of carbon-containing materials at high temperatures

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Abstract. The article is devoted to high-temperature tribological testing of carbon-containing materials during friction on 40X13 steel in the temperature range from +20 to +800°C in atmospheric conditions. The choice of temperature and test environment is determined by the prospects of creating spacecraft drives for operation without lubrication in extreme conditions. The researches have shown that the modified friction surface of CCCM in the environment of tellurium, selenium and polytetrafluoroethylene combined with steel 40X13 reduces the coefficient of friction. At a load of 1.0 MPa, sliding speeds of 0.05; 0.16; 0.25 m/s and a temperature range of +20°С - +600°С, the friction coefficient does not exceed the value of 0.3. At a temperature of 600°С, a load of 1.0 MPa, and a speed of 0.16 m/s, the friction coefficient of the samples treated in tellurium, selenium, and polytetrafluoroethylene environments is 1.8 and 4.8 times lower than that of CCCM, respectively.

1. Introduction
Reducing energy consumption in friction nodes is possible by increasing the antifriction of friction pairs. By lowering the coefficient of sliding friction, we thereby reduce friction losses and decrease the wear rate of the mating part [1]. When operating friction units at high temperatures, it is necessary to use materials having a low coefficient of friction in the friction pair.

To check the operability of friction pairs at high temperatures, it is necessary to simulate the operation of friction units, which requires the creation of special equipment and experimental methods. The lack of standardized test methods and techniques is explained by the complexity of the processes occurring during friction, the presence of a large number of factors affecting the friction process.

Promising materials for working in high-temperature friction units are carbon-carbon composite materials (CCCM) [2]. CCCM has an extremely low density, good characteristics of strength and resistance to adhesive setting, high temperature resistance determine the interest in their use in spacecraft (SC), especially to ensure the operability of friction units, for example, rotation mechanisms of antennas, mobile planetary platforms [3].

The materials in the friction units must have good resistance to adhesion bond, low friction coefficient and low surface wear [4]. The tribotechnical properties of CCCM at high temperatures have been studied enough [5].

The aim of the article is to study the antifriction properties of carbon-containing materials at high temperatures and ways to increase them during friction on 40X13 steel.
2. Materials and methods
CCCM-2D [6] and the counterbody material 40X13 steel were chosen as materials for the studied samples. Tribological tests were carried out at VTMT-1000 high-temperature test bench, which provided friction of the samples according to the finger scheme in the temperature range from +20 to +1000°C under the conditions of the range of normal loads from 35 to 300 N [7]. The stand design provides thermal insulation of the sample testing heating unit, which allows the test samples to be heated to a temperature of +1000°C. Tests should provide conditions that simulate the operation of the full-scale friction unit. In this regard, the most acceptable method of tribological testing of materials is a disk-finger scheme, because the bench test results of the samples can be extended to other sliding bearing designs. The temperature of the steel disk, which was used to test CCCM samples (heated to a given temperature), was measured using a chromel-alumel thermocouple recorded on a ZET 7120 instrument. The temperature control at the input from CAT sensor is limited to 1200 °C. The samples were tested under conditions of rotational motion with a constant angular velocity. The installation drive is powered by an asynchronous electric motor. The set rotation speed is set by changing the frequency of the current using a frequency converter having a range of output frequency of 0.1 - 400 Hz. The tests were carried out on samples of CCCM-2D material. The dimensions of the samples were 10×10×8 mm. The friction process was carried out in tandem with steel 40X13 [8]. The contact area was 300 mm², the average diameter of the sample arrangement was 66 mm, the linear velocity was 0.05; 0.16; 0.25 m/s, axial load is 1.0 MPa, the temperature is +20 ... +800°C. During the tests, the temperature on the friction surface and the moment of friction were measured continuously. The tests were carried out in atmospheric conditions.

3. Results
To increase the antifriction properties of carbon-containing materials, the friction surface of CCCM was modified. Considering the fact that CCCM material has a porous structure, to change the structure of the friction surface, the friction surface was processed in a protective chamber in the atmosphere:

- tellurium (Te) at a temperature of +880°C with preliminary vacuum pumping to a temperature of 300°C;
- selenium and polytetrafluoroethylene (Se-PTFE). The processing of samples from CCCM was carried out in a protective chamber at a temperature of 820°C [9].

Three types of samples were tested: CCCM, CCCM -Te and CCCM -Se-PTFE. As a result of the tests, the dependence of the friction coefficient at a load of 1.0 MPa and a velocity of 0.05 m/s for the CCCM and CCCM -Te samples was established (figure 1).

![Figure 1](image_url)
With increasing temperature from +20°C to +300°C, the friction coefficient for CCCM decreases from 0.12 to 0.07. With an increase in test temperature to +800°C, the friction coefficient increases to 0.38. When tested in an atmosphere of air, the carbon-carbon composite experiences strong high temperature oxidation, which causes rapid degradation and erosion. Carbon becomes susceptible to oxidation when heated above +350°C, and the oxidation rate increases rapidly with temperature. As a result, carbon-carbon decomposition occurs in the presence of air [10]. When creating friction units, it is necessary to protect the friction surface of the carbon-carbon composite using an oxidation-resistant surface coating or a protective gas environment. The values of the coefficient of friction of the modified CCCM surface in Te medium in the temperature range +20°C - +800°C vary in the range of 0.21-0.29. The treated surface is protected from atmospheric oxygen. Figure 2 shows the dependence of the friction coefficient on temperature at a load of 1.0 MPa and a speed of 0.16 m s for: CCCM, CCCM -Te and CCCM -Se-PTFE.

![Figure 2. Dependence of the coefficient of friction on temperature at load 1.0 MPa and speed of 0.16 m/s for: 1- CCCM, 2- CCCM -Te, 3- CCCM -Se-PTFE.](image)

The dependence of the coefficient of friction for CCCM is similar to that at a speed of 0.05 m/s. The values of the coefficient of friction for CCCM -Te in the temperature range +20°C - +800°C varies in the range 0.19-0.26. The friction surface treated in CCCM-Se-PTFE medium has a coefficient of friction in the range of 0.08-0.2 in the temperature range +20°C - +600°C. The dependence of the friction coefficient on temperature at a load of 1.0 MPa and a velocity of 0.25 m/s for CCCM and CCCM -Te is shown in figure 3.

![Figure 3. Dependence of the friction coefficient on temperature at a load of 1.0 MPa and a speed of 0.25 m/s for: 1- CCCM, 2- CCCM –Te.](image)
With an increase in the sliding speed, the intensity of the friction process increased. The coefficient of friction of CCCM in the temperature range \(+20^\circ\text{C} - +600^\circ\text{C}\) varies in the range of 0.17-0.42, and CCCM -Te in the same temperature range has a friction coefficient of 0.2-0.26. Tests of CCCM -Te and CCCM-Se-PTFE showed that at a load of 1.0 MPa, sliding speeds of 0.05; 0.16; 0.25 m/s and a temperature range of \(+20^\circ\text{C} - +600^\circ\text{C}\), the friction coefficient does not exceed the value of 0.3. The increased value of the coefficient of friction in the design of friction units will entail an increase in the capacities of the executive bodies (for example, drives of antennas of spacecraft, gearboxes, opening mechanisms, etc.).

4. Conclusion
The researches have shown that the modified friction surface of CCCM in the environment of tellurium, selenium and polytetrafluoroethylene paired with steel 40X13 reduces the coefficient of friction. With a load of 1.0 MPa, sliding speeds of 0.05; 0.16; 0.25 m/s and a temperature range of \(+20^\circ\text{C} - +600^\circ\text{C}\), the friction coefficient does not exceed the value of 0.3. At a temperature of 600\(^\circ\text{C}\), a load of 1.0 MPa, and a speed of 0.16 m/s, the friction coefficient of the samples treated in tellurium, selenium, and polytetrafluoroethylene environments is 1.8 and 4.8 times lower than that of CCCM, respectively.

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