High-temperature tribological tests of composite materials

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Abstract. The work is devoted to high-temperature tribological tests of carbon-containing materials during friction on 40Kh13 steel in the temperature range of 20 - 800 °C. The choice of test temperature is based on prospects of creating spacecraft drives for operation without lubrication in the atmosphere of Venus. The studies have shown that at the same load and temperature with increasing slip speed, the friction coefficient increases. With increasing load, the friction coefficient at a given temperature decreases. At a temperature of 300 °C for speeds of 0.05; 0.16; 0.25; 0.3; 0.37 m / s with increasing load from 0.3 MPa to 1.0 MPa, the friction coefficient decreases by 1.4; 1.8; 1.1; 1.5; 1.5 times, respectively. At a temperature of 500 °C in the same range of speeds and loads, the friction coefficient decreases by 1.1; 1.4; 1.5; 1.7; 1.6 times, respectively.

1. Introduction
When creating new equipment operating in extreme operating conditions, for example, at high temperatures, new antifriction materials are required for friction units. The simulation of the friction units operating at high temperatures is complicated by 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. The problem of choosing materials for friction units is complicated by the fact that under extreme conditions of testing the operation of friction units, it is necessary to create conditions close to real ones [1]. When designing aerospace engineering, one of the key requirements for structural materials is the effectiveness of the strength properties of the material by mass - specific strength [2]. Promising material for working in high-temperature friction units is carbon-carbon composite materials (CCCM) [3]. The CCCM material has an extremely low density, good strength and adhesion resistance characteristics, high temperature resistance determine the interest in their use in spacecraft (SC), especially to ensure the friction units, for example, antenna rotation mechanisms, mobile planetary platforms [4].

The materials in the friction units must have good resistance to adhesion setting low coefficient of friction and low wear of surfaces. In conditions of high temperatures, for example, when flying towards the Sun [5], and also in aggressive environments, for example, on the planet Venus at a temperature of 467 °C, high heat resistance is required [6]. The tribotechnical properties of CCCM at high temperatures have been little studied. For the widespread use of CCCM in friction units, measures are required to improve the antifriction properties.
The purpose of the work is to study the effect of sliding speed, load and temperature on the tribological characteristics of a carbon-carbon composite during friction on 40X13 steel in the temperature range (20 °C ... 800°C).

2. Materials and equipment

CCCM “Argolon-2D” has been selected as a test object [7]. Tribological tests were carried out on a VTTM-1000 high-temperature stand [8], which provides friction of the samples according to the finger pattern in the temperature range of 20–1000 °C under the normal load range of 35–300 N. The stand design provides thermal insulation of the heating unit, which allows the test samples to be heated to temperature 1000°C. The tests should provide conditions that simulate the operation of the full-scale friction unit. In this regard, the most acceptable method of tribological tests of materials is a disk-finger scheme, because stand test results are easier to extend to other sliding bearings schemes. During the tests, the moment of friction was measured. The moment of rotation friction was fixed continuously and is stored in the computer memory. The temperature of the steel disk, which was used to move the tested CCCM samples (heated to a predetermined temperature), was carried out with a chromel-alumel thermocouple recorded on the device using ZET 7120 temperature sensors. The input temperature control from the TXA sensor is limited to 1200 °C. The samples were tested under conditions of rotational motion with a constant angular velocity. The linear velocity was 0.05 - 0.37 m/s. 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.

3. The results of the experiment

The tests were carried out on samples made of Argolon-2D material. The dimensions of the samples were 10 × 10 × 10 mm. The friction process was carried out in tandem with steel 40X13 [9]. The contact area was 300 mm2, the average diameter of the sample arrangement was 66 mm, the linear velocity was 0.05-0.37 m/s, the axial load was 0.22 - 1.0 MPa, and the temperature was 20 - 800 °C. During the tests, the temperature on the friction surface and the moment of friction were measured continuously.

As a result of the tests, the dependence of the friction coefficient at a load of 0.5 MPa (figure 1) and 1.0 MPa (figure 2) was established in the temperature range from 20 °C to 800 °C for the tested samples. From the analysis of the graphs of figures 1 and 2 at sliding speeds of 0.05 and 0.16 m/s, a break in the curve of the graph of the friction coefficient at a temperature of 300 °C and a change in the growth rate of the friction coefficient are observed. At speeds of 0.25-0.37 m/s, a fracture is observed at a temperature of 100 °C. 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 decay occurs in the presence of air [10, 11]. The friction surface of the carbon-carbon composite must be protected using an oxidation-resistant surface coating. The carbon-carbon tiles on the orbiter space shuttle, for example, are coated with silicon carbide to provide protection against oxidation up to about 1200 °C [12]. So, for example, at a load of 1.0 MPa and a slip velocity of 0.16 m/s, the modified friction surface with selenium and polytetrafluoroethylene leads to the performance of the samples in the temperature range 20 °C–600 °C, the friction coefficient decreases with increasing temperature from 0.2 to 0.09, respectively [13]. Modification of the friction surface leads to positive results. In the temperature range of 400-500 °C at speeds of 0.05-0.37 m/s and a load of 0.5 MPa, the friction coefficient varies in the range of 0.28-0.55, and at a load of 1.0 MPa, the friction coefficient changes in the range of 0.25-0.42. The design of friction units for such ranges of the coefficient of friction will entail an increase in the capacities of the executive bodies. The dependence of the change in the friction coefficient on the influence of the load at sliding speeds of 0.05-0.37 m/s at a temperature of 300 °C is shown in figure 3, and at a temperature of 500 °C it is shown in figure 4. The values of the coefficient of friction with increasing load at temperatures of 300 °C and 500 °C fall. At the same load and temperature, with an increase in the sliding speed, the friction coefficient increases. So, for example, at
a temperature of 300 °C for speeds of 0.05; 0.16; 0.25; 0.3; 0.37 m/s with increasing load from 0.3 MPa to 1.0 MPa, the friction coefficient decreases by 1.4; 1.8; 1.1; 1.5; 1.5 times, respectively. At a temperature of 500 °C in the same range of speeds and loads, the friction coefficient decreases by 1.1; 1.4; 1.5; 1.7; 1.6 times, respectively.

**Figure 1.** The dependence of the coefficient of friction on temperature at a load of 0.5 MPa and speed, m / s: 1 - 0.05; 2 - 0.16; 3 - 0.25; 4 - 0.3; 5 - 0.37.

**Figure 2.** The dependence of the coefficient of friction on temperature at a load of 1.0 MPa and speed, m / s: 1 - 0.05; 2 - 0.16; 3 - 0.25; 4 - 0.3; 5 - 0.37.

**Figure 3.** The dependence of the coefficient of friction on the load at a temperature of 300 °C and speed, m / s: 1 - 0.05; 2 - 0.16; 3 - 0.25; 4 - 0.3; 5 - 0.37.
4. Conclusions
Studies have shown that at the same load and temperature with increasing slip speed, the friction coefficient increases. With increasing load, the friction coefficient at a given temperature decreases. At a temperature of 300 °C for speeds of 0.05; 0.16; 0.25; 0.3; 0.37 m/s with a load range from 0.3 MPa to 1.0 MPa, the friction coefficient decreases by 1.4; 1.8; 1.1; 1.5; 1.5 times, respectively. At a temperature of 500 °C in the same range of speeds and loads, the friction coefficient decreases by 1.1; 1.4; 1.5; 1.7; 1.6 times, respectively.

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