Carbon-containing materials for high-temperature friction units

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Abstract. The paper considers frictional interaction of carbon-containing composites with steel at high temperatures. Material "Hardcarb-TPG" has better tribological characteristics than materials "Hardcarb" and "Hardcarb-TP". At a speed of 0.16 m/s and a load of 1.0 MPa, the friction coefficient of the Hardcarb-TPG material is 23% lower than that of the Hardcarb-TP material. Thus, at a temperature of 500 °C and a load of 1.0 MPa, the friction coefficient of the Hardcarb-TPG material at a speed of 0.16 and 0.25 m/s is 8 and 14% higher than at a speed of 0.05 m/s, respectively. The friction coefficient of the Hardcarb-TPG material at a speed of 0.16 m/s and a load of 1.0 MPa in the temperature range 300...600 °C varies from 0.13 to 0.30.

1. Introduction

The present period of development of metallurgy is characterized by a radical change in both the scale of production of high-quality and high-quality steel, and its share in total production and production methods.

High requirements for the quality of steel in modern metallurgy have led to the development of a large number of new technologies, which has significantly changed the state of affairs in the steel industry in recent years.

It is known that carbon-base materials are the materials for various purposes based on natural or artificial graphite. Carbon materials technology includes heat treatment processes. Structural graphites and electrodes, as a rule, are fired at 900-1100 °C and graphitized at 2400-3000 °C. To protect against oxidation during operation in oxidizing environments at t> 600 °C, diffusion-reaction coatings (DRC) are applied to articles made of carbon materials: slip-firing carbide, boride and glass-silicide classes and are obtained by a chemical reaction from steam (for example, based on SiC). When operating carbon products with a coating in oxidizing environments at t> 1500 °C, coatings of the carbide-boride class of the Hf(Zr)-B-Si-C system or the oxide-boride class of the Hf(Zr)-B-Si-O system are recommended. At an operating temperature of 1300 - 1500 °C, glass-silicide class coatings based on borosilicate glass and Mo (W) Si2 are used.

Fields of application carbon materials with DRC: crucibles for melting metals and their alloys, heaters of electric furnaces, elements of metallurgical furnaces (roller tables, valves, etc.) operating at high temperatures in air, as well as heat-stressed parts of spacecraft (wing edges, nose cone), aviation gas turbine (elements of the combustion chamber, directional apparatus, turbine impellers) and ramjet engines.
Scope of carbon-base materials in steelmaking: carburizing steel (carbon-containing material with a fraction of 0-10 mm sits down during metal tapping); the use of a lump carbon-base materials as additional heat energy for the steel smelting process (supply of a lump carbon-base materials with a fraction of 25-50 mm to the convector allows to reduce the consumption of liquid iron for the steel smelting process and increase the proportion of filled up scrap, replacing part of the liquid iron with scrap provides a reduction in the cost of steel); use of carbon-base materials powder for slag foaming.

In the process of creating and operating new equipment capable of operating under extreme conditions, for example, at high temperatures, it is required to use materials in the friction units of the executive bodies that have a low coefficient of friction in friction pairs. Materials used in assemblies at high temperatures must ensure its performance and reliability. To rise the antifriction of the friction unit at high temperatures, high-temperature lubricants or solid lubricating coatings are used [1, 2]. When creating friction units for operation in aggressive atmospheric conditions and high temperatures, materials based on carbon-carbon compositions (CCCM) are used [3]. CCCM material has good characteristics in terms of specific gravity and strength. The production of CCCM material is constantly being improved [4]. Carbon nanotubes are introduced into the composition of the CCCM material to improve the mechanical properties [5]. At high temperatures CCCM is subject to oxidation [6]. Mechanical properties of CCCM at high temperatures are widely studied [7]. Tribological parameters of CCCM materials at high temperatures have not been considered to a full extent.

This work is being carried out jointly by the Institute of Mechanical Engineering named after A. A. Blagonravov of the Russian Academy of Sciences and Joint Stock Company "Scientific and Production Association named after S.A. Lavochkin". The research is being carried out in the expediency of using in the design of spacecraft new promising materials of friction units operating in the conditions of: open space, the atmosphere of Venus.

Structural carbon-containing composite materials are of interest in the space and aviation industries due to their low specific gravity, high strength characteristics and the ability to work at high temperatures. In friction units of various-purpose apparatuses, an additional requirement for the materials used is antifriction characteristics. High coefficients of friction lead to an increase in the power of the executive bodies, and this leads to an increase in the mass of spacecraft. The performance of CCCM friction units at high temperatures depends on the rate of graphite oxidation, which leads to a loss of mass and strength properties of parts. In this paper, the issues of tribological testing of promising materials are partially considered. Tribological research is associated with high costs, both material and financial. Carrying out large-scale research is not possible due to the impossibility of ensuring the operating conditions of the units. Basically, high-temperature tribological tests of carbon-containing materials are carried out to solve particular problems to increase the resource and reliability of friction units [8]. Carrying out high-temperature tribological tests of carbon-containing materials in the creation of spacecraft of the future is an urgent task. Among the problems of the future are the tasks of Venus exploration, which require the creation of devices for long-term operation on the planet's surface, both stationary and mobile platforms. The tribological characteristics of CCCM have been insufficiently studied. With a large amount of research on the effect of temperature on the strength properties of carbon composites, there are very few studies of the tribological properties of CCCM, especially in the field of high-temperature tests.

The purpose of this work is to test the tribological properties of carbon-containing composites at high temperatures during friction against 40X13 steel.

2. Materials and methods
The samples were made of volume-reinforced carbon-containing composite materials of the following brands: "Hardcarb", "Hardcarb-TP", "Harkearb-TPG". Materials of the "Hardcarb" type have the following fiber composition:

- "Hardcarb" is made of carbon technical fabric of the T-0.5P-22N type (viscose).
- "Hardcarb-TP" is made of carbon fabric such as Serzha 2 / 2-1000-12K-400 (PAN fiber).
"Hardcarb-TPG" is made of PAN fiber with graphitization.

Samples of heat-resistant corrosion-resistant steel 40X13 were used as a counterbody. Tribological studies were carried out on a modernized high-temperature test bench VTMT-1000 [9].

The test was carried out on specimens according to the "disc-finger" scheme in the temperature range of 300 - 800 °C at a load of 0.3…1.0 MPa and a sliding speed of 0.05; 0.16; 0.25 m/s. Which was installed discretely. The tests should simulate the operating conditions of a full-scale friction unit. The implemented test scheme "disk-finger" allows you to extend the results of bench tests to other interface schemes. In tribological tests of materials, on some test installations, the "disk-finger" test scheme is widely used. The test results of the samples during the experiment are easier to adapt to other mobile schemes of sliding pairs. The laboratory test unit can measure the moment of friction and temperature in the contact zone, the signals from the sensors are transmitted online to the control computer for processing.

3. Results and discussion

Tribological tests of the "Hardcarb-TPG" material at sliding speeds: 0.05; 0.16; 0.25 m/s, a load of 1.0 MPa paired with 40X13 steel at temperatures from 300 to 800 °C, it was found that the coefficient of friction increases with increasing sliding speed (Figure 1, curves 1; 2; 3 at a speed, m/s-0.05; 0.16; 0.25- respectively). Thus, at a load of 1.0 MPa, a temperature of 500 °C and a speed of 0.16 and 0.25 m/s, the coefficient of friction is 8 and 14% higher than at a speed of 0.05 m/s, respectively.

![Figure 1. Temperature dependence of the coefficient of friction "Hardcarb-TPG" at a load of 1.0 MPa.](image)

Figure 2 (at a load of 1.0 MPa and a speed of 0.16 m/s) shows the temperature dependence of the coefficient of friction of Hardcarb and Hardcarb-TPG materials at a load of 1.0 MPa and a speed of 0.16 m/s. In the temperature range of 300...600 °C the coefficient of friction of the Hardcarb-TPG material varies in the range of 0.13...0.30. With an increase in temperature above 300 °C, the coefficient of friction of the Hardcarb material increases. At a temperature of 400 °C, the coefficient of friction is 20% greater, and at a temperature of 500 °C, it is 38% greater than the coefficient of friction of the Hardcarb-TPG material. When testing Hardcarb and Hardcarb-TPG materials, with an increase in temperature above 300 °C, the mechanical characteristics, including hardness, decrease. The surface deformation component of the friction force increases with a decrease in hardness, therefore, an increase in the coefficient of friction is observed. The change in the friction coefficient for the Hardcarb-TPG material is shown in figure 3 (at a temperature of 500 °C and a speed of, m / s: 1-0.05; 2-0.16; 3-0.25). With an increase in the test load at a temperature of 500 °C, the friction coefficient for the Hardcarb-TPG material...
The change in the friction coefficient of the Hardcarb-TP and Hardcarb-TPG materials from the sliding speed is shown in figure 4 (load 1.0 MPa and temperature 500°C). The friction coefficient of the Hardcarb-TPG material in the sliding speed range of 0.05...0.25 m/s is lower than that of the material "Hardcarb-TP". At a speed of 0.16 m/s, the friction coefficient of the Hardcarb-TPG material is 23% lower than that of the Hardcarb-TP material. Technological innovations in the manufacture of the "Hardcarb-TPG" material with the use of graphitization lead to a reduced coefficient of friction than that of the "Hardcarb-TP" material.
Figure 4. The effect of speed on the coefficient of friction: 1- "Hardcarb-TP", 2- "Hardcarb-TPG".

4. Conclusion

Material "Hardcarb-TPG" has better tribological characteristics than materials "Hardcarb" and "Hardcarb-TP". At a speed of 0.16 m/s and a load of 1.0 MPa, the friction coefficient of the Hardcarb-TPG material is 23% lower than that of the Hardcarb-TP material. Thus, at a temperature of 500 °C and a load of 1.0 MPa, the friction coefficient of the Hardcarb-TPG material at a speed of 0.16 and 0.25 m/s is 8 and 14% higher than at a speed of 0.05 m/s, respectively. At temperatures from 300 to 600 °C, a load of 1.0 MP and a speed of 0.16 m/s, the coefficient of friction of the Hardcarb-TPG material varies from 0.13 to 0.30. The experimental results obtained in the work can be used in the design of friction units operating at high temperatures.

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