

# Improvement of tribological parameters of carbon-carbon material by modification of the friction surface

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**Abstract.** The results of high-temperature tribological research of carbon-carbon material at friction on heat-resistant stainless steel 40X13 in the temperature range from +20 to +700 °C are presented. Friction surface modifiers change the structure of the friction surface of carbon-carbon material CCCM-2D, improve its antifriction properties, and reduce the friction coefficient. The structurally modified friction surface provided by modifiers PTFE, SnSe-PTFE and InSb-Sn-PTFE achieves friction coefficient values of 0.08 to 0.15 in the temperature range of +300 to +500 °C. These results are intended for use in the creation of sliding bearings for operation at high temperature, as they show that structurally modified friction surfaces of carbon-carbon material can withstand high temperatures without losing their friction-reducing abilities.

## 1 Introduction

When operating units with friction joints at high temperatures, it is crucial to ensure that heat generation does not increase, as this can lead to changes in lubrication conditions. When designing plain bearings, it is essential to ensure compatibility of friction pairs and to ensure a low coefficient of friction. Increasing the anti-friction of a friction pair will reduce the coefficient of friction and heat generation. Technological and design methods can and should be used to reduce heat generation in the friction joint. Select compatible materials for the design of plain bearings. Surface treatment and surface roughness must be changed. It is possible to change lubrication conditions and use high-temperature lubricants. The use of solid lubricant coating (SLC) and antifriction materials will reduce the coefficient of friction in plain bearings [1-3]. It is a fact that increasing the temperature in a plain bearing affects the viscosity of the lubricant. High-temperature lubricants are the way to go for plain bearings. The effect of temperature rise on the reduction of the viscosity of the lubricant is minimal. As the temperature rises, the viscosity of the grease decreases, which results in a thinner grease film. When this film ruptures, the friction surfaces make rigid contact, leading to increased wear. Sliding bearings operating at high temperatures present a challenge when it comes to creating a system with liquid lubrication. At high temperatures and low speeds, the use of SLC, which reduces the coefficient of friction, is

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the only way to go [4, 5]. Antifriction additives are introduced into the SLC structure to increase the efficiency of SLC use in the friction joint. These additives reduce the friction coefficient [6-8], contributing to improved efficiency. In work [9], we examine the technological methods of preparing friction surfaces that contribute to the improvement of wearability of pairs and the reduction of the friction coefficient. The quality of the rubbing parts' surface is crucial. With sliding, the rough surface will change, but it will tend to a stable value. Surface roughness class affects the running-in process of contacting parts. During running-in, the roughness of the parts' surfaces is established. This is not dependent on the size and nature of the original roughness obtained during machining. It is dependent on the conditions of wear of the rubbing surfaces. Roughness affects the formation of a lubricating film in contact. When the lubricating film breaks, the rough surface of the contacted parts comes into contact with the lubricating film [10].

In friction bearings, non-metallic sleeves are used. To increase the antifriction of the friction pair, polytetrafluoroethylene is introduced into the structure of the bushing material [11, 12]. At high temperatures, carbon-carbon composite materials (CCCM) are the go-to for friction bearings [13, 14]. Friction bearings using CCCMs have low coefficients of friction, which provides low wear of friction surfaces at high temperatures. The tribotechnical characteristics of CCCM are insufficient at high temperatures, which restricts its application.

The objective of this study is to determine if it is possible to enhance the tribological characteristics of carbon-carbon material at high temperatures by modifying the friction surface structure.

## 2 Materials and Methods

Research on improvement of tribological properties of carbon-carbon material was conducted on the material of 'Argolon-2D' mark (hereinafter CCCM-2D). CCCM-2D was tested in pair with heat-resistant steel 40X13. In order to improve tribological parameters of the friction surface of CCCM-2D at high temperature, the structure of the friction surface was changed. The friction surface of CCCM-2D was saturated with antifriction compositions. CCCM-2D samples were placed in a sealed special chamber from which air was pumped out. Then the chamber was heated to a certain temperature and kept for a certain time for each antifriction modifier. Several options for saturating the friction surface of CCCM-2D to improve its antifriction properties were considered:

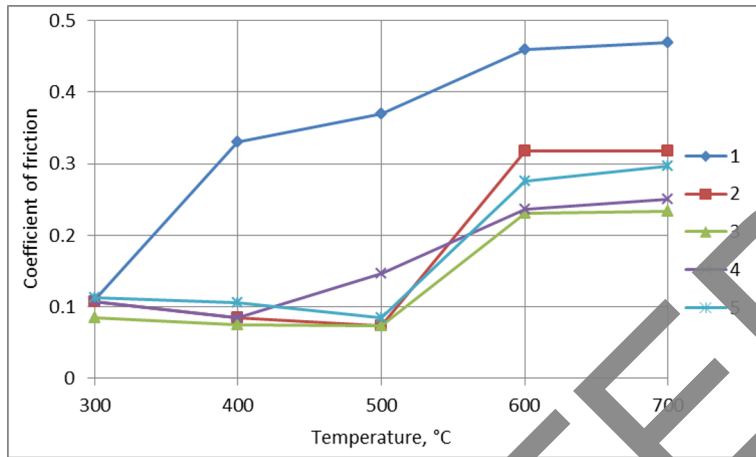
- 1- polytetrafluoroethylene (PTFE). Treatment temperature was 680 °C;
- 2- tin selenide (SnSe) - PTFE. Treatment temperature was 680 °C to 880 °C;
- 3- molybdenum selenide and tin selenide ( $\text{MoSe}_2\text{-SnSe}$ ) - PTFE. Treatment temperature was 680 - 880 °C;
- 4- indium antimonide (InSb) - Se - PTFE. Treatment temperature was 680 to 770 °C.

Tribological tests of CCCM-2D samples with structurally modified friction surface in pair with heat-resistant steel 40X13 were conducted on high-temperature tribometer VTMT-1000. The tribometer implemented the scheme of testing samples, "disk-finger" in the temperature range from +20 to +700 °C at contact pressure of 0.3...1.0 MPa [15-17]. Tests of friction pairs in the experiment should correspond to the conditions that reflect the work of a full-scale friction joint. In tribological tests of materials, in some testing facilities, the "disk-finger" testing scheme is widely used. The results of sample testing in the experiment are more easily adaptable to other sliding pair arrangements. The laboratory test machine can measure the friction torque and temperature in the contact zone, and the sensor signals are transmitted to the control computer online for processing. Linear speed at testing of samples was set stepwise and made 0.5 - 0.37 m/s, axial pressure was in a range of 0.3 ...

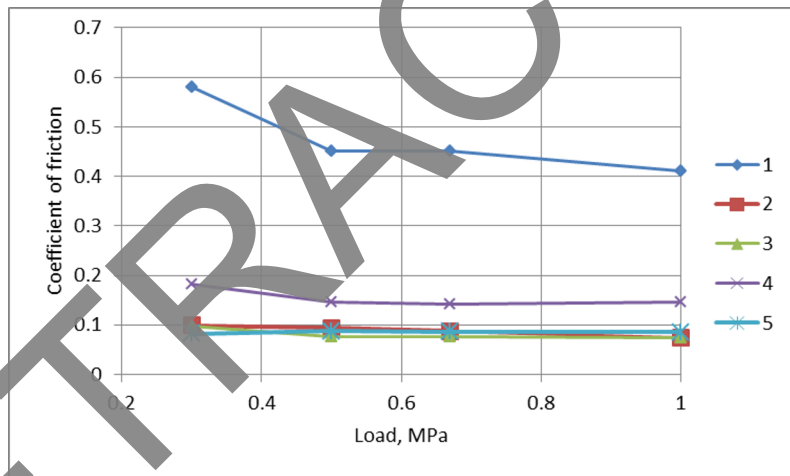
1.0 MPa, temperature +20 ... +700 °C. Control of temperature and friction torque was carried out continuously.

### 3 Results

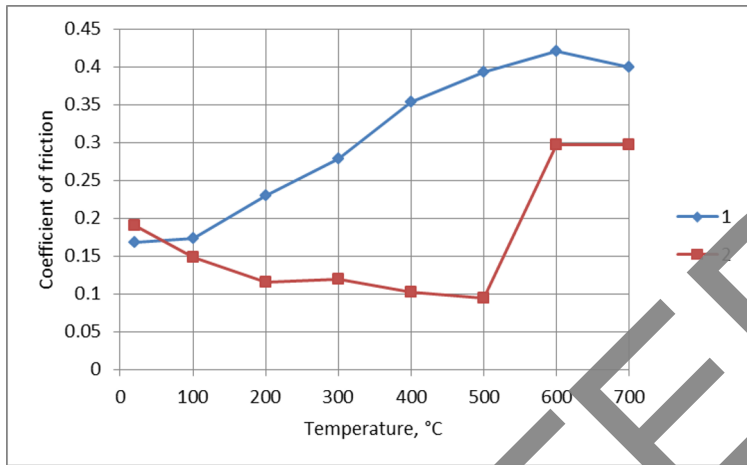
Research of tribological parameters was carried out on samples with structurally modified friction surface using materials: CCCM-2D+PTFE, CCCM-2D+SnSe-PTFE, CCCM-2D+MoSe<sub>2</sub>-SnSe-PTFE, CCCM-2D+InSb-Se-PTFE and for comparison with a sample from CCCM-2D material. The variation of friction coefficient with temperature, load and speed from the test results is shown in Figure 1. In a range of temperatures 300...500 °C structurally changed friction surface by materials PTFE, SnSe-PTFE, InSb-Se-PTFE have a low coefficient of friction, the values of which are in a range 0.08 - 0.15. In the temperature range 300 ... 500 °C friction coefficient of material CCCM-2D varies in the range 0.13 - 0.37, and with increasing temperature above 500 °C friction coefficient continues to increase and at a temperature of +700 °C reaches a value of 0.4. At a temperature of 500 °C friction coefficient structurally modified friction surface of the material CCCM-2D+PTFE, CCCM-2D+SnSe-PTFE is less than the coefficient of the material CCCM-2D more than 5 times, and the material InSb-Se-PTFE is less than 4.3 times. The increase in the friction coefficient is explained by oxidative processes of carbon under atmospheric conditions. Modifiers slow down the oxidative process of carbon. The effect of load on the friction coefficient at a velocity of 0.16 m/s and a temperature 500 °C of materials: CCCM-2D, CCCM-2D+PTFE, CCCM-2D+SnSe-PTFE, CCCM-2D+MoSe<sub>2</sub>-SnSe-PTFE, CCCM-2D+InSb-Se-PTFE is shown in Figure 2. The surface modifiers decrease the coefficient of friction with increasing load. The friction coefficient of the modified surface decreases with increasing load. PTFE, SnSe-PTFE, MoSe<sub>2</sub>-SnSe-PTFE and MoSe<sub>2</sub>-SnSe-PTFE modifiers were more effective in the load range of 0.3 - 1.0 MPa. The friction coefficient at a temperature of 500 °C and a velocity of 0.16 m/s varies in the range of 0.073 - 0.085, which is 1.7 times less than the friction coefficient at a structurally modified surface with InSb-Se-PTFE material. The effect of temperature on the friction coefficient at a load of 1.0MPa, and a velocity of 0.25m/s of CCCM-2D, CCCM-2D+InSb-Se-PTFE materials is shown in Figure 3. The effect of temperature from 20 °C to 500 °C on the friction coefficient of InSb-Se-PTFE modified surface decreases from 0.19 to 0.095. At 200 °C the friction coefficient of the structurally modified CCCM-2D friction surface by the InSb-Se-PTFE modifier is 2 times less than the friction coefficient of the CCCM-2D material, and at 500 °C the friction coefficient of the structurally modified CCCM-2D surface by the InSb-Se-PTFE material is 4.13 times less. The effect of speed on the friction coefficient at temperature 500 °C and load 1.0 MPa of materials: CCCM-2D, CCCM-2D+InSb-Se-PTFE is shown in Figure 4. At temperature 500 °C the effect of velocity 0.16 m/s on the friction coefficient of structurally modified friction surface of CCCM-2D+InSb-PTFE is 4.35 times less than the material CCCM-2D, and the effect of velocity 0.25 m/s on the friction coefficient of structurally modified friction surface of CCCM-2D+InSb-PTFE is 4.1 times less than the material CCCM-2D. Analysis of tribological test results showed that the change of friction coefficient from load and temperature when using modifying materials PTFE, SnSe-PTFE, InSb-Se-PTFE has more effective value than the friction coefficient of structurally modified surface by MoSe<sub>2</sub>-SnSe material. CCCM-2D material when tested in air atmosphere experiences severe high temperature oxidation, which causes rapid degradation and erosion and the oxidation rate increases rapidly with increasing temperature. In the presence of air, the decomposition of carbon-containing material occurs.



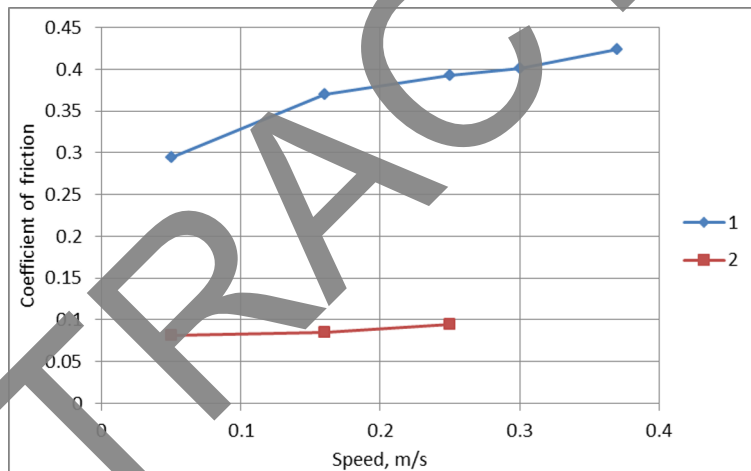
**Fig. 1.** Effect of temperature on the coefficient of friction at a velocity of 0.16 m/sec and load 1.0 MPa of materials: 1 - CCCM-2D, 2 - CCCM-2D+PTFE, 3 - CCCM-2D+SnSe-PTFE, 4 - CCCM-2D+MoSe2-SnSe-PTFE, 5 - CCCM-2D+InSb-Se-PTFE



**Fig. 2.** Effect of load on friction coefficient at speed 0.16m/s and temperature 500 °C of materials: 1- CCCM-2D, 2- CCCM-2D+PTFE, 3- CCCM-2D+SnSe-PTFE, 4- CCCM-2D+MoSe2-SnSe-PTFE, 5- CCCM-2D+InSb-Se-PTFE



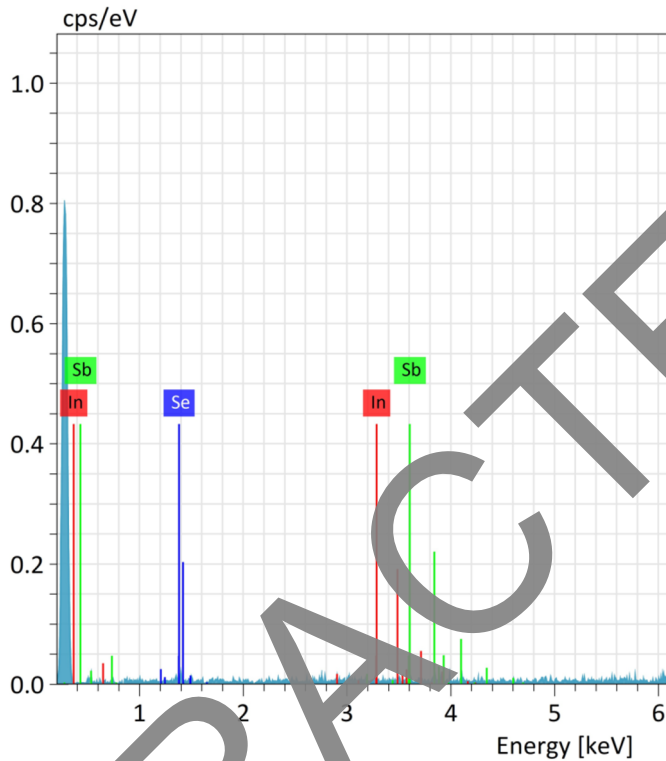
**Fig. 3.** Effect of temperature on the coefficient of friction at a velocity of 0.25 m/s and a load of 1.0 MPa materials: 1- CCCM-2D, 2- CCCM-2D+InSb-Se-PTFE



**Fig. 4.** Effect of velocity on friction coefficient at temperature 500 °C and 1.0 MPa load on materials: 1- CCCM-2D, 2- CCCM-2D+InSb-Se-PTFE

Friction surface modifiers change the surface structure of CCCM-2D material, create a surface more resistant to temperatures and atmospheric oxygen, as it showed tribological experiments under normal atmospheric conditions. Tribological tests carried out at high temperature confirmed the extension of the temperature range of CCCM-2D material performance and reduction of friction coefficient. The structurally modified surface at high temperature heating is more resistant to oxidative process. Figure 6 shows the spectral diagram of the elemental composition of the friction surface of the sample. The diagram was obtained on electron microscope SNE-4500M Plus with an attachment for quantitative Ethylcyclopentane analysis of bulk samples. The sample CCCM-2D with surface modification by InSb-Se-PTFE composition was analyzed, which underwent a cycle of tribological tests in the temperature range +20...+700 °C. The spectrogram revealed chemical elements In, Sb, Se, which were used in the composition of the modifier. At

temperature heating and deformation mechanical impact during friction, the elements included in the modified surface were preserved, which is confirmed on the spectrogram.



**Fig. 6.** Spectral diagram of the elemental composition of the sample friction surface, where the horizontal axis is the energy scale (Kilo-eletron Volt; vertical axis -Critical peaks corresponding to each element)

## 4 Discussion

Changing the structure of the friction surface of carbon-carbon material in order to expand the temperature range of its operability and reduce the friction coefficient has been studied in various works. For instance, in the research of the modified friction surface of carbon-carbon material "Hardkarb-TP" Se and PTFE at temperature +20...+700 °C was carried out [18]. The modified structure of the friction surface of the material "Hardkarb-TP" by modifiers improves tribological properties of the friction surface. In the work [15] the effect of modifiers Se and PTFE on the change of the friction surface structure of carbon-carbon material "Hardkarb-T" is considered. Tribological tests were carried out in pair with 40X13 steel. Structurally modified surface has better tribological parameters of friction surface.

## 5 Conclusion

The structurally modified friction surface of carbon-carbon material CCCM-2D by modifiers is demonstrably superior to other materials in terms of antifriction properties and has a significantly lower friction coefficient. The structurally modified friction surface, when influenced by materials PTFE, SnSe-PTFE, and InSb-Se-PTFE, provides values of

the friction coefficient in the range of 0.08 to 0.15 in the temperature range of 300 to 500 °C. The results of testing the structurally modified friction surface of carbon-carbon material at high temperature for friction are intended for use in the creation of friction bearings for operation at high temperature.

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