Composite antifriction coating modified with copper complex and fluoropolymer

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Abstract. A composite antifriction coating modified with copper complex and fluoropolymer has been developed. Studies were carried out on the effect of modifiers on obtaining a solid lubricating coating of a certain thickness, depending on the heat treatment modes, and measurements of friction and adhesion coefficient were carried out. This coating can be used in friction units of machines and mechanisms operating in an air environment with frequent cyclic loads, temperature drops, as well as in vacuum. On the basis of experimental data, the optimal structure of the composite coating components has been developed.

1. Introduction
Composite antifriction coatings are successfully used to reduce friction and wear in the units of machines and mechanisms [1-4]. A large number of coatings are used in industry, and especially solid lubricating coatings should be noted [4-6].

When designing a friction unit, it is necessary to develop a coating in advance, depending on the operating conditions, purpose, specified resource, as well as possible physicochemical reactions in the friction zone [7-9].

It is known that the use of the ideology of the phase-disordered state of the surface participating in friction allows the creation of coatings with desired properties for a specific structural unit without a large analysis of possible components that may be included in the composition of the coating [10].

For the operation of friction units at frequent cyclic loads and changing temperatures in the air, a composite coating has been developed containing copper complex and fluoropolymer [11].

2. Experimental results and discussion
In order to improve the operation of the tribo unit under cyclic loads and operable in a wide temperature range, a composite antifriction coating has been developed, which can be applied both to steel and copper alloys [11]. Based on the literature review of analogues [1-30], a composition has been developed containing molybdenum disulfide, copper complex, fluorine-containing polymer, silver nitrate. An aqueous solution of nitric acid, phosphoric acid, copper oxide was taken as a binder. All components are experimentally optimally selected [11].

Table 1 shows the structure of the developed compositions, the components of which are taken in the following ratio, mas. %.

| Component | Mass Ratio |
|-----------|------------|
| Fluoropolymer | 0.4-0.06 microns |
| Copper complex | |
| Molybdenum disulfide | |
| Flouroine-containing polymer | |
| Silver nitrate | |
| Nitric acid | |
| Phosphoric acid | |
| Copper oxide | |

The fluoropolymer is added to the composition in the form of a suspension of fluoroplastic F-4D and is an aqueous suspension of fluoroplastic 4D particles with a particle size of 0.4-0.06 microns.
Table 1. Structure of the composition

| Component                   | mas. % |
|-----------------------------|--------|
| Molybdenum disulfide        | 20-70  |
| Copper complex              | 2-12   |
| Fluoropolymer               | 5-25   |
| Nitric acid                 | 2-9    |
| Phosphoric acid             | 7-15   |
| Copper oxide                | 1-4    |
| Water                       | Rest   |

The combined content of a copper complex and a fluorine-containing polymer in an antifriction coating allows achieving a synergistic effect.

The formation of phases of the solid and lubricant components on the surface of the composite antifriction solid coating, the possible transfer of copper particles to the adjacent friction surface lead to a significant improvement in the tribotechnical properties of the developed coating.

The technology for creating a composite anti-friction coating consists of several stages:

- creating a suspension;
- steel surface preparation;
- coating steel surface;
- heat treatment of the coating;
- polishing the coating to a specified thickness.

The heat treatment mode was selected experimentally. It was found that for the crystallization of aluminophosphates and their diffusion into the steel surface, as well as for the removal of crystallization water, a temperature of 3000°C with a duration of heat treatment for two hours is required, which is the optimal condition for the formation of a coating applied by a brush.

Fig. 1, 2 shows photos of the surface of the resulting composite antifriction coating.

![Image](image1.png)

**Figure 1.** The surface of the applied composite antifriction coating on the steel base after heat treatment: a - x20; b - x 100; c - x200; d -x500; i -x1000. Heat treatment temperature is 3000°C for 120 minutes
The photographs show that the surface of the developed composite antifriction coating has a layered-block structure. The phosphate layer actually envelops the molybdenum disulfide particles and forms a layered-block cellular structure.

Thus, not only the surface of the base, but also the solid lubricant (molybdenum disulfide) is reliably protected from oxidation and fixed on the surface. In this case, the layered-block cellular structure is optimal for the implementation of high antifriction characteristics of conjugate friction pairs.

The properties of the obtained composite antifriction coating were tested on a reciprocating friction machine with a displacement speed \( V = 0.132 \text{ m/s} \), \( P = 20.2 \text{ MPa} \). The coating was applied to steel samples. Steel samples made of ShKh15 steel were used as a counterbody. The test was carried out up to ultimate wear under cyclic loads. Running time for one cycle was 5 seconds.

Fig. 3, 4, 5 show the results of measuring the coefficient of friction depending on the thickness of the developed composite antifriction coating, the duration of the test and the ambient temperature.

**Figure 2.** Photos of the developed composite antifriction coating, taken with a two-beam scanning electron/ ion microscope ZEISS CrossBeam 340: a - x100; b - x 2000.

**Figure 3.** The results of measuring the coefficient of friction depending on the thickness of the developed composite antifriction coating (ambient temperature is 20°C).
Figure 4. The results of measuring the coefficient of friction depending on the duration of the test (coating thickness is 10 microns, ambient temperature is 20°C).

Figure 5. The results of measuring the coefficient of friction depending on the ambient temperature (coating thickness is 10 microns).

Fig. 6 shows the results of measuring the adhesion of the developed composite antifriction coating depending on its thickness.

The measurements were carried out by the method of lattice notches using an adhesion meter RN in points.

Figure 6. The results of measuring the adhesion of the obtained composite antifriction coating depending on its thickness (base is steel 40X).

Based on the results obtained, it can be assumed that the developed composite antifriction coating modified with copper complex and fluoropolymer can be used in industry, and it has a low coefficient of friction, and also has good adhesion to the substrate.
Conclusions

1. A composite antifriction coating modified with copper complex and fluoropolymer has been developed.

2. Based on the results of the experiments and the obtained dependences, the structure of the composition was determined, the optimal conditions for obtaining a composite antifriction coating modified with copper complex and fluoropolymer were determined.

3. Tests of a composite antifriction coating modified with copper complex and fluoropolymer have been carried out. Thickness, coefficient of friction, adhesion was determined.

4. The developed composite antifriction coating modified with copper complex and fluoropolymer can be used to improve the operation of tribo assemblies in a wide temperature range.

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