Tribological behavior of magnetron sputtered nanocomposite coatings on base of Cu-Mo-S

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Abstract. Tribological properties of solid lubricant electrical conductive magnetron coatings based on the Cu-Mo-S system were studied. Wear resistance increasing and lubricating mechanisms of the coating during adhesive wear tests in inert atmosphere has been demonstrating.

1. Introduction
There is a wide variety of friction parts made of non-ferrous metals in modern engineering. A special feature of non-ferrous metal sliding is their high tendency to adhesive wear, i.e. to adhesion and transfer of metal during sliding [1, 2]. This problem is most relevant for sliding of components, which operates under vacuum or inert conditions. Various lubricants are used to reduce the adhesive interaction between the contacting surfaces during sliding. For lubrication of units operating in severe conditions of operation (such as high vacuum, space, high sliding speed, high loads and very low or high temperatures), where liquid lubricants cannot provide the required performance or durability, solid lubricants are used [3, 4]. To date, a large number of solid lubricant coatings have been developed and studied [5–9], but there are few reports of solid lubricants with high electrical conductivity, with the exception of graphite and systems based on it [10]. However, for effective lubrication, such systems require a humid ambient atmosphere [11], which is not possible for the operation of such components as current collectors in Earth remote sensing satellites.

This work is devoted to the study of the tribological properties of magnetron Cu-Mo-S coatings during sliding in an inert atmosphere.

2. Experimental part
Polished parallelepipeds of copper were used as experimental samples. Coatings based on the Cu–Mo–S system were deposited on the working surface of the samples using a magnetron equipped with a target, which contain copper and molybdenum disulfide. A pulse glow discharge from the magnetron was initiated using a 0.4 kW bipolar pulse power source and a frequency of 50 kHz and a pulse duty factor of 80%. The thickness of the deposited coatings was ~60 µm.

Wear tests were carried out in conjunction with a copper counterface in an argon atmosphere according to the “block-on-ring” test to create extreme conditions of adhesive wear. The relative
sliding velocity was 0.5 m/s with a force of pressure of the sample on the counterface 0.4 N. The surface morphology of the wear track surface was obtained by scanning electron microscopy (SEM) on the microscope LEO EVO 50XVP (ZEISS).

The electrical resistivity of the deposited coatings was measured by the four-point probe method. The coatings were deposited on a glass substrate. The cross section at the glass substrate with the coating was made after the measuring of current-voltage characteristic for measuring of coating thickness by SEM. The electrical resistivity of the coating \( \rho \) was calculated using the formula [12]:

\[
\rho = 4.53 \frac{U}{I} \cdot d, \tag{1}
\]

where \( I \) – is the current on external probes, \( U \) – the voltage on the internal probes, \( d \) – the coating thickness.

3. Results and discussion

Figure 1 shows the wear curve of a copper sample with a Cu–Mo–S coating under friction paired with a copper counterface in an argon atmosphere.

The curve in figure 1 is characteristic of fatigue wear and can be divided into 3 stages. For the first meters of run, a coating material with a mass of \( \sim 0.6 \) mg is transferred to the surface of the counterface. Further stage I proceeds (\( \sim 12 \) km). This stage is accompanied by low wear, and the amount of mass wear using weighing could not be determined. During stage I, fatigue stresses accumulate in the surface layer of the sample, caused by plastic deformation of the coating (figure 2). The deformation of the coating generates the initiation of microcracks in it, the combination of which causes the destruction of the material with the removal of wear debris.

From this point on, the stage of linear wear of the sample begins (stage II). The wear rate on this site is \( 6 \cdot 10^{-6} \text{ mm}^3/(\text{N} \cdot \text{m}) \). When separating the wear debris, the lubricating coating material is gradually taken out of the friction zone. The juvenile pitting areas adsorb the transfer film from the surface of the counterface, thereby "healing" themselves and causing a decrease in the thickness of the transfer film on the counterface. At that moment, when the destruction of the boundary layer of the coating material begins to prevail over its new formation, a gradual transition from fatigue to adhesive wear begins (stage III). After stage III, the boundary layers are completely destroyed, and the stage of adhesive wear begins.

The study of the wear scar morphology of Cu–Mo–S coating by SEM (figure 3) showed that the lubricating film on the sample surface is not a continuous smooth, but an “island” surface, the “islands” of which are small and relatively large (marked by circles) conglomerates of the coating material.
Figure 2. The deformed state of the Cu–Mo–S coating after a run of 1 km.

Figure 3. SEM image of the wear scar of the Cu–Mo–S coating after a run of 10 km.

It can be assumed that lubrication is carried out by sliding and moving from the sample surface to the counterface surface and back to discrete conglomerates, which formed from the coating material in sliding process.

4. Conclusions
The electrically conductive magnetron Cu–Mo–S coatings effectively provide lubrication of the copper friction pair during sliding in an argon atmosphere. Lubrication is carried out by moving from the sample to the counterface and back to discrete conglomerates formed in the friction zone from the material of the boundary layers of the coating. The coating significantly reduces the wear rate, which at the stage of steady wear is $6 \times 10^{-6} \ mm^3/(N \cdot m)$.
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