Wear resistance of composite electrochemical coatings containing polyepoxides

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Abstract. The expediency of polymer-metal coatings reinforced with polyepoxides use for increasing the wear resistance of machine parts is described. The composition and structure of composite coatings providing the highest wear resistance are presented in an optimized way.

1. Introduction

The application of composite electrochemical coatings (CECs) is a promising practice for restoring and increasing the wear resistance of machine parts [1-4]. The wear resistance and the antifriction properties are the most important characteristics that ensure the performance of coated machine parts. However, they are not sufficient in case of harsh operating conditions (i.e. the high values of specific pressure and the lack of lubrication).

An effective way to increase the wear resistance and the antifriction properties of CECs is to use dry lubricants (polymer powders, molybdenum disulfide) and the like as fillers. Their effect is similar to that of the selective transfer and is based on the formation of boundary lubricating films, whose effectiveness depends on the state of the surfaces [4-6]. However, the usage of such CECs by machine-building companies is limited by the lack of information on their production conditions and their properties.

Therefore, the aim of the work was to explore how the composition and conditions of production of polymer-metal composite electrochemical coatings (PMCECs) based on iron and its alloys influence their wear resistance and antifriction properties in case of their contact with various materials under harsh operating conditions.

2. Research Technique

Iron-based PMCECs samples containing polymer powders of polyamide PA12-10 (Industrial Standard 6-05-425-76) and polyepoxide composition P-EP-971 (Industrial Standard 6-05-425-76) were used in the studies.

Coatings were obtained from an iron electrolyte suspension (solution FeCl₂ * 4H₂O - 500 kg/m³) at current density (Dₖ) - 20 A/dm². Iron-nickel precipitations were obtained from the electrolyte...
composition, kg/m$^3$: FeCl$_2$*-4H$_2$O – 500; NiSO$_4$ – 7H$_2$O – 40, Na$_2$C$_4$H$_4$O$_6$ - 2 H$_2$O – 2, at current density (D$_k$) - 20 A/dm$^2$. Anodic treatment was carried out in an electrolyte: H$_2$SO$_4$ – 300-350 kg/m$^3$; FeCl$_2$*-4H$_2$O – 20-22 kg/m$^3$ [5].

To determine the wear resistance a SMC-1 friction machine was used. Experiments with the study of antifriction properties of PMCECs were performed according to the cone-ring sample scheme on a MAST-1 friction machine as soon as the preliminary running-in of friction pairs was carried out and as soon as the considerable wear rate was confirmed. The load range was

p = 0.1 ... 15 MPa. Under the conditions of boundary friction, paired parts were lubricated with M10G2, the oil, which was supplied in the form of drops after a certain time.

The testing process involved determining the friction moment, temperature and morphological structure of the friction surface, as well as the change in the surface microhardness. The microhardness of coatings was investigated with the help of a PMT-3 microhardness tester in accordance with GOST 9450-76. The time-frame of the procedure depended on how soon a considerable wear rate (J, mg) was obtained. To determine the wear coefficient, a gravimetric method with a determinate error of 0.05 mg was used. «Pure» iron–containing coatings and bronze-containing coatings such as OTsS 5-5-5 and AMCO 8-1 were used as models.

3. Results and discussion
The PMCECs obtained were high-quality and dense and had no layers and cracks (figure 1). The microstructure was characterized by a fairly equal distribution of the dispersed phase and by the absence of particles in the basic layers of the coating near the interface between the coating and the substrate. This is consistent with the current data and confirms the insignificant influence of the particles on the adhesion between the coating and the substrate [2].

![Figure 1. Structure of the iron-boron carbide composite (×250): a - iron-nickel - PA 12-10 (50 kg/m$^3$); b - iron-nickel - P-EP 971 (100 kg/m$^3$).](image)

Experiments with the study of the wear resistance of PMCECs containing polyepoxides have shown that the polymer dispersed phase (DP) improves the antifriction properties of coatings and enhances the ability to hold boundary lubricating layers up to a temperature of 240°C, which exceeds the oil flashpoint.

The friction coefficient of «the PMCEC – OTsS 5-5-5 bronze» pair was 20...30% less than that of «clean» coatings (figure 2). As far as friction with bronze was concerned, PMCECs with DP PA 12-10 (50 kg/m$^3$) showed the best antifriction properties.

The friction coefficient of «the PMCEC - AMCO alloy» pair was 15% less than in case of coatings containing no polymers. In this case, the best antifriction properties were found among coatings based on the iron-nickel alloy with the addition of P-EP-97.
Figure 2. Influence of the composition of the PMCEC and the heating temperature of the friction pair on the coefficient of friction with OTsS bronze (a) and AMCO alloy (b) at p=10Mpa.

Electrolytic iron and iron-nickel without fillers were connected with the aluminum alloy at a temperature of 200…220°C respectively. Thus, PMCECs were better wetted with oil and retained the lubricant better than coatings without particles. These properties led to a significant decrease in the wear rate of PMCECs as compared with the clean coatings used in the SMC machine at a sliding speed of 2,1 m/s (figure 3). The wear rate of the counter body (the rider) made of OTsS bronze and AMCO alloy also decreased.

The dependence of the wear rate on the composition of the ES is directly connected with a minimum point corresponding to the polymeric materials concentration equal to 40 ... 80 kg/m$^3$ (22...33% vol.) which was found in the ES. In case of friction with bronze, the wear resistance of the CEC with P-EP-974 was 2...7 times higher than that of pure coatings, and the wear resistance of the CEC with a PA of 12-10 was 2-3 times higher than that of pure coatings.
In case of friction with AMCO-alloy, the wear resistance of the CEC with P-EP-971 was almost similar to that of coatings containing polyamide PA 12-10. At the same time, the CEC with PA 12-10 caused more considerable wear of the counterbody as compared with the CEC with P-EP-971. With a load of 10 MPa, the wear resistance of the CEC is 1.5...2 times higher than that of coatings without additives.

Investigations of the dependence of the wear resistance of PMCECs on the load have shown that with an increase in the specific pressure, the wear rate of coatings initially decreased to 1.5...12.5 MPa, and then stabilized or even increased slightly (figure 4). Moreover, the minimum point in contact with AMCO was shifted (in contrast to OTsS bronze) towards greater loads (12.5...15 MPa).

The wear resistance of the aluminum counterbody paired with the PMCEC was slightly higher than that of the bronze counterbody. Analysis of the test results has shown that the wear resistance of bronze paired with the PMCEC is 2...7 times higher, in general, than in case of electrolytic iron as a friction pair element. The high wear resistance of polymer-metal coatings is explained by their better antifriction properties, high anti-seize and operating properties of the polymer component of the composite, as well as by increased hardness of the PMCEC, whose maximum point was 7...9 GPa and belonged to the concentration range corresponding to obtaining the most wear-resistant PMCECs.
Figure 4. Influence of loads on the wear rate of the PMCEC- OTsS (a), PMCEC -AMCO (b) mating in the oil bath (oil + silica sand, p=10 MPa, see the designation in figure 2).

Thus, the hardest PMCECs which suffer from less work-hardening during the friction process are less destroyed by friction. An increase in the amount of the polymer filler above the optimal level (over 32…35% (vol.)) leads to a slight decrease in the wear resistance of PMCECs due to the discontinuity of the matrix frame structure accompanied with the formation of direct contacts between particles. As a result, such «weakened» areas of the matrix are easier to disperse during friction under loading.

Investigations of the state of the friction surface of PMCECs have made it possible to establish that in the process of wear the DP particles form boundary films on the surface of the roller and the pad. These films prevent the contact with metal and the destruction of the micro-parts of the surface. The favourable effect of such boundary layers on the wear resistance of metals is noted in the research papers [5-6]. The lubricant, in its turn, prevents the surfaces from oxidating, and contributes to the formation and fixation of boundary films, creating favorable conditions for the transfer of polymer particles between the contacting bodies.
The emergence of the polymer on the friction surface occurs with the wear of coatings, as well as with thermal microextrusion due to the fact that the surface layers of coatings are heated during friction. Polymeric materials in comparison with metals have a significantly greater thermal expansion coefficient. Therefore, the probability of polymer microextrusion during the friction process is very high [6-8]. Particles-fixing points also serve as additional lubricant reservoirs on the working surface of the machine part. These lubricant reservoirs contribute to maintenance of the appropriate boundary friction mode.

4. Conclusion
The conditions for the production of PMCECs based on iron and its alloys with better wear-resistant and antifriction properties than those of "pure" coatings have been established.

It has been shown that polymeric additives breaching the surface are able to create boundary separating layers creating a positive gradient of physical and mechanical properties of the surface of paired parts and reducing the wear due to the transfer of film products from one rubbing surface to another, which contributes to a significant increase in the wear resistance of PMCECs.

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