Wear Resistance of Composite Coatings Based on Iron Alloys

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Abstract. The influence of the volume content of a solid dispersed phase on the coefficient of variation of the microhardness of composite electrochemical coatings is shown. A theoretical model of the description of the relationship between the volume content of a solid dispersed phase and the coefficient of variation of the micro-hardness is given.

1. Introduction
The deposition of iron-based composite electrochemical coatings (CECs) makes it possible to significantly expand the range of efficient application of the technology due to the considerable improvement in the quality and wear resistance of electrodeposited coatings [1–3]. The selection of an electrolyte for obtaining a CEC matrix and a filler is determined by the scope of the treated components and the conditions of their operation. White alumina micropowders are promising as CEC fillers. Meanwhile, iron-based alloys, which allow improving the physico-mechanical properties of CECs, are used as a binding agent [4, 5]. However, data on their operation capability in conditions of abrasive wear are scarce. It is impossible to find the relationship between the mechanical properties of coatings and the conditions of their obtaining on the basis of available data, which limits the possibilities to select a CEC matrix and to objectively judge the regularities of the behavior of remanufactured components in the course of their operation. At the same time, it has not been determined in a unique fashion which sizes and volume content of particles of the disperse phase (DP) in a coating provide the highest wear resistances of CECs in conditions of abrasive wear. To develop the operating procedure of the deposition of composite coatings on fast wearing components of agricultural equipment, it is necessary to study the influence of DP on the operation capability of CECs and to select the optimum conditions for obtaining of the most wear-resisting base.

Therefore, the aim of this work was to develop a method for the enhancement of the lifetime of fast wearing components of agricultural equipment by means of composite electrochemical coatings based on iron–nickel alloys.

2. Research technique
The iron–nickel coatings were obtained from an electrolyte of the following composition, kg/m³: 500FeCl₂ ·4H₂O; 100NiSO₄ ·7H₂O; 1.5Na₂H₄C₄O₆ ·2H₂O. The iron–cobalt deposits were obtained from the following electrolyte, kg/m³: FeCl₂ 4H₂O—500; CoSO₄ 7H₂O—100; Al₂(SO₄)₃ 18H₂O—80. The electrolysis modes were varied as follows: the electrolyte temperature T ranged from 30 to 80°C;
the current density $D$, from 13.4 to 46.8 A/dm$^2$; the solution pH, from 0.2 to 1.2. Studies of the steel preparation conditions and the determination of the possibilities to use literature recommendations concerning the anode treatment were carried out in the electrolyte: 300–350 kg/m$^3$ H$_2$SO$_4$ and 20–22 kg/m$^3$—FeCl$_2$ · 4H$_2$O [2]. The influence of the electrolysis parameters on the properties and abrasive wear resistance of the coatings was studied with the use of second-order central rotatable uniform planning at $k = 3$ [6].

The CEC samples were obtained from an iron–nickel electrolyte suspension (ES) containing white alumina DP (M2–M40 grades) in a special bath with a volume of 51 (figure 1).

![Figure 1. Bath with a concave bottom and a perforated baffle plate for deposition of CECs: (1) depicts the anode; (2) the cathode; (3) the thermometer; (4) the mixer; (5) the Venturi flow-rate meter; and (6) the contact heater.](image)

The velocity of the flow of the ES was set on the basis of the recommendations in [2]. The ES flow entered the working part of the bath through the perforated bottom damper. To measure the flow velocity in a separate section, a Venturi-type flow-rate meter with a differential gage was designed and installed. The powder content in the ES was varied from 25 to 150 kg/m$^3$.

The microhardness of the coatings was determined by means of a PMT-3 microhardness gage according to the State Standard GOST 9450-76. The abrasion tests for friction using loose abrasive particles were carried out according to GOST 23.208-79 by means of an ad hoc laboratory installation (figure 2).

![Figure 2. Diagram of the installation for the abrasion resistance testing of the samples: (1) is the rubber roller; (2) the sample; (3) the support; and (4) the abrasive material.](image)

Electrochemical coatings with a thickness of 0.5±0.1 mm were deposited on plates of steel St3 (with a length of 30 mm, a width of 30 mm, and a thickness of 1 mm). The force of the pressing of a sample to the rubber roller $P$ ranged from 20 to 88 N; the roller revolutions varied from 60 to 325 r/min, which corresponds to the variation of the relative sliding velocity $V_{rel}$ from to 0.9 m/s. The time of the tests was governed by the necessity to obtain an appreciable value of the wear $J$ (mg), which was
measured by the weight method to a precision of 0.05 mg.

As an abrasive material, we used fluvial sand with a grain size of no more than 1 mm. The comparison standards were samples of quenched steel 65G, which is most commonly used for the production of cutting units of tillage equipment; “pure” iron–nickel; and iron–cobalt coatings.

3. Results and discussion

The studies showed that the abrasive wear resistance of the iron–nickel base in realistic conditions depends on the electrolysis parameters. By the regression analysis of factorial experiments, we obtained an empirical relation adequately describing the dependence of the wear of the electrolytic alloys on the electrolysis parameters. After the suppression of the insignificant coefficients, the equation took the following form (X₁ is the temperature, °C; X₂ is the current density, A/dm²; and X₃ is the solution pH): 

$$J_{Fe-Ni} = 8.8 + 0.95X_1 - 0.6X_3 + 0.69X_2^3 + 0.5X_3X_2 + 0.94X_1X_3 + 0.66X_3$$

A decrease in the temperature led to an increase in the wear resistance of the coatings; the optimum value of the solution’s pH is at the center of the experiment’s design (Figs. 3). As the current density grew, the wear of the alloys increased and passed through maximum at 35–40 A/dm² (figure 3). Thus, the optimum mode of obtaining of wear-resistant deposits free from inclusions is as follows: the solution pH = 0.7–1.0; D = 35–40 A/dm²; T = 40–45°C. The adherence to the recommended conditions for the deposition of the alloys allows obtaining deposits with their wear resistance being higher by a factor of 1.5–2 than that of the steel of a commercial plough [7].

![Figure 3. Influence of the electrolysis modes on the microhardness (1) and wear (2).](image)

The study of the influence of the content and size of the DP on the wear of the coatings revealed that the solid particles of white alumina allow enhancing the wear resistance of the CECs under abrasive wear by a factor of 4–5 as compared to “pure” iron-nickel coatings and by a factor of 8–10 as compared to quenched steel 65G. The highest wear resistance is found in the CECs with the volume content of the DP up to 26–28 vol % deposited from an ES containing micropowder of M14 aluminum oxide.
in an amount of 80–90 kg/m³ (figure 4).

In the conditions of the operation of the working parts of tillage equipment, the wear takes place most often as a result of repeated plastic deformation-redeformation of the material’s surface microvolumes by rolling abrasive grains. It is known that a variation in the sliding velocity and the force of pressing of the rubbing surfaces leads to a change in the mode of interaction between the rubbing surface and the abrasive material from the particles rolling to sliding and microcutting [8].

The analysis of the test results showed that an increase in the load and the relative sliding velocity of the friction pair led to an increase in the wear rate \( I \) (mg/min) of the standards and samples coated with the CECs (figure 5).

In addition, the wear of the samples with iron–nickel coatings and the standard of the quenched steel 65G was more severe than that of the CECs. The wear rate of the composite increased linearly with the load, remaining less by a factor of 4 than that of the coatings without the DP and by a factor of 8 than the standard of the quenched steel 65G. The strongest influence on the wear resistance of the CECs was exerted by the relative sliding velocity; as it increased from 0.3 to 0.9 m/s, the wear varied by a factor of 1.5. At \( V_{rel} = 0.9 \) m/s, it was higher than the standard of the quenched steel 65G by a factor of 12.

The high wear resistance of the CECs upon the stiffening of the operation conditions can be explained by the circumstance that, in the conditions of the combined wearing-out processes, the solid phase exhibits a considerable resistance to deformations and wear as well as by the fact that, with the particle inclusion, the strength of the binding material increases, although the level of its internal stresses remains relatively high. An increase in the load and the sliding velocity results in an increase in the
component of the microcutting and edging of the coating surface by the abrasive particles. The filler particles play the role of contact patches and barriers at the direct destruction of the surface; they distribute the stresses and shift the process of destruction to a polydeformation one. This circumstance leads to a significant increase in the relative wear resistance of the CECs in comparison with coatings without DP.

The field service tests of the plough shares reinforced with CECs showed that their wear resistance is higher by a factor of 1.5-2 than that of commercial plough shares [7]. The iron-nickel and iron–cobalt coatings, as well as the CECs on their basis, exhibited high efficiency in the reconditioning and enhancement of the wear resistance of excavator teeth, hydraulic control valve spools, K-700 friction plates, wrist pins, and lifter bodies of 10D100 and D50 Diesel engines.

4. Conclusions
The conditions of obtaining of CECs based on iron alloys with inclusion of white alumina as a filler, which exhibit high wear resistance in conditions of abrasive wear, were found. The introduction of solid particles of M14 grade in a solution of 80–90 kg/m³ (in a coating of 26–28 vol %) into alloys of electrolytic iron allows increasing their abrasive wear resistance by a factor of 8–10 in comparison with quenched steel alloys and by a factor of 4–5 in comparison with coatings without DP.

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