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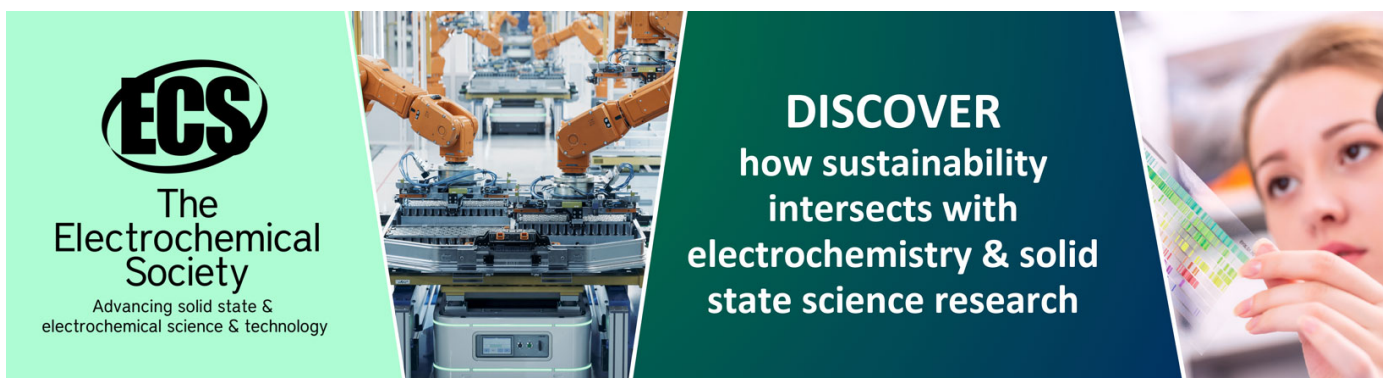
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Electroexplosive electrical erosion resistant coatings of the Ag-W system used for electrical contacts of power mine equipment

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Abstract. In this paper the coatings of the Ag-W system obtained by electroexplosive coating on copper electrical contacts of power mine equipment were studied. The modes of deposition and sample weights of silver and tungsten powders were chosen, metallographic research by the methods of light and atomic force microscopy, microhardness tests were carried out. The results of the tests show that the copper electrical contacts of KPV-604 controller have increased values of microhardness and are characterized by a submicrocrystalline structure based on tungsten and silver. The optimum mode of electroexplosive deposition is established at a voltage value 2.5 kV. In this mode, the coating layer has the greatest average microhardness value, in comparison with other investigated regimes. This value is 457.5 ± 55.2 HV, which is 3.8 times higher than the average value of microhardness in the copper substrate. The analysis of the thin section roughness showed that the average roughness value of the coating is greater than the average roughness values of the substrate and the layer with the altered state by 50.015 nm and 22.849 nm, respectively. The coating of the Ag-W system on the copper contacts improves their mechanical and physical properties. The studied treatment modes make it possible to increase significantly the microhardness of the surface contact layer, as well as to increase their electroerosion resistance due to the presence of tungsten particles in the coating, and to maintain the necessary electrical conductivity, facilitated by the presence of silver.

1. Introduction

Many metal contacts are exposed to electrical erosion, that is, the destruction of a conductive material under the influence of electrical discharges. It is well known that the magnitude of erosion failure decreases with the increase in the melting temperature of the material [1]. The application of coatings from refractory materials on contacts makes it possible to protect them from electrical erosion alongside with the preservation of electrical conductivity, thereby extend the products life cycle [2-4].

At present, scientists use different methods of coating by concentrated energy flows: deposition of galvanic coatings, gas-thermal method, method of electron-beam evaporation–condensation in vacuum, method of applying protective coatings by plasma spraying, ion-plasma coating methods, etc.

Electroexplosive deposition plays an important role in the modern development of methods for the formation of protective coatings. Electroexplosive deposition is a method of applying hardening coatings from electric explosion products of foil and powder samples to the materials surface. This method makes it possible to obtain a modified material with increased strength, durometric and



tribological properties on a metallic substrate, as it was noted in [5-10]. Hardening is achieved due to the formation of coatings with the formation of finely dispersed phases in a viscous metal matrix [5].

Thus, the aim of this paper is to study coatings of the Ag-W system obtained by means of electrospray deposition on copper contacts.

2. Materials and methods of research

In this study, composite coatings of the Ag-W system were applied to a copper substrate (KPV-604 contacts) by the method of electroexplosive deposition on the electric explosive device EVU 60/10 (Siberian State Industrial University, Novokuznetsk). The electric explosion unit has the following plasma parameters formed during the electrical explosion of a silver foil with a sample weight of tungsten powder: the plasma action time is $\sim 100 \mu\text{s}$, the absorbed power density at the jet axis is $\sim 8.2 \text{ GW/m}^2$, the pressure in the shock-compressed layer near the surface is $\sim 18.8 \text{ MPa}$.

An end scheme of explosion was applied [5], in order to increase the intensity of the thermal action on the material surface prior to its melting and to provide the conditions for the deposition. A silver foil with weight 0.2463 g was clamped between coaxial electrodes, to which a regulated voltage was applied via a vacuum discharger. The silver foil was filled with a tungsten powder with weight of 0.434 g. The coatings are applied in the conditions of thermal action, which causes the heating of the substrate surface up to the melting point under in three energy modes, different in the values of the absorbing power density at the coaxial electrodes: $U_1 = 2.4 \text{ kV}$, $U_2 = 2.5 \text{ kV}$, $U_3 = 2.6 \text{ kV}$. When the capacitive accumulator is discharged, the peripheral region of the foil adjacent to the external electrode-nozzle becomes the source of the condensed phase of the explosion products, and the foil section above the central electrode, where the tungsten powder is filled, acts as a source of ionized vapour [10].

After the electric-explosive spraying, the samples obtained under different conditions were examined for microhardness by the Vickers method (microhardness meter HVS-1000A). The load was constant for all modes and was 0.05 HV.

The study of the structure of straight thin sections was carried out on the metallographic microscope Olympus GX-51. The study of the coating porosity and the zone of thermal effect of the samples was performed on the atomic force microscope NT-MDT Solver "NEXT".

With the help of Image Analysis 3.5 software built onto the software interface of the atomic force microscope, the analysis of the coating roughness, the layer with the changed state and the substrate material (copper) was performed, the distribution of the surface relief height of the straight thin section depending on the distance was studied.

3. Results and discussion

When analyzing the structure on the metallographic cross-sectional microscope of all three samples, the formation of a multilayer structure is revealed, which consists of a low-porosity coating, slightly varying thickness, a liquid-phase alloying layer, and a heat-effected layer (figure 1). The coating thickness equals to $49.04 \pm 0.7 \mu\text{m}$ for mode 1, $68.5 \pm 0.9 \mu\text{m}$ for mode 2 and $61.26 \pm 0.6 \mu\text{m}$ for mode 3. Coating thickness is measured using the vertical secant method.

Coatings in modes 2 and 3 were more uniform in width than in mode 1, which can be explained by the higher temperature of the jet and, therefore, the rate of coating diffusion to cooling was higher.

It can be seen from figure 1 that in the first treatment mode, pores of 3 to 30 μm in size are present in the coating. In treatment mode 2, the pore size decreases compared to mode 1. The average pore size in the second mode is 16 μm . In the third treatment mode, the average pore size is 8 μm . Thus, as the absorbing power density increases, the average pore size in the coating of the Ag-W system decreases.

The average value of the layer thickness with the changed state between the coating and the substrate is 14 μm for mode 1, 18.5 μm for mode 2 and 20 μm for mode 3. The width of the layer of the changed state between the substrate and the coating increases as the values of the absorbing power density on the coaxial electrodes increases as well.

The analysis of the transition layer between the coating and the substrate (figure 2) showed that the boundary is not even. A zone of mutual mixing of the coating with the substrate is formed.

Analyzing the data of the comparative histogram (figure 3), it can be concluded that the processing mode 2 has the maximum average microhardness of the coating layer, in comparison with other investigated modes. It is 457.5 ± 55.2 . In the substrate the microhardness values are smaller than in the coating layer and are 119.4 ± 2.5 HV and 122.0 ± 3.3 HV at a distance of 5 and 40 μm from the coating, respectively.

It is also important to note that the average microhardness at a distance of 5 μm from the coating for all treatment modes is less than the average microhardness at 40 μm from the coating. It is possible to make an assumption that the reason for this is the heat effect, which is realized when the coating of the Ag-W system is applied by the electroexplosive deposition method [11].

The final stage of the complex study of the regularities in the formation of electroexplosive electroerosion-resistant coatings of the Ag-W system was the atomic force microscopy of the coating obtained in the optimal exposure mode (mode 2). The topography of the sample direct thin section, treated in accordance with mode 2, is shown in figure 4.

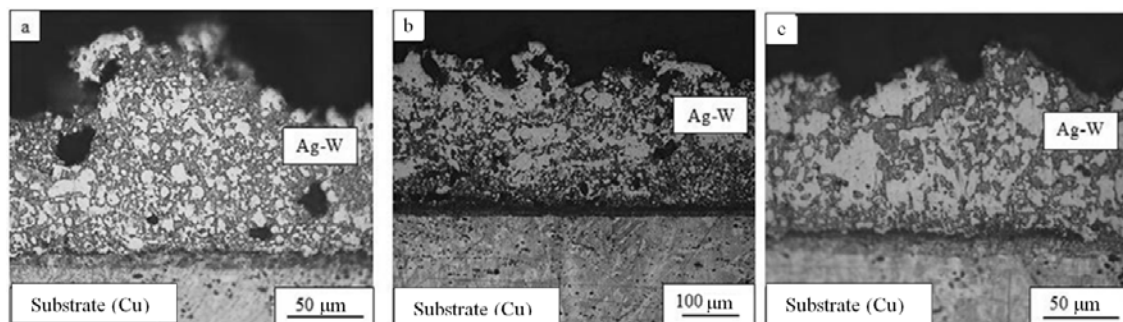


Figure 1. The structure of the cross-sections of the electroexplosive coatings of the Ag-W-Cu system obtained in various treatment modes (a – mode 1, b – mode 2, c – mode 3).

The atomic-force image made it possible to establish that the application of coatings of the Ag-W system on the copper contact by the method of electroexplosive deposition in the optimal treatment mode leads to the formation of a structure consisting of a coating, a layer of changed state and a substrate material. The average thickness value of the layer with the changed state located between the coating and the substrate is 16 μm , which correlates with the data obtained in the metallographic analysis.

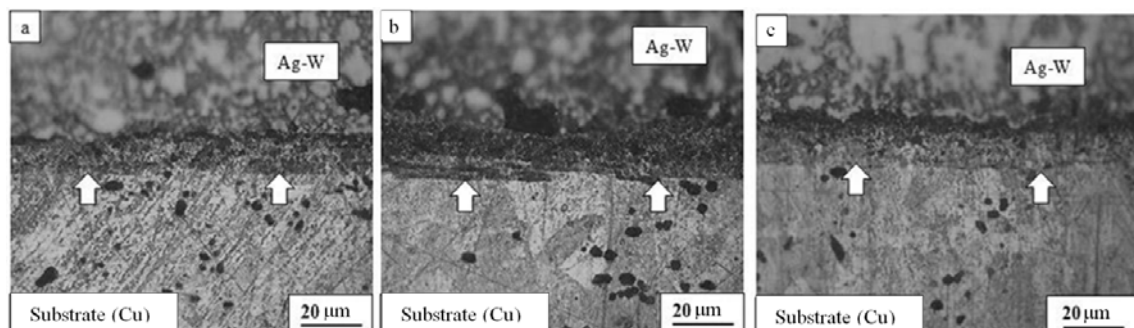


Figure 2. The structure of electroexplosive coatings cross-sections of the Ag-W-Cu system at the coating boundary with the substrate, obtained in different treatment modes (a – mode 1, b – mode 2, c – mode 3). The arrows indicate the areas of mutual mixing of the coating with the substrate.

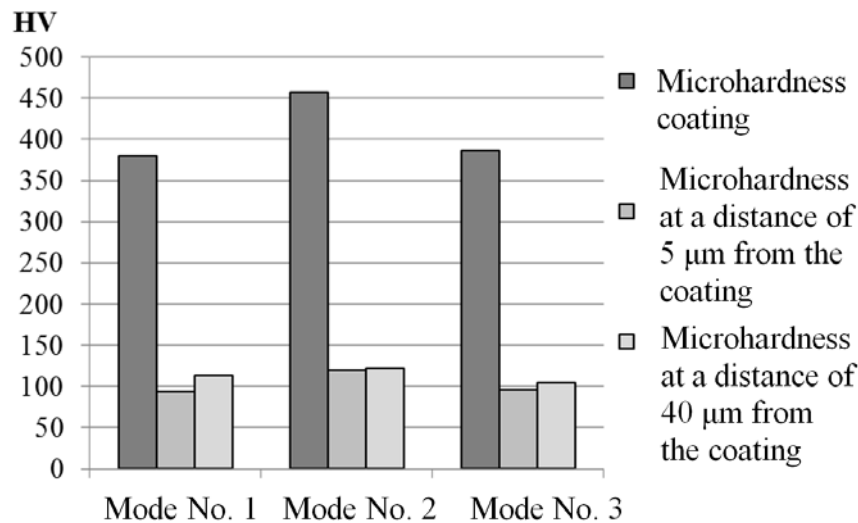


Figure 3. The comparative histogram of coating microhardness of the Ag-W system obtained in different modes of KPV-604 copper contacts treatment.

The analysis of the presented in figure 5 distribution graph of the surface height Z from the distance X (the original image is given in figure 4) shows that the height of the coating profile is higher than the height of the substrate, as well as the layer with the changed state. The greatest value of relief height is achieved at 40 microns (figure 4). The average height at this point is 661.5 nm – this

point corresponds to the boundary of transition from the layer with the changed state to the coating layer.

The study of the coating roughness, the layer with the changed state, and the substrate material (copper) in mode 2 revealed the following roughness values:

1. The average substrate roughness is 25.397 nm.

2. The average roughness value of the layer with the changed state is 52.563 nm.

3. The average coating roughness is 75.412 nm.

Thus, the analysis of the atomic force image showed that the average roughness value of the coating is larger than the average roughness values of the substrate and the layer with the changed state by 50.015 and 22.849 nm, respectively.

The study of the distribution of the surface relief height depending on the distance is shown in figure 5.

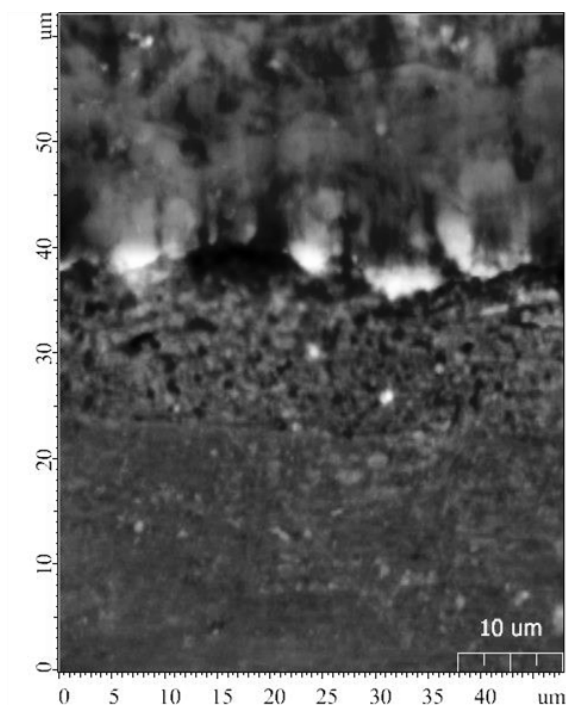


Figure 4. Atomic force microscopy of the surface profile of the Ag-W coating system deposited on the copper contact (mode 2).

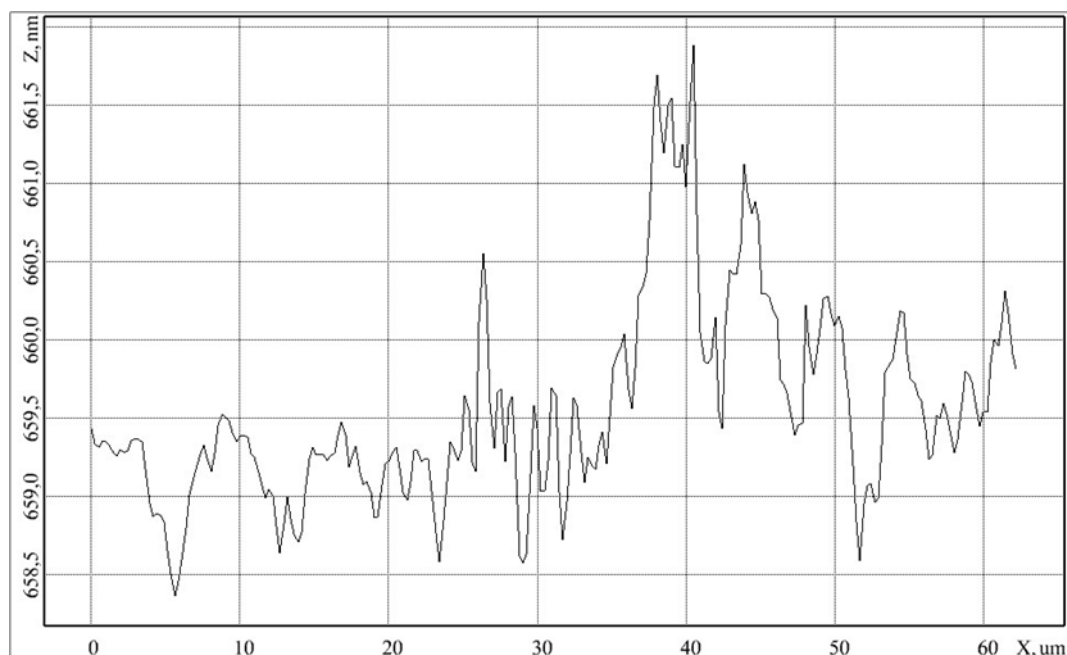


Figure 5. Distribution of the surface relief height depending on the distance (mode 2).

4. Conclusions

In the present research devoted to the investigation of electroexplosive coatings of the Ag-W system formed on copper contacts KPV-604, the modes of deposition and the sample weights of Ag-W powder were chosen, coatings were applied by electroexplosive deposition on copper contacts in various modes, metallographic studies for microhardness were carried out and atomic force microscopy of the coatings obtained.

The results of microindentation made it possible to reveal the optimum deposition mode ($U_2 = 2.5$ kV), in which the coating layer has the greatest average microhardness value in comparison with other investigated modes. This value is 457.5 ± 55.2 HV, which is 3.8 times higher than the average value of microhardness in the copper substrate.

The analysis of the thin section roughness in Mode 2 showed that the average roughness value of the coating is greater than the average roughness values of the substrate and the layer with the changed state by 50.015 nm and 22.849 nm, respectively.

Thus, coating of the Ag-W system on copper contacts improves their mechanical and physical properties. The treatment modes studied can significantly increase the microhardness of the surface contact layer, as well as increase their electroerosion resistance due to the presence of tungsten particles in the coating, and also maintain the necessary electrical conductivity due to the presence of silver particles.

The results of the study show that coatings of the Ag-W system obtained on copper contacts can be recommended for use in design developments aimed at reduction of contacts electroerosion and extension of their service life.

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