Features of treatment of metal surface layers by pulsed plasma jets formed during electrical explosion of conductors

E A Budovskikh, L P Bashchenko and S V Raykov
Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
E-mail: budovskikh@mail.ru

Abstract. The results analysis of the experimental studies obtained by the methods of modern physical materials science of metals and alloys surface layers after electroexplosive alloying and coating is presented.

1. Introduction
One of the promising methods of surface treatment that have been developed in recent years is electric explosive alloying (EEA) and electric explosive coating (EEC) [1 – 3].

2. Technological processes of surface alloying and coating
The diagram of the realized technological processes of surface treatment on EVU 60/10 installation is shown in figure 1 (here \( q \) is the power density absorbed by the surface during processing and determined by the charge energy; \( m \) is the mass of the exploding conductor and powder sample placed in the explosion zone). Coating with powder particles is possible, coatings with condensed explosion products, application of thin films from explosion products, and hardening from a solid state are possible in the first zone, when the absorbed power density is \( 10^3 \) W/cm\(^2\), depending on the mass of the exploding conductor. The mass of the exploding conductor of approximately 100 mg provides coating by powder particles. Reduction in the mass up to values 10 mg provides coating with condensed explosion products. With a further decrease in the mass of the exploding conductor, the content and dispersion of the condensed particles of the explosion products in the jet decreases. In this case, it is possible to deposit thin films on the irradiated surface. For small values of the mass of the exploded conductor, a positive treatment effect is also achieved due to the pulsed hardening of the surface layers from a solid state. In the second zone, where the absorbed power density is approximately \( 10^5 \) W/cm\(^2\), treatment with powder coatings makes it possible to conduct reinforcement of the melted surface layers with particles of various substances (carbides, oxides, borides, etc.) placed in the explosion zone and transferred to the irradiated surface.

In the case when powder samples are not used, it is possible to carry out such type of EEA in which the melt formed on the surface is saturated with the products of the explosion of conductors, the material of which can be, for example, thin foils of metals and alloys, carbon and other fibers.

Prospects for further scientific research and practical development in the field of EEA and EEC are associated with the electric explosive formation of new structural phase states on the surface of metals and alloys using heat-sensitive components. For example, in the case of electroexplosive titanium and nickel plating of the aluminum substrate, despite the pulsed character of processing with a duration of 100 \( \mu \)m, surface layers 150–200 \( \mu \)m thick are formed.
Figure 1. Diagram of technological processes of surface alloying and protective coatings application using multiphase plasma jets implemented on an EVU 60/10 installation.

This is due to the fact that during the interaction of the components, in addition to heat release, their active convective mixing occurs. It is in particular proved by the structural features near the interface between the substrate and the surface layer formed during EEA (figure 2). The acceleration of the interaction processes of alloying elements with the substrate material due to heat generation and convective mixing is accompanied by the synthesis of hardening phases (figure 3).

Figure 2. The image of the interface structural features of electric explosive titanium-plating zone of aluminum substrate. Light microscopy, × 1000.
3. The results and consideration of issues on electroexplosive carburization and titanium carboboronation

Electroexplosive carburization and titanium carboboronation make it possible to obtain modified surface layers with a thickness up to 30 μm [4]. During EEC, coatings with a thickness of 200–250 μm are formed on the surface of a titanium substrate using a composite electric conductor consisting of titanium foil, carbon fibers, and amorphous boron powder, containing titanium carbide particles synthesized during the spraying process and uniformly distributed over the layer depth. In this case, the interface between the coating and the substrate is even, while the coating has a metallurgical bond with the substrate. It can be seen (figure 4) that the particles of the main phase have a dendritic morphology. The first-order axes reach a length of 10–20 μm. Axes of the second order are weakly expressed. Fine particles with characteristic sizes of several micrometers are observed between the axes.

Figure 3. The surface diffraction pattern of electroexplosive nickel-plating zone of aluminum substrate.

Figure 4. Features of the crystallization structure of the Ti–C–B coating systems.
Light microscopy, × 200.
The phase composition of the coating is formed mainly by two phases – titanium carbide TiC and titanium diboride TiB₂ (figure 5).

![Diffraction pattern of the Ti–C–B coating system.](image)

**Figure 5.** Diffraction pattern of the Ti–C–B coating system.

![Structural features of electroexplosive coatings of the Ti – B system.](image)

**Figure 6.** Structural features of electroexplosive coatings of the Ti – B system. Scanning electron microscopy.

During EEC on the titanium substrate using a composite electric conductor consisting of titanium foil and amorphous boron powder, coatings are formed mainly hardened by particles of titanium diboride TiB₂ (figures 6 and 7). In this case, the particles of the strengthening phases located in the viscous metal matrix have predominantly equiaxial morphology with characteristic sizes of 1-3 μm.
4. Conclusion

The most promising directions for the practical use of EEA and EEC are the following:

1. Hardening of cutting and stamping metalworking tools (drills, cutters, punches, dies, etc.).
2. Hardening of drawing, drilling and mining cutting tools from tungsten carbide hard alloys.
3. Surface protection of the copper electrical contacts from electroerosive destruction. Currently, more than a dozen types of coatings have been developed for the W – Cu, Mo – Cu, TiB\(_2\) – Cu, W – C – Cu and Mo – C – Cu systems. The maximum surface area to be treated is 30 cm\(^2\).
4. Improvement of the wear and heat resistance of titanium alloys with various types of alloying.

When choosing the nomenclature of parts and tools for treatment, it is necessary to take into account, first of all, the size and shape of the hardened surface. Best results are achieved on flat surfaces with a diameter up to 30 mm.

References

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