ELECTRO-EXPLOSIVE DOPING OF VT6 TITANIUM ALLOY SURFACE BY BORON CARBIDE

T Yu Kobzareva[1], V E Gromov[1], Yu F Ivanov[2], E A Budovskkh[1] and S V Konovalov[1]

[1] Department of Physics n.a. Prof. V.M. Finkel, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
[2] Institute of High Current Electronics, Siberian Brunch of the Russian Academy of Sciences, 2/3 Akademichesky Ave, Tomsk, 634055, Russia

E-mail: gromov@physics.sibsiu.ru

Abstract. The studies carried out in this work target detection of changes in the surface layer of titanium alloy VT6 after electro-explosive alloying (EEA) by boron carbide. EEA of VT6 titanium alloy surface is the plasma alloying formed during the electric explosion of foil with the sample powder of boron carbide. Carbon fibers with weight 140 mg were used as an explosive conductor. Sample powder of boron carbide B4C was placed in the area of explosion on the carbon fibers. It was revealed that EEA of the surface layers of titanium alloy samples VT6 leads to the modification of the layer, thickness of which changes from 10 µm to 50 µm. Heterogeneous distribution of alloying elements was found in the treatment zone by the methods of X-ray microanalysis. A significant difference in their concentration in the identified layers leads to difference in their structural and tribological behaviour. It was revealed that after electro-explosive alloying the microhardness of titanium alloy VT6 significantly increases. Electro-explosive alloying leads to the formation of a structure of submicro- and nano-scale level. It allows strength and tribological properties of the treated surface to be increased.

1. Introduction

Nowadays, titanium and its alloys is one of the advanced structural metals. More than one hundred types of titanium alloys are known. However, only about 30% of titanium alloys have found their practical application in different areas: aviation, rocket engineering, shipbuilding, chemical and medicine industries [1-3].

Titanium and its alloys are characterized by absence of coldbrittleness, high plasticity, durability and corrosion resistance, especially in oxidizing and chlorinated mediums and they also have high antifriction properties [4]. Beyond that point these materials have low wear resistance, high tendency to sticking, high index of friction in pair with most materials [5]. The listed disadvantages of titanium alloys limit their usage in the manufacture of details exposed to friction.

To improve the surface properties of the products from titanium and its alloys and to protect them from the external influences (temperature, pressure, corrosion, erosion, etc.), different coatings are applied [6-10]. Coatings application solves two important problems: change in the original physical

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and chemical properties of the treated surface, as well as the restoration of properties, sizes, mass of the influence surface under operation conditions.

One of the advanced methods of modification of the metals and alloys surface is the method of electro-explosive alloying (EEA), in which the surface is influenced by the pulsed plasma jets formed during the discharge of capacitive energy storage through the conductive material. Working medium of the plasma accelerator serves for heating and alloying of the material surface layer [11]. The main advantage of EEA over analogues methods of surface treatment is that any conducting material (thin foils of metals and alloys, graphitized carbon fibers and other fibers) can be used as a plasma forming substance.

Powder weights of different substances can be placed into the explosion area. They are carried by the formed jet to the irradiated surface partially transformed into the plasma state [12]. Thus, EEA allows the melting of the surface layer of the component, liquid-phase alloying by the products of conductors explosion with the subsequent self-hardening to be conducted in a single technological cycle. Industrial discharge-pulse installations having constructive simplicity, high reliability and relatively low cost can be used for implementation of EEA technology.

The aim of this research is to analyze the structural conditions of the modified layer, formed by the methods of electro-explosive alloying.

2. Materials and methods

The alloy based on VT6 titanium was used as a material for research. The chemical composition of the alloy corresponded to State Standard 19807-91.

The treatment of the surface layer was carried out by the methods of electro-explosive alloying [14]. Carbon fibers with weight 140 mg, were used as an explosive conductor. Sample powder of boron carbide B4C with weight 496 mg was placed into the area of explosion.

Electro-explosive laboratory-scale plant of EVU 60/10 type with the following characteristics was used for electro-explosive alloying: absorbed power density during the treatment of material surface ~109 W/m2, pressure in the shock-compressed layer of plasma near the irradiated area 106–107 Pa, processing time ~100 μs.

Conditions for a pulse liquid-phase alloying were set by the value of charge voltage of the accelerator energy storage, diameter of nozzle channel and the distance from its exit to the sample. Formation of the plasma flow was carried out at U=2.4 kV [11, 15].

The studies of the modified material structure were carried out by the methods of scanning electron microscopy. The elemental composition of the surface layer was analyzed by X-ray microanalysis. Microhardness of structural elements was carried out by Vickers method on the unit HV-1000A at the load 1 N. [16].

3. Results and discussion

After electro-explosive alloying of the surface of titanium alloy VT6 by boron carbide, a highly developed relief is formed, that includes lappings, drops, craters, and various surface defects – microcracks, micropores. Typical images of the surface structure after treatment are given in Figure 1. The scale of the structure elements of surface alloying is varied in a very wide range – from hundreds of micrometers (Figure 1a) up to tens-hundreds of nanometers (Figure 1b, c).

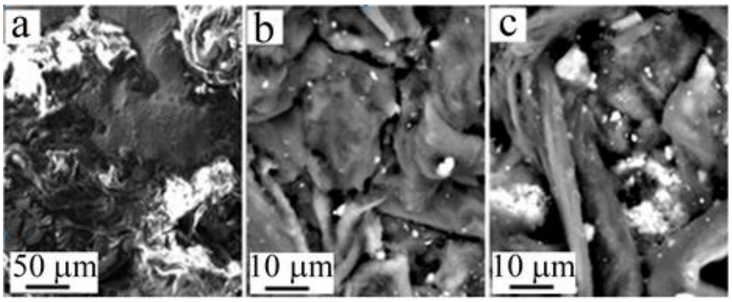

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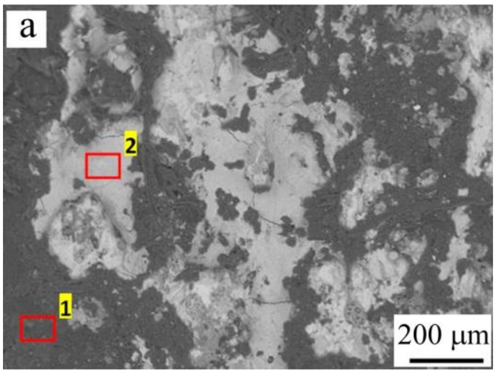
Figure 1. Surface structure of titanium alloy VT6 after electro-explosive alloying by boron carbide.



Element	Spectra, at. %	
	1	2
B	7.51	5.03
C	73.87	7.97
O	18.55	22.99
Ti	0.07	59.29
Al	0.0	2.82
V	0.0	1.9

Figure 2. X-ray microanalysis of titanium alloy VT6 surface after EEA by boron carbide. a – surface structure of titanium alloy VT6; b – energy spectrum obtained from area No. 2. The results of X-ray microanalysis of the areas, indicated in (a), are given in the table.

A heterogeneous distribution of alloying elements is observed in the layer of treatment. At a qualitative level it is confirmed by studies of the alloying surface in the back scattered electrons. Black-and-white contrast in Figure 2a proves the formation of areas enriched by the heavy element (titanium) and relatively light elements (carbon and boron). Quantitative analysis of alloying elements distribution on the alloyed surface was carried out by methods of X-ray microanalysis due to differences in elemental composition of different areas.

Analyzing the results from the table located in Figure 2, it may be noted that heterogeneity coefficient of alloying elements distribution in the surface layer (ratio of the total amount of boron, carbon and oxygen in the light and dark areas) reaches 2.8. Thus, electro-explosive alloying of titanium by boron carbide powder leads to the formation of volumes in the surface layer, in which the concentration of alloying elements differ by more than 2.5 times.

After the treatment, the high level of structural heterogeneity of the modified layer over its thickness and the distribution of alloying elements is observed. More clearly it can be seen while studying the structure of cross-sections. Because of the highly developed relief of the surface the total thickness of the alloyed layer varies from 10 μm to 50 μm (Figure 3).

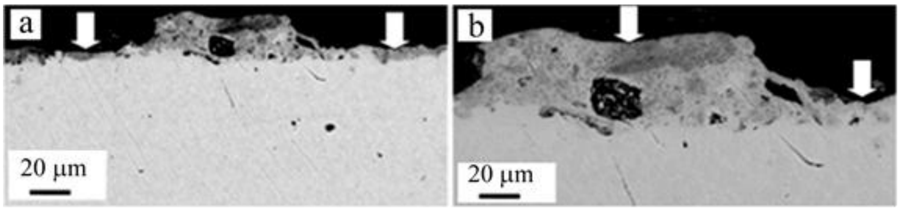


Figure 3. Surface structure of titanium alloy VT6 after EEA. a, b – structure of the cross-section. The EEA surface is indicated by the arrows.

Based on the morphological feature (degree of etchability) it is possible to distinguish at least four layers in the alloyed volume: surface layer (Figure 4, layer 1), intermediate layer (Figure 4, layer 2), transition layer (Figure 4, layer 3), and a layer of thermal influence, smoothly transforming into the bulk of the sample.

It should be noted, that the difference in the degree of etchability is observed not only between the layers but within each layer (Figure 4b). The identified layers are characterized by the substructure, in which the elements sizes vary within 1 μm (Figure 4c, d). Surface and intermediate layers predominantly are of acicular structure. Round shaped areas, differed from the surrounding volume of material in structure and composition are found in the alloyed layer (Figure 4, 5).

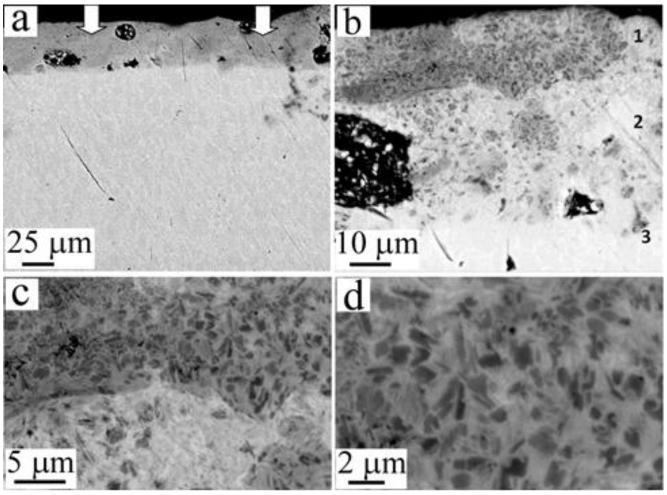
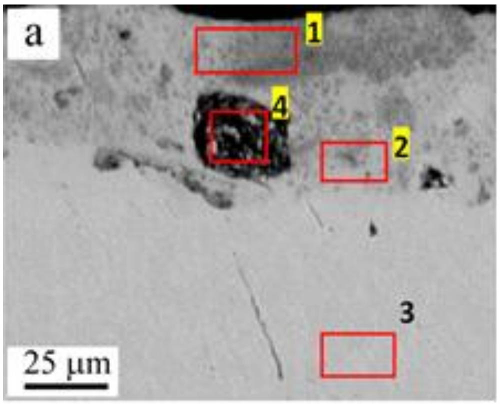


Figure 4. Cross-section structure of titanium alloy VT6 exposed to EEA by boron carbide. a – structure of the cross-section. The EEA surface is indicated by the arrows; b – identified layers. Layers are indicated by figures: 1 – surface layer; 2 – intermediate layer; 3 – transition layer; c – substructure of the surface and intermediate layers; d – substructure of the surface layer.

Different degree of layers etchability shows their difference in phase and elemental composition. The example of the elemental composition analysis of the alloyed layer is given in Figure 5.



Element	Spectra, at. %			
	1	2	3	4
B	40.75	10.28	0.0	0.0
C	13.22	10.42	4.77	49.93
O	0.0	0.0	0.0	24.29
Si	0.0	0.0	0.0	5.3
Al	3.62	5.1	9.97	1.61
Ti	42.40	57.11	88.28	17.88
V	1.55	1.9	3.02	0.75

Figure 5. The X-ray microanalysis of the cross-section of titanium alloy VT6 after EEA by boron carbide. The table contains the results of X-ray microanalysis of the areas indicated in a (a – surface structure of titanium alloy VT6; b – energy spectrum obtained from area No. 1).

Analyzing the results from the table in Figure 4, a definite pattern in the distribution of alloying elements (carbon and boron) can be revealed. Namely, as the distance from the alloying surface increases (spectra 1-3) the concentration of boron and carbon atoms is reduced. In some cases, round shaped areas (Figure 4, section 4) are found in the alloyed layer, which significantly differs from the surrounding volume of material in structure and elemental composition. The main elements of these areas are carbon, oxygen and silicon (Figure 4, table, spectrum 4).

After EEA with the use of powder sample of TiB2 two layers can be identified (Figure 6) in the microhardness distribution in the depth of the alloying area. The thickness of the surface layer is 20-25 µm and of the transition layer is up to 20 µm. Increase in the weight of B4C powder sample by 8 times leads to the increase of microhardness in the surface layer from 850 to 2400 HV, i.e. by 2.8 times.

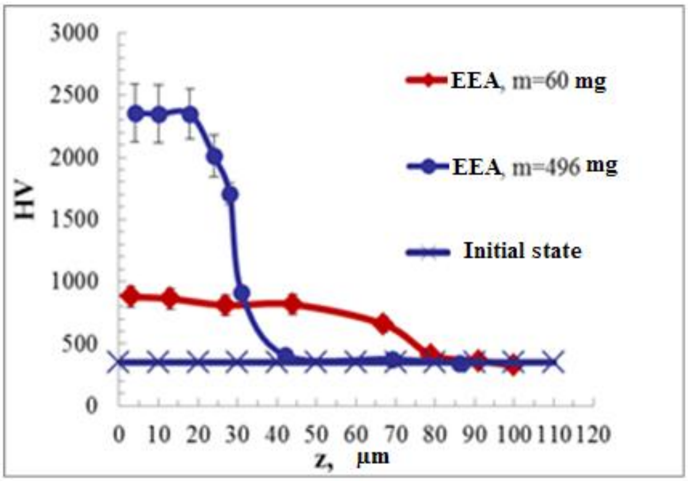


Figure 6. Microhardness distribution in the depth of EEA zone of titanium alloy surface VT6 by boron carbide.

4. Conclusions

Electro-explosive alloying of titanium alloy VT6 by boron carbide powder is carried out. The formation of the modified layer is revealed. Its thickness varies from 10 μm to 50 μm. It is shown that this layer has a gradient structure, characterized by regular change in the elemental composition depending on the distance to the alloyed surface. Microhardness of the surface exposed to EEA by boron carbide increases manifold.

5. Acknowledgements

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