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Surface Modification of Ti Alloy by Electro-explosive Alloying and Electron-Beam Treatment

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Abstract. By methods of modern physical metallurgy the analysis of structure phase states of titanium alloy VT6 is carried out after electric explosion alloying with boron carbide and subsequent irradiation by pulsed electron beam. The formation of an electro-explosive alloying zone of a thickness up to 50 μm, having a gradient structure, characterized by decrease in the concentration of carbon and boron with increasing distance to the treatable surface has been revealed. Subsequent electron-beam treatment of alloying zone leads to smoothing of the alloying area surface and is accompanied by the multilayer structure formation at the depth of 30 μm with alternating layers with different alloying degrees having the structure of submicro - and nanoscale level.

INTRODUCTION

Titanium alloys are employed in aerospace industry because of their remarkable characteristics: high strength to weight ratio, excellent resistance to wear, good fatigue performance etc. The nature of material surface is of major importance, in particular for corrosion and wear resistance properties. Therefore, surface treatment can be used to improve the material performance. Various methods of surface modification (coating formation, surface alloying and mechanical processing, etc.) are used for improvement of wear resistance of metals and alloys. Electro-explosive alloying (EEA) is one of them, in which pulsed plasma jets appear as the tool of surface impact, being generated at the discharge of energy storage capacitors through the conductive material [1, 2].

A high roughness level of a modified surface and significant inhomogeneity of the alloying elements distribution in the volume of the alloyed layer is a constraint for a wide practical use of EEA. The interaction of high current pulsed electron beam with materials has recently received enormous attention for surface treatment [3-7]. The high current pulsed electron beam treatment (EBT) is a new surface modification process and can be applied in many fields. The sources of high-intensity pulsed low-energy electron beams providing remelting and high-speed crystallization, forming nanosized nanophase surface layers with improved physical and mechanical properties can be used as a tool for removing defects of EEA. The combination of this processes (EEA and EBT) makes it possible to modify substantially the surface characteristics and in many cases, improve the mechanical properties faster and more efficiently than conventional surface treatment techniques [2, 8, 9].

The aim of this work is structural-phase states analysis of the VT6 titanium alloy surface layer, formed as a result of electro-explosive alloying with boron carbide and the subsequent treatment with high-intensity pulsed electron beam.

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MATERIALS AND METHODS

VT6 titanium alloy was used as a material for study. It belongs to the class of two-phase alloys containing α-Ti and β-Ti [8] after the type of structure. The chemical composition of the alloy corresponded to Russian National State Standard GOST 19807-91 (Table1).

TABLE 1. VT6 alloy chemical composition (% by weight)

Fe	**C**	**Si**	**V**	**N**	**Ti**	**Al**	**Zr**	**O**	**H**	Impurities
to 0.6	to 0.1	to 0.1	3.5 – 5.3	to 0.05	86.45 – 90.9	5.3 – 6.8	to 0.3	to 0.2	to 0.015	others 0.3

Note: Ti – base.

The EEA methodology did not differ from that described in the works [1, 2]. Titanium foils with a thickness of 20 μm and a weight of 0.25 g was used as exploded conductor. The weight powder samples of boron carbide B_4C (of a mass 0.5 g) was placed in the explosion area.

Subsequent electron-beam treatment (EBT) was carried out with the following parameters [1, 2, 9]: energy of accelerated electrons 18 keV**;** the electron beam energy density of 50 J/cm^2 and 60 J/cm^2; pulse duration of the electron beam impact 100 μs; pulse repetition frequency 0.3 sec^{-1}; the number of irradiation pulses - 10.

Structural study of the modified material was carried out using scanning electron microscopy. The elemental composition of the surface layer was analyzed by X-ray microanalysis.

RESEARCH RESULTS AND DISCUSSION

Modified Layers Structure after EEA

The scale of the surface alloying structural elements varies in a very wide range – from hundreds of micrometers to tens-hundreds of nanometers (Fig. 1).

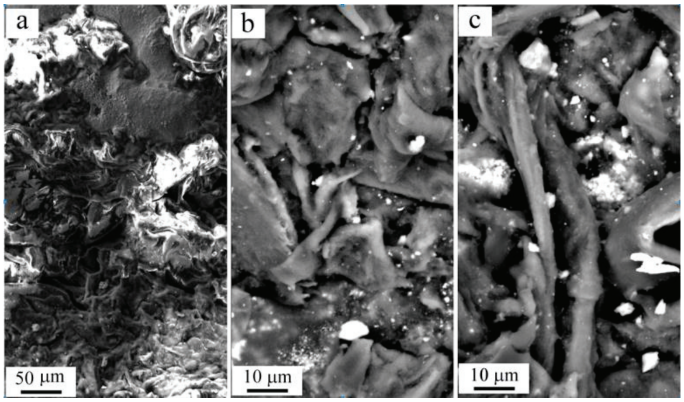


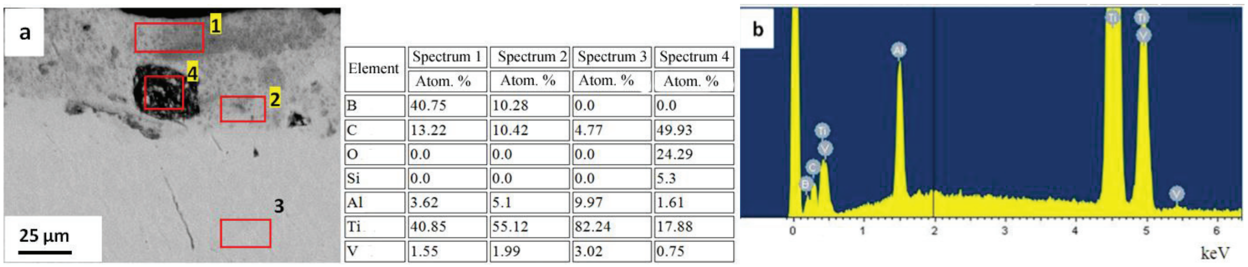
FIGURE 1. VT6 alloy surface structure of electro-explosive alloying

Distribution of alloying elements in the alloying zone is inhomogeneous as well. The coefficient of inhomogeneity in the distribution of alloying elements in the surface layer (the ratio of the total amount of boron, carbon and oxygen in different areas) reaches 2.8.

The total thickness of the alloyed layer ranges from 10 to 50 μm due to the highly developed surface relief.

Four layers can be distinguished on morphological grounds in alloyed volume: surface (Fig. 2a, layer 1), intermediate (Fig. 2a, layer 2), transitional (Fig. 2a, layer 3) and a layer of thermal influence, gradually turning into the main volume of the sample.

It was established that the concentration of boron atoms and carbon is reduced with increasing distance from the surface alloying. In some cases, areas of rounded shape (Fig. 2, area 4) are found in the alloyed layer, significantly different from the surrounding volume of material in the structure and elemental composition. Carbon, oxygen and silicon (Fig. 2, table, spectrum 4) are the main elements of these areas.



Element	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
	Atom. %	Atom. %	Atom. %	Atom. %
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	40.85	55.12	82.24	17.88
V	1.55	1.99	3.02	0.75

FIGURE 2. The structure of the transverse section of the alloy based on titanium VT6, subjected to electro-explosive alloying (a); (b) – energy spectrum obtained from the section no.1. The Table shows results of X-ray microanalysis of sections listed in (a)

Structure of the Modified Layers after EEA and Subsequent EBT

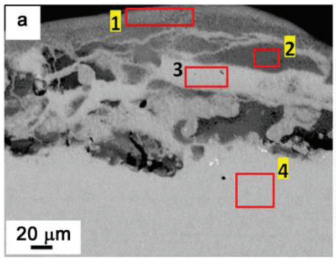
High-speed melting and subsequent high-speed self-hardening of surface layer after EEA due to heat dissipation in integrated cold sample volume not only lead to the smoothing of the relief, but also to significant transformation of the material structure. Surface analysis revealed two characteristic type of structure formed exclusively as a result of EBT with energy density 50 J/cm^2. The first type represents area with an acicular structure. Longitudinal sizes of needles vary in the range up to 10 µm, transverse - to 1 µm. Needles are arranged mainly perpendicular to the radiation surface, that is in the direction of the heat sink. Second type represents relatively smooth areas, the elements sizes of which may vary in the range of 100 nm.

The areas differ in elemental composition. Results of X-ray analysis indicate that areas with nanoscale substructure are formed exclusively by atoms of the initial material with a small admixture of carbon. One expects that these areas contain carbide phase particles. Areas with an acicular structure contain elements of the alloying powder and VT6 titanium alloy; therefore, they were formed as a result of liquid-phase alloying of titanium with boron, carbon and oxygen, and therefore must have a relatively complex phase composition.

The electron beam energy density increase to 60 J/cm^2 leads to the predominant formation of structure of the acicular type. X-ray microanalysis of areas with acicular structure revealed the presence of alloying elements and elements of the original alloy. This fact indicates an increase in the degree of dissolution of boron carbide particles in titanium with increase in energy density of the electron beam. It increases the level of homogeneity of the modified surface layer.

The structure of modified layer has a laminated construction. The layers enriched and depleted with alloying elements are found. At that, concentration of alloying elements within each layer is weakly dependent on the distance to the radiation surface. This fact indicates the formation of a multilayer structure in the material, in which layers with high alloying levels (more durable layers) are alternating with layers with low alloying level (less durable layers).

Elements distribution revealed by methods of X-ray microanalysis, definitively testifies also in favor of the laminated structure of surface layer formed during combined treatment of the alloy. When analyzing results presented in the Table for Fig. 3, it can be noted that layers being different in contrast are significantly different in the concentration of alloying elements as well.



Element	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
	Atom. %	Atom. %	Atom. %	Atom. %
B	49.7	60.75	0.0	0.0
C	17.64	18.05	8.45	5.88
Al	0.82	0.56	9.11	11.37
Ti	30.77	20.19	79.13	79.64
V	1.07	0.44	3.31	3.11

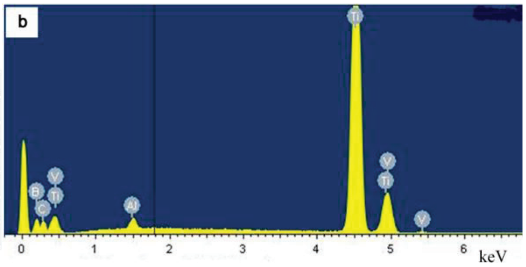


FIGURE 3. Structure of the transverse section of VT6 alloy on the base of titanium, subjected to electro-explosive alloying and subsequent electron beam irradiation (16 keV; 60 J/cm^2; 100 µs; 10 pulses;) (a); (b) – energy spectrum obtained from the section 2. The Table shows results of X-ray analysis of sections listed on (a)

CONCLUSIONS

In electro-explosion alloying of titanium alloy VT6 with boron carbide the modified layer is formed to 50 µm in thickness with a gradient structure. This structure has four layers with different degree of chemical etching. The distribution of alloying elements in depth and along each layer is characterized by inhomogeneity. Thus, the concentration of carbon and boron decreases with depth.

Subsequent electron-beam treatment leads to smoothing irradiation surface and alloying elements redistribution along the surface. Areas are revealed with element composition close to the composition of boron carbide particles, areas with a high degree of alloying of the titanium base having an acicular structure, and areas with low- degree of alloying with nanosized structure.

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