Electro-explosive alloying of VT6 alloy surface by boron carbide powder with the subsequent electron-beam treatment

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Abstract. The formation of electro-explosive alloying zone with the thickness up to 50 μm has been revealed. It has been shown that it has a gradient structure, characterized by the decrease of carbon and boron concentration with the increase of the distance up to the treatment surface. The subsequent electron-beam treatment of alloying zone leads to flattening of alloying surface relief and is accompanied by the formation of a multilevel structure at the depth up to 30 μm, characterized by the interchange of some layers with a different level of alloying, having structure of a submicro- and nanoscale level.

1. Introduction
The shortcomings of titanium alloys are their low antifriction properties. To increase the metal and alloy wear resistance different surface modification methods (coating formation, surface alloying and mechanical treatment, etc.) are used. One of them is electro-explosive alloying (EEA), in which the effect instrument on the surface are pulsed plasma jets, formed at the discharge of capacitive energy storage through a current-conducting material. The working substance of plasma accelerator serves both for heating of a surface layer of a modified material, and for its alloying [1, 2]. In some works it has been shown that in the capacity of the instrument, that allows avoiding disadvantages of EEA, one can use the sources of pulsed high-intensive low-energy electron beams (electron energy is up to 30 keV, energy density is up to 100 J/cm^2, pulse duration is 50-200 mks) [2]. Pulsed electron beams with such parameters provide remelting and high-speed crystallization of material surface layers with cooling rates up to 106 K/s and give the possibility to form nanoscale surface layers with a low roughness level and the increase of physical-mechanical properties.
The aim of work is the analysis of a structural state of a surface layer of VT6 titanium alloy, formed as a result of electro-explosive alloying with boron carbide powder and the subsequent irradiation with high-intensive pulsed electron beam.

2. Materials and research methods
In the capacity of the research material the alloy based on VT6 titanium has been used. It is used for the production of large-size welded and built-up constructions of aircrafts, for the production of the containers, acting under the internal pressure in large temperature intervals from 196 to 450°C, and a

series of other structural components [3]. By the structure type it refers to the class of two-phase alloys, containing α-Ti and β-Ti [4]. The chemical composition of the alloy has corresponded to the State Standard 19807-91 (Table 1).

Table 1. Chemical composition of VT6 alloy VT6 (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	other 0.3

For EEA the authors of the work has used a laboratory electro-explosive unit EVU 60/10 (EEU 60/10) (power-intensity – to 60 kJ; discharge natural frequency – 10 kHz; maximal value of the charge – 5 kV; mean power consumption – 0.55 kW) with typical values of the absorbed power density at the treatment of the material surface ~10^9 W/m2, the pressure in a shock-compressed plasma layer near the irradiation surface ~106–107 Pa, treatment time - 100 μs, the thickness of the alloying zone in its central area 20-50 μm. In the capacity of the burst conductor a titanium foil with the thickness of 20 μm and mass of 0.25 g. has been used. In the area of the explosion the samples of boron carbide powder B4 Cwith the mass of 0.5 g. have been located. The treatment mode has been set by the value of a charging voltage of the capacitive energy storage, passage diameter of the booster nozzle and the distance from its section to the irradiation surface. At the same time the absorbed power density has been 5.5·109 W/m^2.

The subsequent electron-beam treatment (EBT) of the alloying layer has been carried out by a high-intensive pulsed electron beam at the unit SOLO of the Institute of High Current Electronics Siberian Branch of Russian Academy of Science [5]. The irradiation has been implemented at the following work parameters of electron sources: electron energy is 18 keV; energy density of an electron beam is 50 J/cm^2 and 60 J/cm^2; pulse duration of electron beam impact is 100 μs; impulse repetition frequency is 0.3 s^{-1}; the number of irradiation pulses is equal to 10.

The structure research of the modified material has been fulfilled by the methods of scanning electron microscopy. The elemental composition of a surface layer has been analyzed by the methods of X-ray spectral microanalysis.

3. Results and their discussions

The structure research of the modified material has been fulfilled by the methods of scanning electron microscopy. The elemental composition of a surface layer has been analyzed by the methods of X-ray spectral microanalysis [6].

The subsequent EBT leads to the essential transformation of the relief and the distribution of the alloying elements in the alloying zone. Namely, the surface relief is flattened; black-and-white contrast on the image of the alloying surface is replaced mainly by a grey one; that indicates a more even distribution along the surface of the alloying elements, initiated by the treatment.

High-speed melting and the subsequent high-speed self-hardening of a surface layer owing to the heat removal into an integrally cold sample volume leads not only to the ironing of the relief, but to the essential transformation of the material structure (fig. 1). The analysis of the treatment surface has revealed two character types of the structure, formed exclusively as a result of EBT. The first ones are the areas with a needlelike structure. The longitudinal sizes of the needles reach 10 μm, and the cross ones – 1 μm (fig. 2). The needles are located mainly perpendicularly to the irradiation surface, i.e. along the direction of the heat removal. The second ones are rather smooth areas, the element sizes of which reach 100 nm).

The results of the micro-X-ray spectroscopic analysis are the evidence of the fact that the areas, having a brightly evident dark contrast, are formed exclusively by the alloying elements and oxygen. Therefore, one can suppose that they are formed by the particles of the basic powder, which has not been dissolved at the EEA and the subsequent EBT.

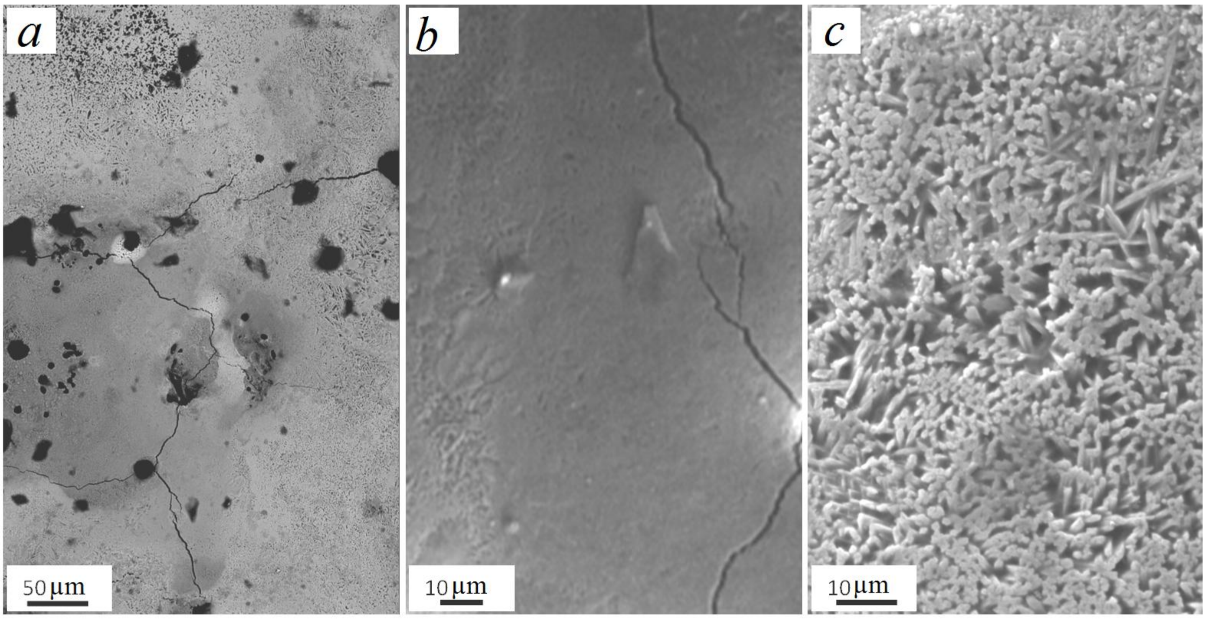

Fig. 1. The structure of the surface area electro-explosive alloying VT6 alloy after electron beam processing
a - the central zone of the sample, b, c - areas on the periphery of the sample

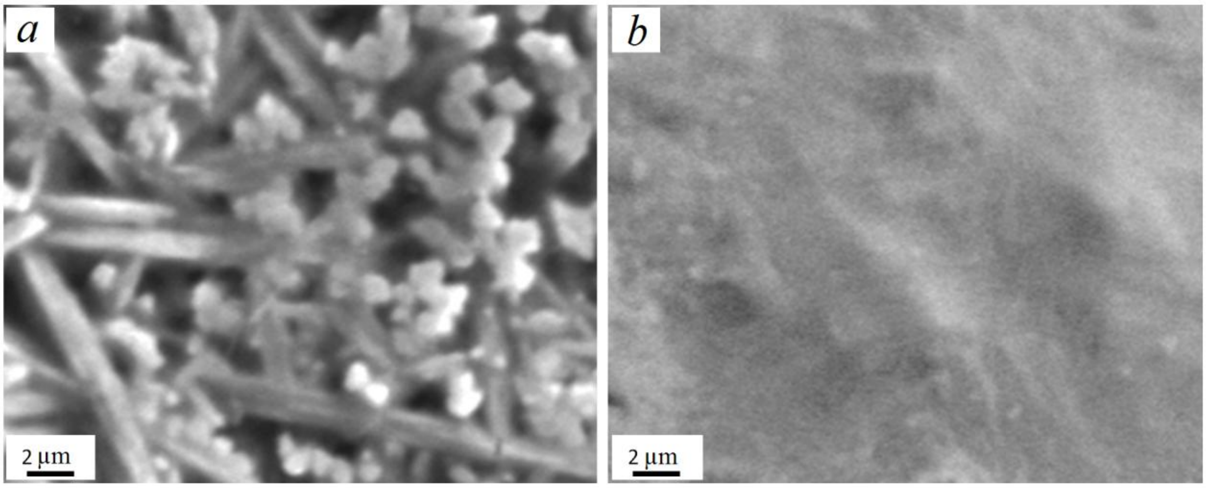

Fig. 2. The structure of the surface area electro-explosive alloying VT6 alloy after electron beam processing
a - the zone with the dendritic crystallization, b - smooth zone

The increase of energy density of electron beams up to 60 J/cm^2 leads to the formation of the structure of a needlelike type mainly. X-ray spectroscopic microanalysis of the areas with a needlelike structure has revealed the presence of both alloying elements, and the elements of a basic alloy. This fact is an indication of the increase of the degree of the dissolution of baron carbide particles in titanium with the development of energy density of the electron beams, i.e. of the increase of the homogeneity level of the modified surface layer.

The structure transformation of the surface layer volume has been analyzed, when studying the chemically etched cross sections. EBT at the energy density of the electron beams of 50 J/cm^2 does not lead to the formation of a homogeneous structure. The surface layer with the thickness to 30 μm has got a needlelike structure; the substructure of an underlying layer is similar to the substructure, formed in the material at EEA. Therefore, EBT at this treatment mode allows to modify the layer with the thickness, which is not more than 30 μm. The structure of the modified layer has often got a laminated structure.

One can also reveal the layers which are enriched and united by the alloying elements. At the same time the concentration of the alloying elements within the limits of each layer depends poorly on the distance up to the irradiation surface. This fact is the evidence of the formation of a multilayer structure in the material; in this structure the layers with the increased alloying level (more durable layers) interchange with the layers with the reduced alloying level (less solid layers).

Consequently, the irradiation of the alloying layer with high-intensive pulsed electron beam does not lead to the homogenization of the modified layer; as well as a peculiar laminated structure is formed. One can expect that the essential difference in the concentration of the alloying elements in the revealed layers will lead to the difference of their strengthening and tribological properties.

4. Conclusion

Electro-explosive alloying of VT6 titanium alloys with plasma, formed at the explosion of a titanium foil with the powder sample of boron carbide has been performed. The formation of the modified layer with the thickness up to 50 μm with a gradient structure has been revealed. It has four layers with a different degree of a chemical etchability. The distribution of the alloying elements both along the depth and each layer is characterized by the heterogeneity. At the same time the concentration of carbon and boron decreases with the depth.

The subsequent alloying surface irradiation with high-intensity pulsed electron beam of submillisecond action time has been carried out. It has been shown that, electron-beam treatment leads to the ironing of irradiation surface and the redistribution of alloying elements along the surface. The areas are revealed, which elemental composition is close to the composition of boron carbide particles, as well as the areas with a high degree of titanium substrate alloying, having a needlelike structure, and the areas with a low degree of alloying, having a nanodimensional structure. The increase of a surface energy density from 50 to 60 J/cm2 leads to a more even distribution of alloying elements along the surface. Along the zone depth of a combined treatment some layers with a different alloying degree are revealed. The increase of a surface energy density leads to the thickness decrease of layers and the increase of their number. The zone depth of electron-beam impact reaches 30 μm. It has been established that high cooling rates, initiated by the electron-beam treatment, leads to the structure formation of a submicro- and nanoscale level, that allows forecasting high strengthening and tribological properties of a modified material.

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