Electrochemical deposition of ceramic-like coatings on Ti-6Al-4V parts fabricated by electron beam melting

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Abstract. The problems of micro-arc oxidation of titanium alloy parts Ti-6Al-4V produced by electron beam melting technology were considered. The phase composition, thickness and roughness of the obtained coating have been evaluated.

1. Introduction
Titanium and titanium alloys are widely used in aerospace, petrochemical, medical equipment field and other fields. Micro-arc oxidation (MAO), also called plasma electrolyte oxidation (PEO) or anodic-spark deposition (ASD), is a high-voltage anodic oxidation process in a plasma environment that is widely used for surface modification of valve metals. Valve metals are metals that can form adhesive, electrically insulating anodic oxide films after anodizing, such as aluminum, tantalum, zirconium, titanium, etc.

Additive manufacturing (AM) is an innovative manufacturing process. The essence of AM is to create components in almost any geometric shape without any subsequent machining, that allows to reduce production waste. The AM of titanium alloys includes two different methods: selective laser melting (SLM) and electron-beam melting (EBM). The main advantage of these methods as compared to traditional methods is that the product is created in one step, directly from computer aided design (CAD) model data [1, 2].

In particular, EBM is the most suitable AM method for chemically active metals such as titanium alloy because of their printing in high vacuum. In addition, EBM offers higher productivity (~80 cm³/h), in contrast to SLM (20 - 30 cm³/h), and more flexibility in the choice of powder particle size (20 - 45 µm with ELP, 45 - 105 µm with SLM) [3–7].

Purpose of work: to investigate the phase composition, thickness and roughness of the micro-arc oxide coating on the titanium alloy Ti-6Al-4V samples produced by electron-beam melting technology.

2. Material and methods
Samples of titanium alloy Ti-6Al-4V with dimensions of 28 mm x 19 mm x 5 mm were made on Arcam A2 machine by EBM of powder layers with thickness of 50 µm, average power of electron beam was 900 W, speed of the beam was 4350 mm/s. The entire process took place under vacuum conditions in a protective gas - helium.
Micro-arc oxidation was carried out on an installation, allowing to set various electric modes of processing, in the bath filled with silicate-hypo-phosphite electrolyte from stainless steel. The process was carried out in soft anode-cathode mode at a total anode and cathode current density of 10 A/dm$^2$ and treatment duration of 10 minutes.

The phase composition was analyzed on an Empyrean diffractometer (PANalytical, Almelo, The Netherlands), in the Cu-Kα spectrum with a wavelength of 1.5405981Å, at 60 kV, a beam current of 30 mA, a diffraction angle 2θ ranging from 25° to 80° with a step size of 0.05.

The cross-sectional morphology of the samples was examined on a VEGA 3 LMH scanning electron microscope (Tescan, Brno, Czech Republic). The samples were ground and polished on a Tegramin-30 machine (Struers, Ballerup, Denmark).

Roughness evaluation was performed on the optical system MicroCAD premium+ (GFM, Berlin, Germany).

3. Results of investigations and discussion

Figure 1 shows diffractograms obtained from pristine and coated samples. The substrate contains two phases, alpha ($\alpha$) and beta ($\beta$). After MAO the intensity of diffraction peaks of $\alpha$- and $\beta$-Ti significantly decreases, and there is a tendency of complete disappearance of $\beta$-Ti. This is due to the fact that during the oxidation process the formed coating overlaps the initial matrix on the surface of the sample. The observation of the $\alpha$-phase is due to the fact that the coating formed by MAO is thin and porous.

![Figure 1. XRD patterns of pristine and coated samples ($\alpha$: $\alpha$-Ti, $\beta$: $\beta$-Ti).](image)

The SEM cross-sectional view of the MAO coated sample is presented in figure 2. The average thickness of the coating was $3.4\pm0.32$ μm. The substrate-coating interface is relatively smooth, which contributes to their adhesion.
Measurements of the surface roughness of the studied samples are presented in table 1. The results show that the surface roughness after the MAO process decreased (the sample without MAO coating: $Ra=5.62 \, \mu m$, $Rz=32.12 \, \mu m$; MAO coating roughness: $Ra=1.82 \, \mu m$, $Rz=10.04 \, \mu m$, respectively). The obtained low values of roughness are associated with uniform application, overlapping pores and irregularities obtained after the process of electro-beam melting.

**Table 1.** The results of determining the position of spectral lines.

| Sample Type                  | $Ra$, $\mu m$ | $Rz$, $\mu m$ |
|------------------------------|---------------|---------------|
| Ti-sample without MAO coating | 5.62          | 32.12         |
| Ti-sample with MAO coating   | 1.82          | 10.04         |

**Figure 2.** The SEM cross-sectional view of the MAO coated sample.
4. Conclusions
Samples of titanium alloy Ti-6Al-4V were fabricated by electron-beam melting, followed by MAO coating. Analysis of the phase composition of the coating showed that after MAO the intensity of diffraction peaks α- and β-Ti significantly decreases, and there is a tendency of complete disappearance of β-Ti. The thickness of the deposited MAO coating was $3.4\pm0.3$ μm. Surface roughness of the deposited MAO coating had values $Ra=1.82$ μm and $Rz=10.04$ μm.

Acknowledgments
We would like to thank the Russian Science Foundation for supporting this work under the grant from the Russian Science Foundation (project No. 21-79-30058).
This work was carried on the equipment of the Collective Use Center of MSTU “STANKIN” (project No. 075-15-2021-695).

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