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Obtaining the bimetallic composition by the electron beam freeform fabrication

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Abstract. This paper is devoted to obtaining the multimaterials using the electron-beam wire-feed additive manufacturing technology. The sample of titanium alloy Ti-6Al-4V and stainless steel 321 composition was obtained. It was found that steel and Ti-alloy form a transitional intermediate layer between themselves. The Ti-alloy layer does not undergo major changes, while the layer of stainless steel undergoes significant cracking.

1. Introduction

Electron beam additive manufacturing (or the electron beam freeform fabrication) is a promising technology for producing various products from metal wire or rod [1]. At the moment, the features of the formation of products made from materials such as Ti-6Al-4V alloy, stainless steel 321 or 316, etc. are rather widely studied [2-5]. But formation of multimaterials in modern literature has been poorly studied.

In a number of works the formation of bimetals from titanium alloys and stainless steels was investigated. In [6], the formation of a bimetal of a Ti-6Al-4V alloy and stainless steel was studied using an intermediate layer of NiCr and laser additive technology. The authors showed that without such a transition layer a bimetallic compound cannot be obtained by laser additive method, since in this case numerous cracks due to residual stresses will form.

In the works [7-10], functional gradient materials of the Ti-Al system, which are used for manufacturing turbo-compressor blades, exhaust valves and other rocket-space products, were investigated. According to the results of these articles, gradient material with a composition from pure titanium to 100% titanium aluminide TiAl is obtained using the two-wire arc additive technology. Also, other polymetallic compounds are known [11-15]. These polymetallic products are of the greatest interest among polymetallic metamaterials. However, the manufacture of such materials by the method of wire electron beam additive manufacturing (EBAM) has not been studied. Among other things, the production of multimetals based on titanium alloys, rather than technically pure titanium, also remains virtually unexplored. In this regard, the study of the formation of polymetallic metamaterials based on titanium alloys is a very urgent and promising task.

2. Materials and Methods

Sample preparation was carried out using an experimental EBAM laboratory equipment at the Institute of Strength Physics and Materials Science SB RAS, Russia (Figure 1). Ti-6Al-4V alloy and AISI 321 stainless steel 1 mm diameter wires were used for EBAM deposition at process parameters shown in Table 1.

Table 1. Parameters of the manufacturing process

Parameter	Value
Voltage, kV	25
First layer beam current (Ti-6Al-4V), mA	35
Last layer beam current (Steel 321), mA	30
Feed rate (Ti-6Al-4V), mm/min	220
Feed rate (Steel 321), mm/min	250

Templates were cut off the obtained sample, and then subjected to mechanical grinding, polishing with diamond paste and chemical etching in the reagent 1 (30 ml HNO_3 + 0.5 ml HCl + 70 ml CH_3COOH) during 30 seconds and in the reagent 2 (100 ml HNO_3 + 1 ml HF) during 2 seconds. The templates were examined using a metallographic microscope Altami MET-1S and a scanning electron microscope SEMTRAC mini.

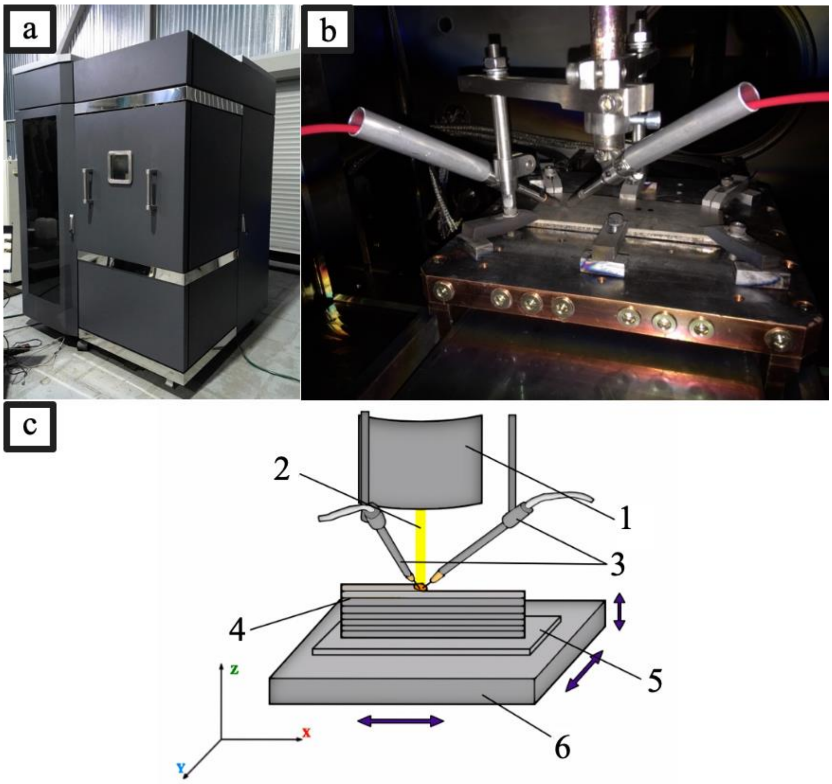

Figure 1. Laboratory equipment (a), vacuum chamber with the table and wire-feeders (b) and the scheme of the EBAM process (c). 1 – Electron beam gun, 2 – electron beam, 3 – wire-feeder, 4 – wall, 5 – substrate, 6 – table

3. Results and discussion

The sample of obtained bimetallic composition is shown in Fig. 2. As can be seen from Figure 2, primary Ti-6Al-4V wall was built successfully, despite its partial mixing with the substrate. This zone of primary wall (zone ***I***) is represented by almost typical cast structure including primary β-grains and thin plates of α-phase, and practically free of macrodefects such as pores and cracks. The direction of grains growth depends on the direction of the heat removal, and in this case, it does not have a clear direction due to poor cooling conditions.

A layer of stainless steel (zone ***II***) deposited on the primary wall has not formed at all. As shown in Fig. 2, all deposited material stack on the right side of the wall. In addition, it is clear that the material has undergone significant cracking throughout the applied volume.

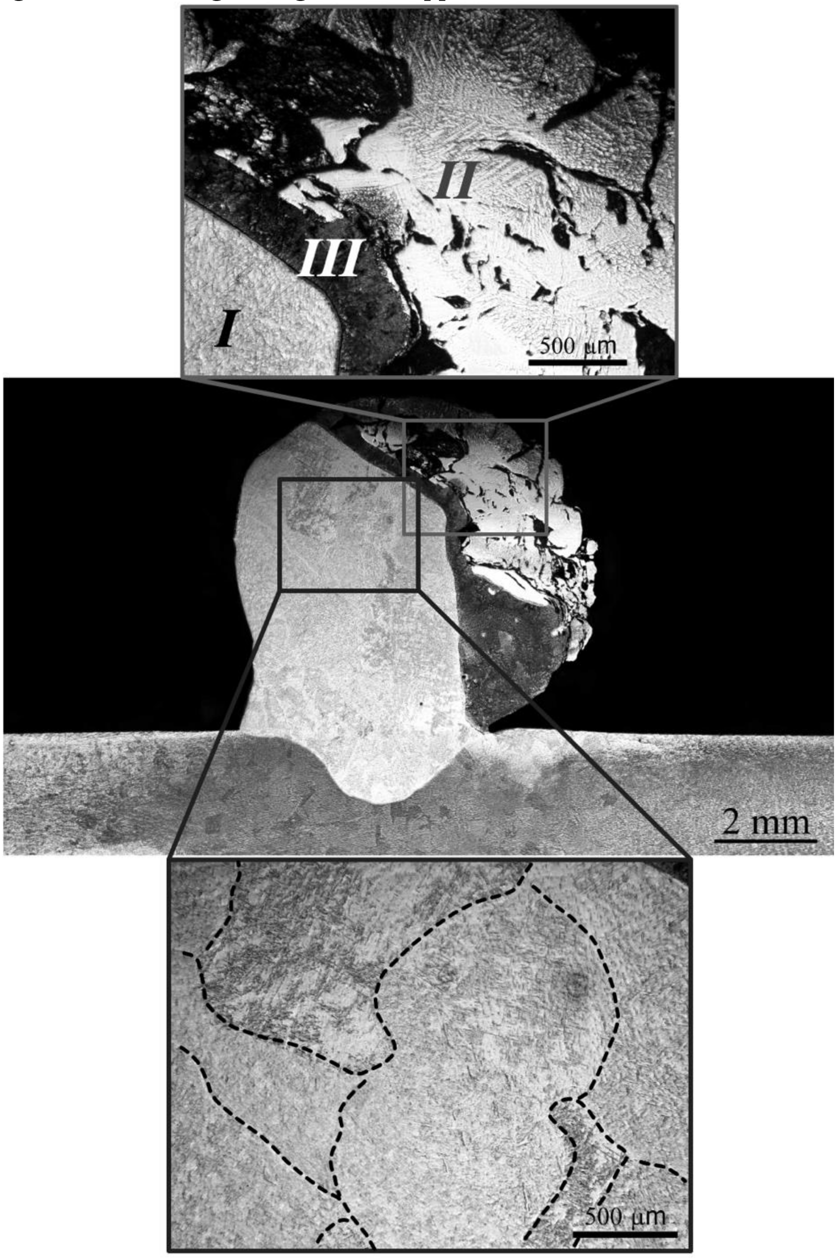

Figure 2. Metallographic image of the sample. I, II, III – zones of different materials, dashed lines – boundaries of primary β-grains in Ti-6Al-4V.

Most interesting is the intermediate layer formed between the two materials. As can be seen from Figure 2 this layer (zone ***III***) is etched differently than other zones and, therefore, has a structure different from these zones. As shown by energy dispersive analysis, the zone ***III*** is mainly represented by titanium (≈50–60%) and iron (≈15–20%). Apparently, this layer is an intermetallic compound. Its structure is also represented by dendrites growing from steel to titanium alloy. The results of energy dispersive analysis of the zone ***III*** are presented in table 2. Figure 3 shows the areas in which the elemental composition was studied. It is worth noting that in the first area Ni is present, and in area 2 it is absent, and they are also distinguished by the presence of aluminum. This suggests that the alloying elements of titanium alloy and steel form two different types of compounds. It can be assumed that the formation of such a layer and intermetallic compounds leads to the embrittlement of the stainless steel layer and its cracking during the crystallization process.

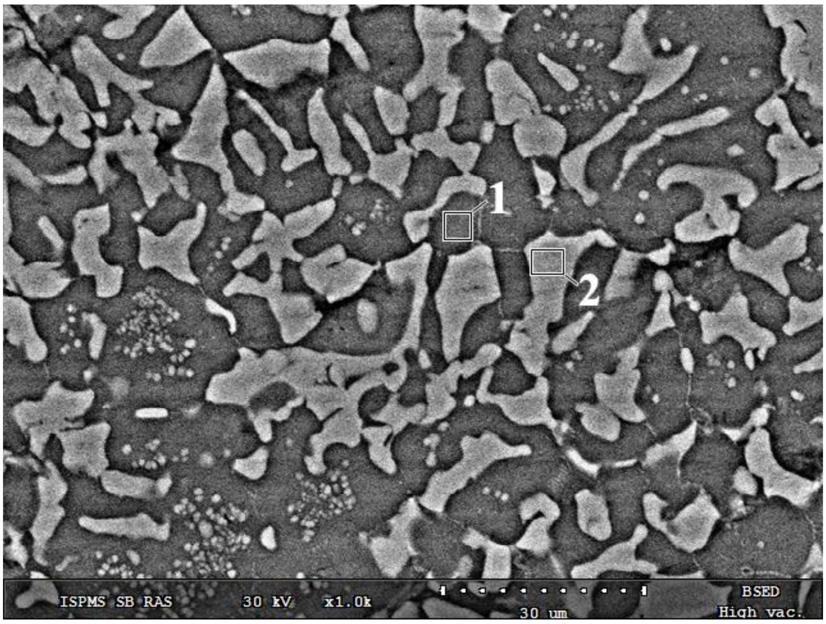

Figure 3. SEM image of microstructure in the zone ***III*** and the areas of elemental analysis

Table 2. The results of energy dispersive analysis, wt.%

Area	Ti	Al	Fe	V	Ni	Si
1	59.500	9.589	14.773	4.981	4.812	6.344
2	54.506	12.010	18.088	5.478	0	9.919

4. Conclusions

Studies of the steel-titanium bimetallic sample showed that the formation of such materials is hampered by the formation of brittle intermetallic compounds, which leads to cracking and deterioration of the stainless steel layer. In this case, the primary wall of titanium alloy does not undergo significant changes. It was revealed that a transition layer mainly represented by Ti and Fe and having a dendritic structure is formed between the materials joined by the EBAM method, this layer has practically no defects, however, it contributes to the embrittlement of the overlying layers due to the presence of intermetallic compounds.

Acknowledgments

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