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APPLICATION OF ADDITIVE ELECTRON BEAM TECHNOLOGIES FOR MANUFACTURE OF PARTS OF VT1-0 TITANIUM ALLOY POWDERS

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The possibility was investigated of application of hydration-dehydration (HDH) titanium powders of domestic production for manufacture of parts using additive electron beam melting on SV-212M installations. HDH powder of commercially pure VT1-0 grade titanium was used for investigations. The elements of technology of part manufacture by 3D layer-by-layer deposition were developed. Part specimens of set shape and 12×12×100 mm size were produced and investigated. Structures of deposited layers were investigated. Absence of porosity and lack of fusion in the produced specimens of the part was noted. The possibility is shown of development of the set shape parts by additive electron beam deposition methods using VT1-0 titanium powder of domestic production. 9 Ref., 1 Table, 12 Figures.

Keywords: *electron beam, layer, additive technologies, titanium powder, structure*

Additive technologies (AT) have found wide application and commercial distribution in manufacture of high-strength volumetric parts of metallic powders. Selective laser melting (SLM) technologies, providing formation of the parts by means of gas-shielded fusion of metal powder using laser beam, and electron beam melting (EBM) technologies, directed on formation of the parts by metal powder using electron beam in vacuum chamber, are mostly used for these purposes.

These technologies are of the great interest for manufacture of complex parts applied in aircraft engine-building. A stable tendency of the last years is implementation of AT in the leading aircraft engine-building companies [1]. «Growing» of the parts using powder materials of titanium alloys [2] for commercial enterprises of domestic machine-building (OJSC «Motor Sich», Gas Turbine Research & Production Complex Zorya-Mashproekt, SE Lutsk Repair Plant «Motor») is a relevant problem in manufacture and repair of gas-turbine engines (GTE), since large number of GDE components are made of these alloys. Traditionally, remelting of titanium alloys for aircraft equipment is carried out in vacuum, laser and gas-shielded arc welding as well as electron beam welding (EBW) are used for welding and surfacing. 3D deposition based on electron beam technologies is good to use in manufacture of aircraft parts of titanium alloys. It allows manufacturing virtually all GDE components providing high-efficient vacuum protection of weld pool deposited metal. Several of engineering solutions [3] are available today. They show the possibility of manufacture of titanium parts using EBW. However, consumables used in these installations, namely titanium alloy powders, have a number of disadvantages. Among them are lack of conformity of powder materials to large number of alloys certified in CIS countries, high price — more than 500 U.S. dollars per 1 kg of powder as well as absence of domestic commercial technologies of their manufacture. Thus, there is a problem of import substitution and supply of raw materials for the equipment used in additive manufacturing.

A relevant problem is a development of installations based on EBW processes using domestic powder materials.

From point of view of EBW technology domestic manufacturers have wide experience of welding and surfacing of titanium alloys, including with complex multi-coordinate system for movement of electron beam guns and deposited parts [3–7]. This provides the background for development of own installations based on electron beam technologies. The problem of application of titanium powder materials of domestic production can be solved applying non-spherical titanium alloys based on hydration-dehydration (HDH) technology [6]. SE SRD Titanium Institute together with STC Titan Zaporozhye ZNTU proposes an innovative technology of manufacture of low prime cost titanium powders from sponge titanium or other titanium containing materials of different quality and fractional composition using hydration-dehydration method [8].

The following problems were solved in this direction, namely providing the necessary chemical and grain-size compositions of powders and possibility of their serial production in Ukraine, which allows forming the price of these materials at the level of 100 U.S. dollars per 1

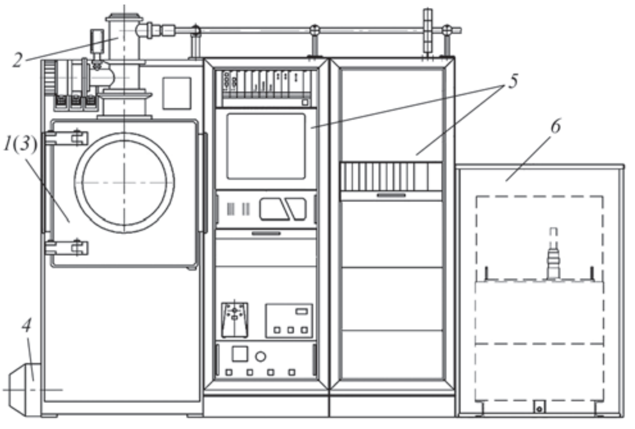

Figure 1. Scheme of SV-212M installation (description *1–6*, see in the text)

kg of powder. However, issues of application of these powder materials for additive processes are still open.

Titanium is a chemically-active metal. Electron beam technologies in vacuum chamber guarantees secure protection of molten and cooling metal, therefore they seem to be the most perspective for development of a technology of direct generation of titanium metallic parts by 3D deposition methods [5].

There are no serially produced domestic installations for this purpose. Foreign manufacturers deliver «key-turn» technology, which does not provide flexibility of manufacture with possibility to replace the raw materials by analogues [7]. The main constraint of commercial development of additive technologies for manufacture and repair of GTE parts in Ukraine is high price of powders [1], therefore application of domestic titanium alloy powders is so perspective.

Aim of the present paper is investigation of possibility of application of titanium alloy powders of domestic production for manufacture of set shape parts by additive electron beam melting.

Non-spherical powder of VT1-0 titanium alloy, provided by STC Titan Zaporozhye ZNTU, was used for manufacture of the parts.

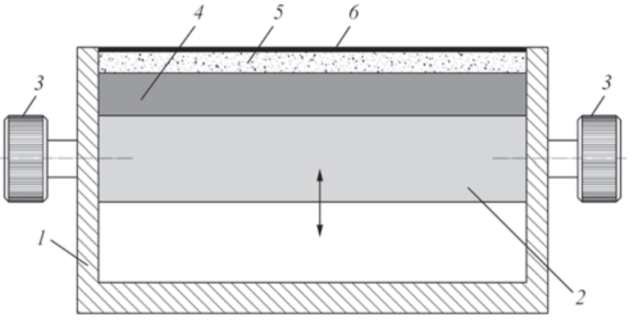

Figure 3. Scheme of modulus for 3D deposition (description *1–7* see in the text); arrow shows direction of table movement

Materials and investigation procedure. The work was carried out on small-size electron beam welding (EBW) installation of SV-212M type with pulse power source 60 kV/60 kW, electron beam gun ELA-60 and application software package for EBW. Equipment and software were developed at the E.O. Paton Electric Welding Institute. Figure 1 presents equipment appearance.

The installation consists of a small-size vacuum chamber *1*, equipped with mobile table and fixed fixture *3* for part growing. Electron beam gun *2* is located on the vacuum chamber. Vacuum system of the installation (pos. 4) provides for value of vacuum in the chamber less than 10^{-4} Torr. Control cabinet *5* contains commercial computer, screen, blocks for control of high-voltage power source and vacuum system. High-voltage source *6* allows obtaining variable voltage to 65 kV and beam current to 1 A.

Figure 2 shows a block diagram of equipment for additive electron beam melting.

A beam of electrons, necessary for heating of the surface with deposited metallic powder, is formed in the electron beam gun (EBG), which is supplied from high-voltage power source. The source is regulated with commercial computer. The systems for control of focusing and beam current are embedded the source. A generator, developing scanning control signals, is

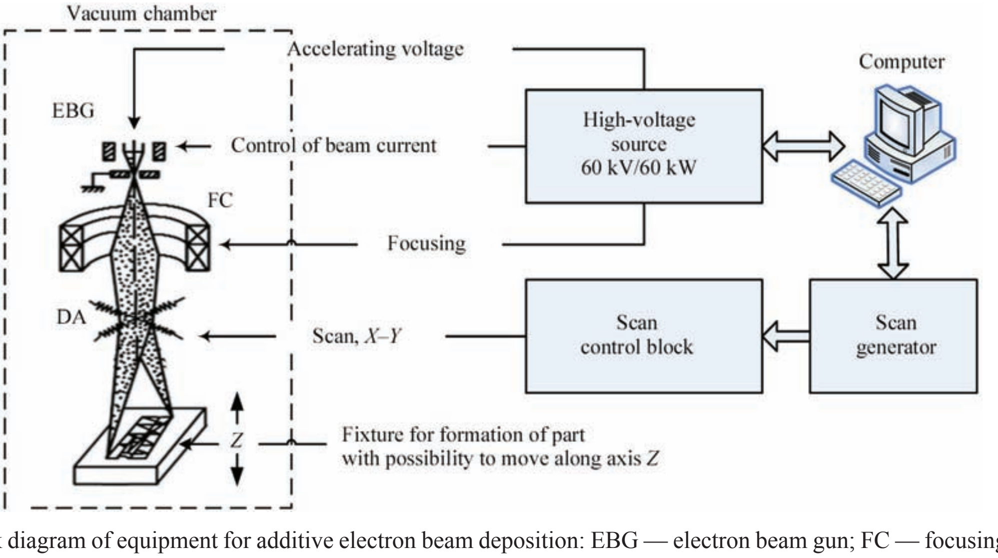

Figure 2. Block diagram of equipment for additive electron beam deposition: EBG — electron beam gun; FC — focusing coil of EBG; DA — EBG deflection-coil assembly

Process characteristics and composition of powder materials of HDH titanium VT1-0

Fraction, μm	Density g/cm^3	Content of additives, wt.%					
		N	C	H	Fe	Si	O
100–160	1.7	≤0.05	≤0.1	0.012	≤0.3	≤0.15	≤0.15
63–100	1.8	≤0.05	≤0.1	0.012	≤0.3	≤0.15	≤0.15

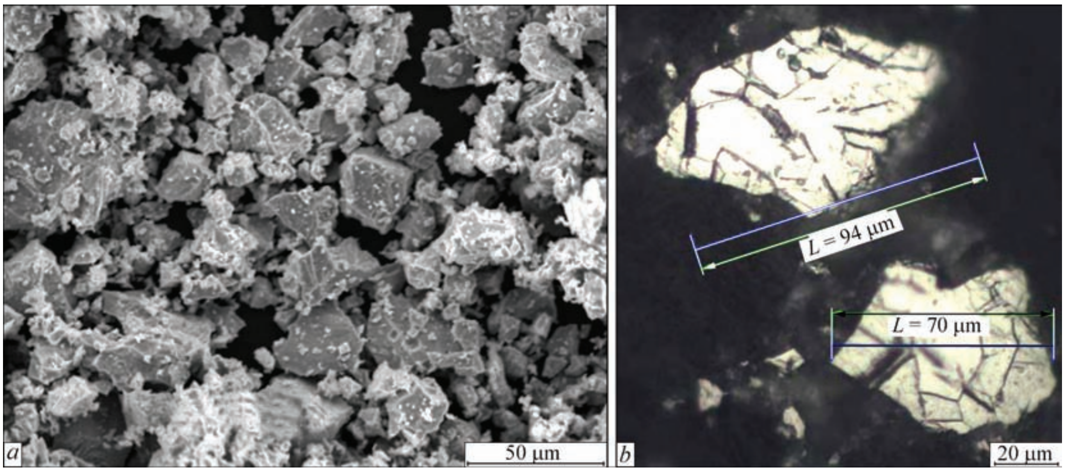

Figure 4. Appearance (*a*) and microstructure (*b*) of HDH powder VT1-0 of 63–100 μm fraction, used for deposition

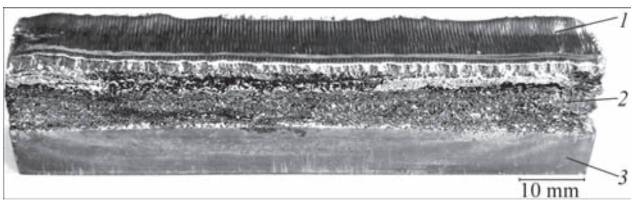

Figure 5. Specimen of part, made by electron beam 3D-deposition method: *1* — upper layer of deposited metal; *2* — interlayer of metal with particles of unmelted powder; *3* — titanium substrate

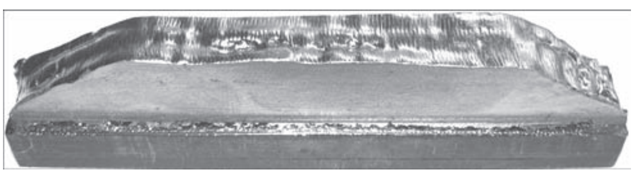

Figure 6. Part after machining

used for melting zone formation. These signals are accelerated in the scanning control block and supplied to EBG deflection coils. The beam of electrons is deflected on *X* and *Y* axes and creates a melting zone of set shape. The process is done following the program in accordance with the process modes. Beam current, focusing current and beam deviation on *X* and *Y* axes are the control objects.

A module of layer-by-layer feeding of powder consumables (Figure 3) was developed to realize the additive processes on standard EBW installation.

This module was installed in a working vacuum chamber. Its structure provided realization of the following process factors, namely change of a layer of powder materials in 50 to 500 μm range; clear formation of 100×15×50 mm working space; application of removable titanium substrate, variation of level of compaction of bulk powder layer. Developed module provides for a possibility of application of spherical as well as pilot non-spherical powder traditionally used in 3D printing machines. An important peculiarity of this device is possibility of powder compaction, which allows rising layer density [9] for non-spherical powders. The module consists of body *1* and table *2* being moved along the vertical line. The table is moved in vertical direction, at that its position is fixed

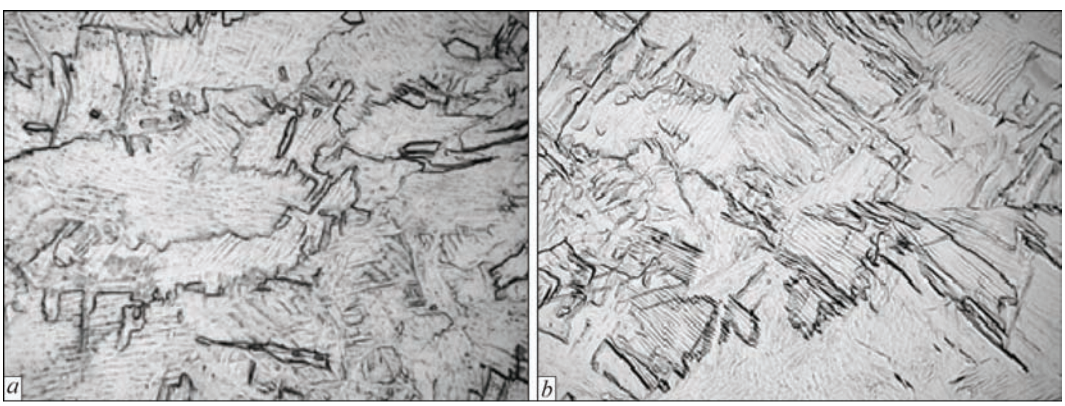

Figure 7. Microstructure (×200) of metal in layer center: *a* — layer up to 100 μm; *b* — layer of more than 100 μm

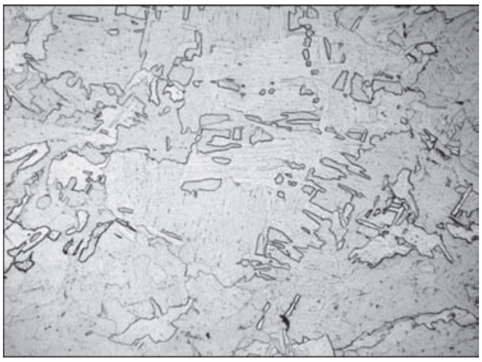

Figure 8. Microstructure (×100) of deposited metal close to fusion line

Figure 10. Microstructure (×100) of metal of deposited outer layers

by screws *3*. Titanium substrate *4* is set on the table and part *5* is built-up on it. The powder is deposited on the substrate with the help of dosing unit. Surpluses are removed by a scrapper, after what the layer is compacted using special forming device if necessary. At that smooth surface with uniformly distributed layer of powder *6* is formed. Before deposition of the next layer, the table is moved down to set value, which is controlled by clockwork type micrometer. At that, distance between an EBM cathode and surface of melting zone is kept fixed and does not change in process of creation of the whole part.

Electron beam melting process takes place in vacuum chamber at vacuum value not less that 1×10^{-4} Torr. Focused beam of the electrons creates a melting zone and forms the part by movement on set trajectory. After melting is finished, the chamber is opened and the next layer of powder is deposited. The part is grown layer-by-layer.

Titanium HDH powders are used as powder materials. They represent themselves VT1-0 titanium alloy granules of non-spherical form with cast microstructure of particles (Figure 4).

Technological characteristics and composition of powder materials of HDH titanium VD1-0 are given in the Table.

Fusion of powders using the scheme given above provided the specimens of parts of set straight shape of 12×12×100 mm (Figure 5).

The photo shows the upper layer of part *1* and substrate *3* with interlayers of deposited metal. Particles of unmelted metallic powder *2* are present on the side surface. This powder is removed later on and metal surface is machined. The specimens for further examinations were received after adjustment of deposition modes taking into account powder fraction, value of layer and size of layers overlapping. Figure 6 shows the part after machining. The surface of deposited metal was milled. Metal structure is homogeneous without obvious damages and inclusions.

Metallographic examinations of microstructure of deposited metal (powder of titanium alloy VT1-0 was made on base of titanium alloy VT-20) were carried out in different sections of the specimen.

The structure of deposited metal consisted of lamellar α-phase. Depending on layer size and powder material fraction there were changes in size of the plates of acicular α-phase as well as α'-phase precipitations were observed. Formation of hardening structures is typical for fractions less than 80 μm that is related with low source energy and fast heat sink in the volume of earlier formed cast metal (Figure 7).

Further the microstructure in the different zones of the specimens made of 63–100 μm fraction powders was examined. Cast structure close to fusion line with substrate differs in size and configuration of α-phase plates. In the first layers of the deposited metal they are coarser and have more polyhedral shape than in the middle part and in the final layers of deposit (Figures 8 and 9). This fact is related with cooling rate, i.e.

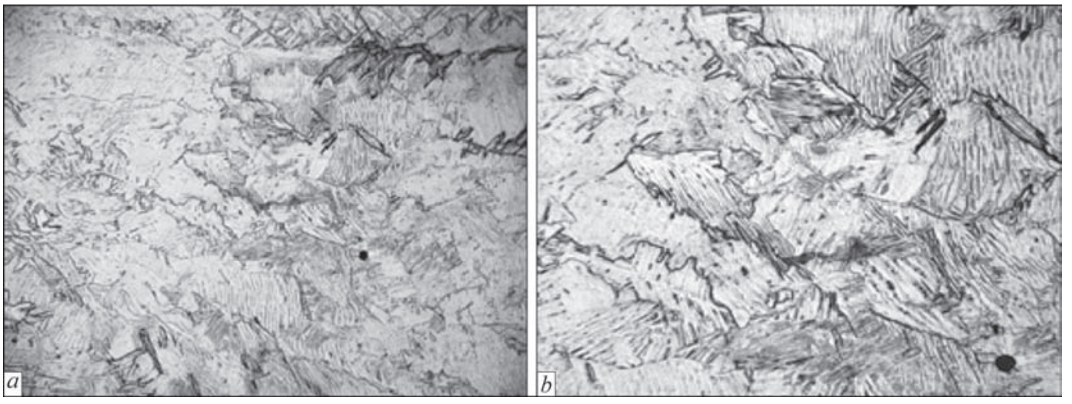

Figure 9. Microstructure of deposited metal in upper part of specimen: *a* — ×100; *b* — ×200

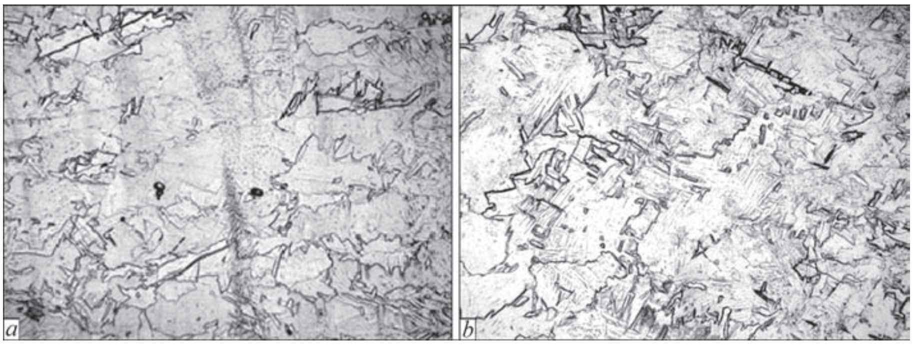

Figure 11. Microstructure of deposition in central part of specimen: *a* — ×200; *b* — ×100

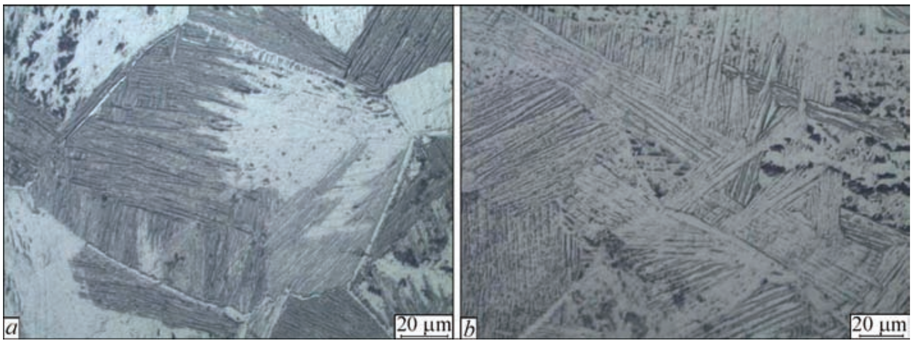

Figure 12. Microstructure of layers: *a* — layer 350; *b* — 120 μm

low rates provide for formation of coarser plates and high ones forms acicular fine α´-structure.

The plates on the outer layers of deposited metal are elongated in a heat sink direction with notched boundaries (Figure 10).

Transition zones of the layers of deposited metal differ by some refining of the plates and rise of amount of acicular α´-phase (Figure 11).

No defects, namely pores and lacks of fusion were found in the structure of examined specimen.

Figure 12 shows the microstructure of layers of built-up metal.

The analysis of microstructures of layers of built-up metal shows that the specimen structure has typical structural zones, size of which depends on their position on deposit height.

Conclusions

1. Quality of fusion of non-spherical shape powders in electron beam 3D deposition was investigated. It is determined that structural differences can be observed in dimensions, structural constituents of α-phase and are the consequence of different rate of layers cooling. It is important to note that structures of the specimens represent themselves α-phase typical for cast titanium alloys independent on powder fraction and layer size. This allows concluding that shape of powder materials, in our case non-spherical, does not affect deposited metal structure.

2. Components of equipment were developed and possibility of manufacture of set shape parts was realized using additive processes by electron beam layer-by-layer build-up method applying HDH powders, which allow getting dense cast structure of deposited metal.

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