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EFFECTS OF ELECTRON BEAM TREATMENT ON MICROSTRUCTURE OF Ti6Al4V ALLOY

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ABSTRACT

The effect of changes in the electron beam current on the microstructure of Ti6Al4V was investigated. Processing was applied with 6 different beam current values: 5, 10, 15, 20, 25 and 30 mA. A rectangular blank with dimensions thickness 10 mm, width 70 mm and length 100 mm was used. The change of the microstructure and the appearance of defects during electron beam treatment of a titanium alloy were investigated. The conducted experimental studies confirm the tendency that as the magnitude of the current increases, both the depth of penetration and the width of the treated area increase proportionally. The average measured value of grain size in fusion zone is in the range (0.72 -1.48) mm.

1. INTRODUCTION

The continuous growth of modern industry and the introduction of new technologies for the production of materials with different microstructure and mechanical characteristics requires the use of electron beam processing. Currently, electron beam treatment (EBT) methods are receiving a lot of attention and have already been successfully introduced in many industries, such as aircraft and automobile manufacturing, for the production of spaceships, railway wagons, etc. At these techniques, the materials are treated by a high-intensity electron beam. The kinetic energyof the electrons is transferred into heat, leading to a formation of thermal distribution from thesurface to the bulk. The heating and cooling rates are quite high which results in changes inthe microstructure, chemical composition, melting the surface, etc.

The technological conditions can be precisely controlled, which allows precise control of the structure and properties of the treatedmaterials [1]. Some advantages of EBT in comparison with conventional methods can be drawn as follows:

- Significantly low cost in comparison with traditional technologies;
- Significantly shorter process time in comparison with traditional technologies;
- Uniform distribution of the energy of the electron beam;
- The technological conditions defined by the technological parameters are highly reproducible [1].

Electron beam processing uses the electron beam machine. It is a heat source and main tool, which allows processing practically all materials by heating, melting, vaporizing, welding, cutting and coating. Such universality of processing leads to the use of the same equipment for the implementation of different technological goals [2].

The EBT process is a versatile technology wherein for each joint, material andgeometry, there should be several standards developed. These parameters can be classified in notably 3categories. They are as follows.

- The parameters characteristic to the Electron Beam are Accelerating Voltage (U_a), Beam Current (I_f), Focusing Current (F), Depth of Penetration (H) and Beam Focal Diameter (d_{fo});

- The parameters characteristic to the Welding Joint Features are Welding Speed (v), Welding Width (B), Focal Distance (d_t), Vacuum Pressure (P_s) and Preheating Temperature (T_{pr});

- Other parameters involve Material Type, Thermo-physical and Chemical features of thematerial and Workpiece Thickness. These parameters do not constitute as being a part of Process Parameters [3].

The main objective of the publication is to determine the influence of the current magnitude (Beam Current (I_b)) depending on the Depth of Penetration (H) and Welding Width (B) after EBT material Ti6Al4V.

2. EXPERIMENTAL PROCEDURES

2.1. The base metal

Ti-6Al-4V is a typical α+β alloy, containing 6 wt% aluminium an α-stabiliser and 4 wt% vanadium, a β-stabiliser (weight percentage), which enables a dual phase microstructure to be developed. The β transus is 995 ± 15ºC and liquidus 1650ºC [4]. Different phases and

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microstructures can be developed under different cooling rate as it can be seem in Fig. 1.

This alloy has been widely used in aerospace application, e.g. front fan and low pressure sections in gas turbines, in both annealed or in solution-treated and aged (STA) conditions. After a typical process route, the lamellar structures contains a β grain size of 600 μm, while the bimodal contains primary α grains of 20 μm and volume fraction of ~60%, and small β grains of 20~40 μm [4].

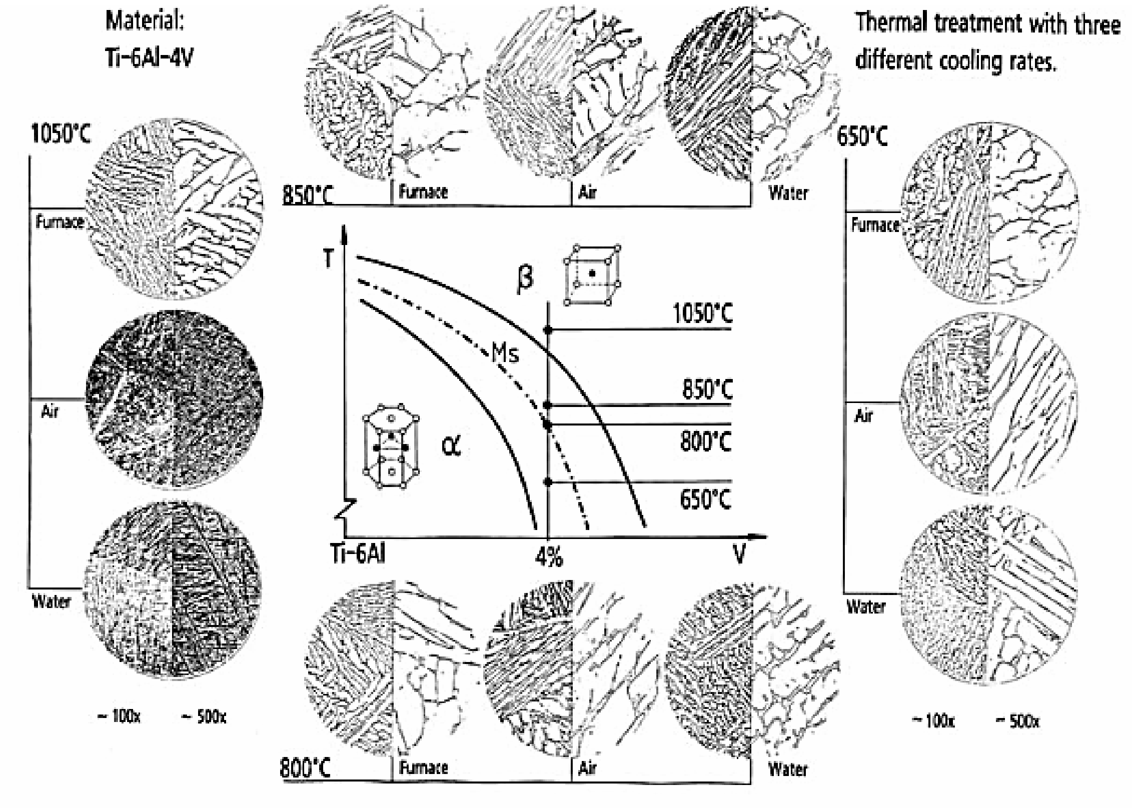

Fig. 1. Different phases and structures developed in Ti-6Al-4V under different cooling rate [4]

In the present study, a rectangular test specimen with dimensions as follows: thickness 10 mm, length 100 mm and width 70 mm was used. It is made of titanium alloy Ti6Al4V with chemical composition indicated in Table 1.

***Table 1** Chemical composition of Ti6Al4V alloy*

Element	*Al*	*V*	*Fe*	*Ti*
Wt, %	*5,5-6,5*	*3,4-4,5*	*0,25*	*Bal.*

2.2. Electron beam treatment

Electron beam treatment was carried out with an Evobeam Cube 400 welding unit manufactured by Evobeam (Fig. 2). In Table 2 was presented Specification of Electron Beam Welding Machine.

The principle of electron beam treatment (EBT) process is illustrated schematically in Fig. 3. In the EBT system, electrons are generated by passing a low current (e.g. 50-200 mA) through a tungsten filament, which can emit a large number of electrons for long time while consuming only little thermal energy. The free electrons emitted by the tungsten filament need to be accelerated to achieve high kinetic energy for treatment. To do this, the filament is attached to the negative side of a high-voltage power supply (30-150 kV); thus, the electrons are accelerated away from the cathode towards the anode. At high vacuum condition, electrons accelerated with a voltage of 150 kV can reach a speed of 2×10^{8} m/s, which is two thirds the speed of light, carrying significant kinetic energy. The divergent high speed electrons needs to be focused to a small spot to achieve the power density of about 1011 W/m^2 required to metals. The beam is focused by magnetic and electrostatic lenses. In most cases the welding process is performed with a stationary electron beam and the workpiece moves beneath it. Sometimes it is also necessary to move the electron beam itself to meet the requirement of the process. This is accomplished using a beam deflecting system which can deflect the beam by application of a magnetic field. By applying an alternating current in the deflection system, the beam can be made to oscillate.

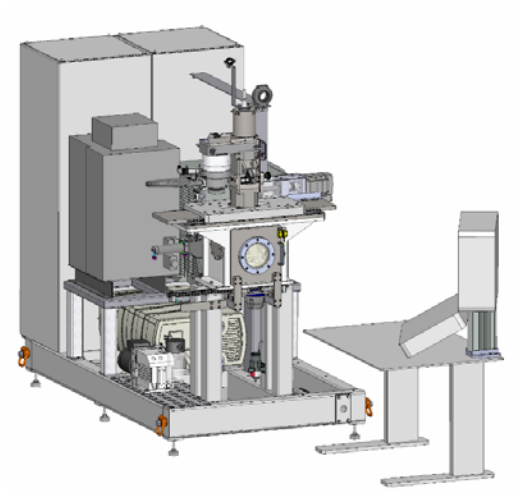

Fig. 2. Evobeam Cube 400 welding unit manufactured by Evobeam

***Table 2** Specification of Electron Beam Welding Machine*

Sl. No	Elements	Description
1.	Vacuum chamber	300 x 300 x 300 mm
2.	Chamber pumping system	High Vacuum Turbo-Molecular-pumpset
3.	Electron Beam gun system	High Vacuum Turbo-Molecular-pumpset
4.	Manipulation system	3 mechanical CNC axes: X, Y and C all interpolated; 4 virtual CNC-Axes: IX, IY, IB und IL
5.	Gun vacuum	5.10^{-4} mbar
6.	Accelerating Voltage (U_a)	60 kV
7.	Beam Current (I_f)	0-100 mA
8.	Welding speed (V)	0-2500 mm/min

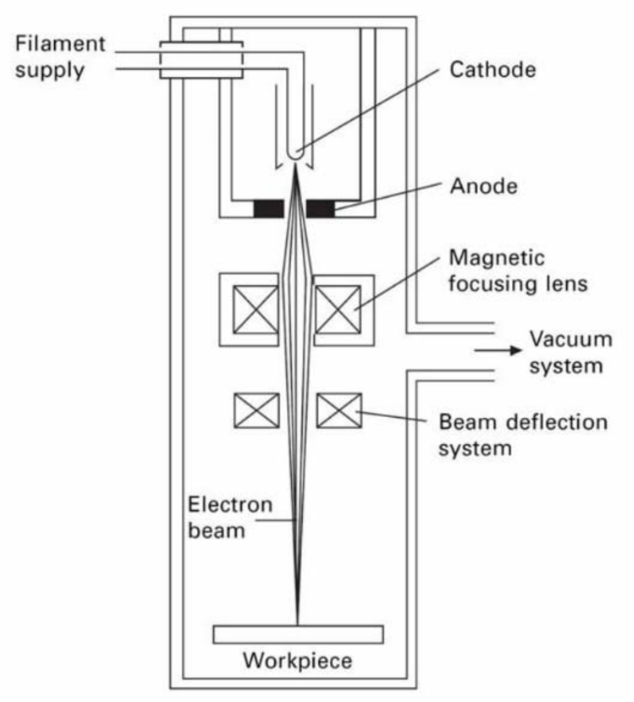

Fig. 3. Schematic Diagram of EBT, Ref. [4]

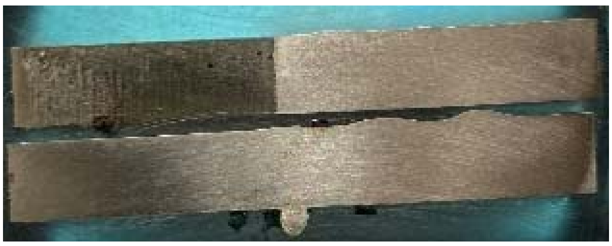

Fig. 4. Microslice of Ti6Al4V

When the focused electron beam impacts on the metal surface, the kinetic energy of electrons is transferred into the metal, causing a rapid increase in temperature. Due to the rapid energy transfer, the metal is locally melted or even evaporated when the temperature is above the boiling point. By using appropriate beam current, accelerating voltage, focus current and welding speed, a weld can be made with a single pass with full penetration [4].

The parameters such as welding speed, beam current and voltage canaffect the EBT conditions. Of this parameters, beam current has more effect on the microstructure, depth of penetration welding width and defects in material after EBT, which is the most important aim of the present work.

The technological parameters of the EBT process are presented in Table 3. These parameters were selected in this way to observe the influence of the current flow on the one hand on the parameters Depth of Penetration (H) and Welding Width (B) and on the other hand in changing the microstructure of the titanium alloy.

***Table 3** Technological parameters of EBT*

Sample	Accelerating voltage U, kV	Focusing current I_f, mA	Welding speed V, mm/min	Beam current I_b, mA
1	60	1510	120	5
2				10
3				15
4				20
5				25
6				30

3. RESULTS AND DISCUSSIONS

To determine the influence of the magnitude of the current from the titanium alloy, a cross section of the specimen was polished and etched (Fig. 4).

To study the effect of current on the microstructure and size grading of different electron beam treated regions and the changes in the geometry of the treatment sites, the sample was cut from the cross section containing all the investigated areas.

The microstructural analysis was done based on a standard metallographic procedure. The test specimen (Fig. 4) was sanded manually using sandpapers of different sizes from 500 to 2500 mm. It was then polished with DiaMax diamond paste and developed with 4-10% aqueous HF solution for an optimum time of 45 s.

Those indicated in Fig. 5 photos were taken using an electron microscope Neophot 32 and magnification x 50.

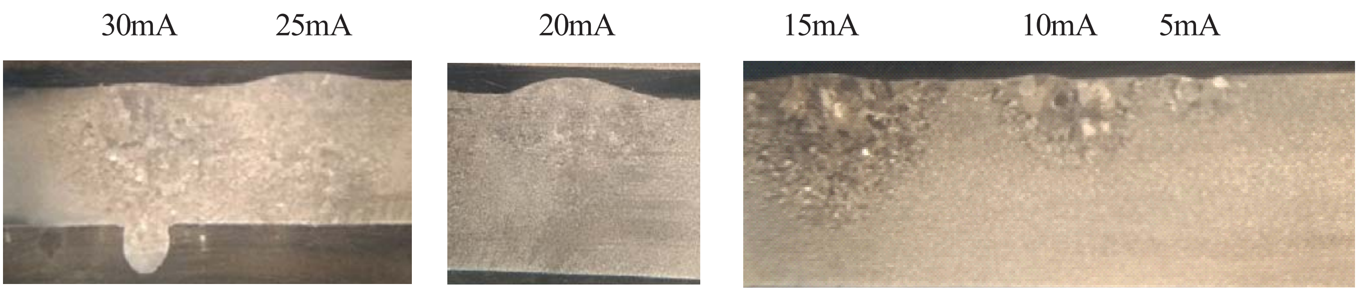

Fig. 5. Photos were taken using an electron microscope

It is clearly seen from Fig. 4 that as the current strength increases, the penetration depth increases up to the magnitude of the current at 30 mA. With this combination of the parameters of electron-beam processing of titanium alloy, a defect is observed, which is of a technological nature - overheating in the base material. A current of 25 mA is also not suitable due to the resulting large thermally affected zones.

At a current of 5 and 10 mA, for a material thickness of 10 mm and more, electron-beam processing is not suitable except in cases of surface modification of layers reaching a certain thickness.

In Fig.6 shows the microstructure of a titanium alloy electron beam treated. Similar to the results in [5] in areas near to the fusion boundary, there is ample opportunity for the new grains to join each other, and thus the coarse grain areas are formed. It is due to higher heat affected zone (HAZ) temperatures. In areas far from the fusion boundary, the conditions for the growth and movement of the boundaries are note as ilyfeasible due to the lower temperature; thus formation of smaller grains has occurred.

The Welding Width (B) of the electron beam treatment at the different magnitudes of the current was measured. From Fig. 7 it can be seen that theWelding Width of the treated area increases proportionally with the increase in the magnitude of the current.

In general, welding speed and heat input have the greatest influence on the type of microstructure.It is clear from Table 3 that during the electron beam processing of the titanium alloy only the current is different and changes in the range (5-30) mA. According to equation (1), the welding current has a direct effect on the heat input [6].

$$Q = \eta . \frac{U . I_b}{V} \quad (1)$$

where Q is the heat input, U is Accelerating voltage, I_b is the beam current, V is the welding speed and η is a constant. The amount of h for electron beam welding is 0.9 [6].

Table 4 gives the calculated heat imput Q at different beam current I_b magnitudes. As expected, as the magnitude of the current increases, so does the heat input.

Measurements of grain size, Welding Width (B) and Depth of Penetration (H) of electron beam machining were made and are shown in Fig. 8. The obtained results are presented in tabular form (Table 5).

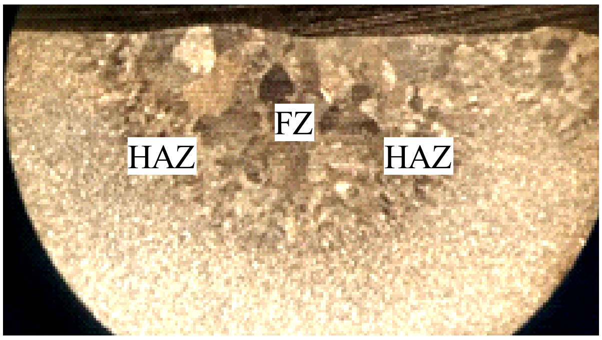

Fig. 6. Microstructure of a sample at a current magnitude of 10 mA

Table 4 *Calculated heat imput Q at different beam current I_b magnitudes*

Sample number	Welding speed V, mm/min	Accelerating voltage U, kV	Beam current I_b, mA	Heat input Q, kJ/m
1	2	60	5	135
2			10	270
3			15	405
4			20	540
5			25	675
6			30	810

Table 5 *Results of measurements of grain size, Welding Width (B) and Depth of Penetration (H) of electron beam machining*

Sample number	Beam current I_b, mA	Depth of Penetration H, mm	Welding Width B, mm	Average grain size
1	5	3,97	1,89	0,72
2	10	7,09	2,03	1,27
3	15	10,52	2,50	1,48
4	20	9,84	4,42	0,97
5	25	13,38	7,65	0,63
6	30	13,28	>10	1,15

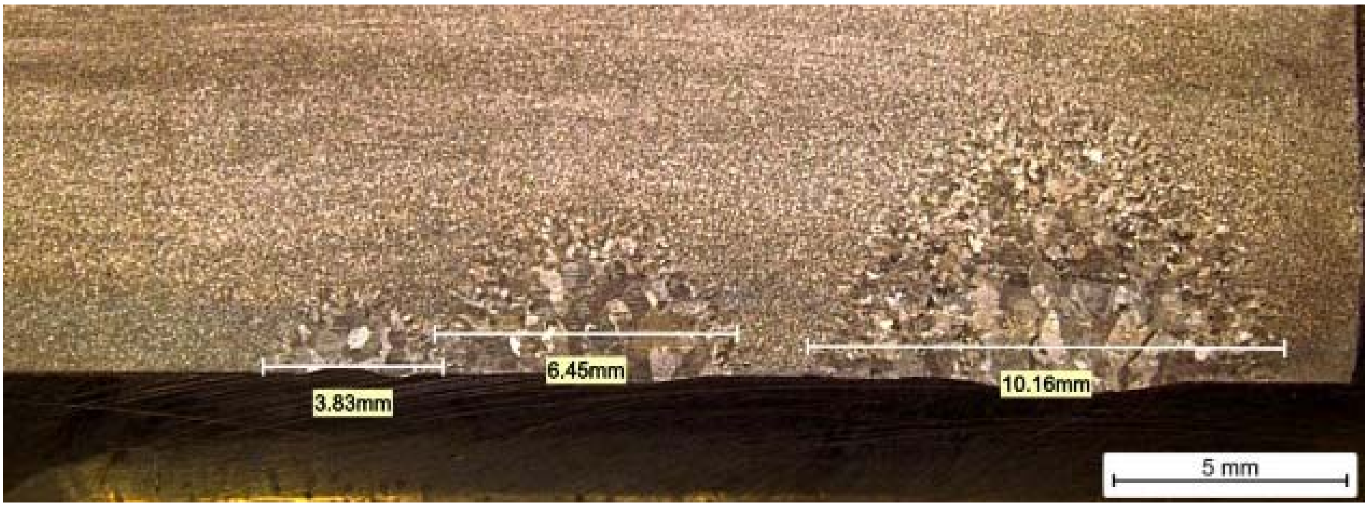

Fig. 7. The Welding Width (B) of the electron beam treatment at current of 5; 10 and 15 mA

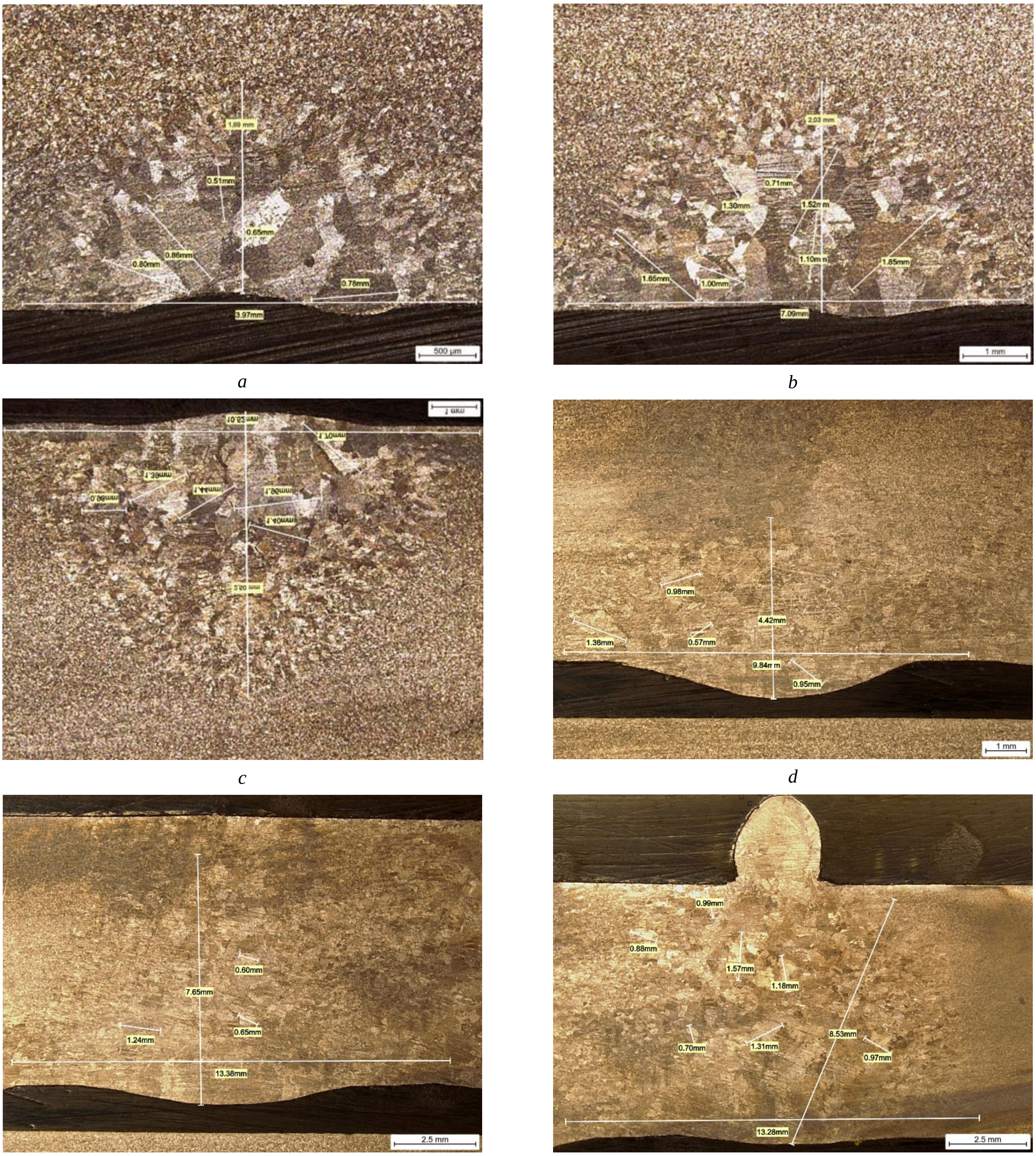

Fig. 8. Measurements of grain size, Welding Width (B) and Depth of Penetration (H) of electron beam machining: a. $I_b = 5\,mA$; b. $I_b = 10\,mA$; c. $I_b = 15\,mA$; d. $I_b = 20\,mA$; e. $I_b = 25\,mA$; f. $I_b = 30\,mA$

4. CONCLUSIONS

The influence of the current during electron beam treatment of titanium alloy on the microstructure and the appearance of defects was determined. Six processing modes were used, varying the magnitude of the welding current. The following conclusions and recommendations can be made:

● regardless of the magnitude of the current, two main zones are observed on the processed sample: FZ and HAZ;

● regarding the microstructure, the statement is confirmed that Welding Width, Depth of Penetration and Heatinputincrease as the current increases;

● the grain sizes in FZ are relatively uniform on the order of (0,97-1,15) mm;

● in the case of surface treatment and depending on the depth of change of the characteristics of the surface layers, it is recommended to use a current of 5-20 mA;

● due to the presence of defects, workpieces with a thickness of more than 10 mm are not recommended to be treated with a current of 30 mA.

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