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ANALYSIS OF WELD JOINTS MADE OF TITANIUM ALLOY GRADE 2 PRODUCED BY ELECTRON BEAM WELDING

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Selected properties of welded joints of 2 mm thick titanium alloy Grade 2 produced by different welding parameters of electron beam welding were investigated. The visual inspection, macro and micro analysis, tensile strength test and microhardness measurements were performed. Samples manufactured by appropriate welding parameters had no internal defects, heat-affected zone (HAZ) was narrow and transformation from α phase to β phase was observed in this area. The failure occurred in the base metal during tensile test, while maximum ultimate tensile strength reached 454,3 MPa.

Keywords: titanium Grade2, electron beam welding, mechanical properties, structural analysis

INTRODUCTION

Titanium is a light metal with a strength close to steel, but its weight in comparison to steel is 45 % lower. Titanium and its alloys are most commonly used in the space, aerospace, chemical, food and petrochemical industries. Titanium has a high affinity for oxygen. Titanium oxide (TiO_2) is rapidly formed on the surface of the metal even at room temperature. [1,2]

From a welding point of view, it should be noted that alloys that can be heat-treated can also be strengthened during the thermal welding cycle. Such alloys during welding may require preheating and subsequent heat treatment. Heat treatment of titanium alloy welded joints can lead to dimensional stability and thus reduces cracking and corrosion cracking. Because of the high reactivity of titanium with oxygen at higher temperatures, it can be welded only in perfect gas protection (argon, helium) or in the vacuum chamber. [3] Electron beam welding uses the energy of concentrated electron beam in the process of joining metallic materials.

This welding method is characterized by high energy density, which allows deep beam penetration into the welded materials. Electron beam welding is most often carried out in a high vacuum. The advantages of electron beam welding include the very good appearance of welds with a very fine surface structure, the minimum specific heat input leading to further advantages such as a narrow heat-affected zone (HAZ) and minimal deformations. [3]

On the other hand, only a small percentage of the total time is used for welding due to the chamber depleting. [4]

Fusion welding and solid-state welding are used for welding titanium and its alloys as well. The results of the two-phase welding of Ti6Al4V alloy by the fiber, disk and Nd:YAG laser has also been published. The authors observed increased microhardness in weld metal as a result of the martensitic structure in the weld [5-7].

Information on electron beam welding of Ti alloys is rather insufficient. The published sources involve the data on the welding of the cast ZTC4 Ti alloy. Structure of the weld joints was formed by martensite. Strength of the weld joints was higher compared to the parent metal [8].

MATERIALS AND METHODS

As a base metal (BM), the commercial titanium alloy Grade 2 was used. The size of samples was 100 × 100 × 2 mm. The chemical composition is shown in Table 1 and mechanical properties in Table 2.

Table 1 **Typical chemical composition of titanium alloy Grade 2 / wt. %**

O	N	C	H	Fe	Other	Ti
0,25	0,03	0,08	0,015	0,3	0,5	Bal.

Table 2 **Typical mechanical properties of titanium alloy Grade 2**

Yield strength / $R_{p\,0.2}$	345 - 450 MPa
Tensile strength / R_m	485 MPa
Elongation / A_5	28 %
Reduction of area / Z	55 %
Hardness / HV	160 - 200
Modulus of elasticity / E	103 GPa
Impact toughness / K_{IC}	40 - 82 J

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The objective of the experiment was to set up the appropriate welding parameters for electron beam welding of titanium alloy Grade 2. Welding was realized at the MTF STU using the equipment shown in Figure 1.

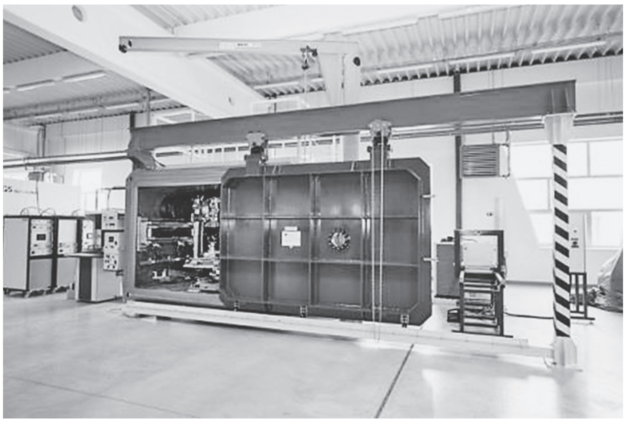

Figure 1 Electron beam welding device

In the first step of the experiment, the welding was carried out at a constant welding speed of 30 mm/s, and the welding current was the variable parameter. The welding parameters at constant welding speed and accelerated voltage of 55 kV, are shown in Table 3. Based on the visual inspection, the welding current of 70 mA was evaluated as the best and set up as constant. In the second step, the welding speed varied. The welding parameters for the constant welding current, accelerated voltage of 55 kV and varying welding speed are shown in Table 4.

Table 3 **Welding parameters at constant welding speed**

Sample	I_z / mA	I_f / mA	v_z / mm/s	P / kJ/mm
1.1	60	890	30	0,099
1.2	80	890	30	0,132
1.3	100	890	30	0,165
1.4	40	890	30	0,066
2.1	70	890	30	0,115
2.2	90	890	30	0,148
2.3	50	890	30	0,082
2.4	30	890	30	0,049

I_z – welding current, I_f – focusation current, v_z – welding speed, P – specific heat input

Table 4 **Welding parameters at constant welding current**

Sample	I_z / mA	I_f / mA	v_z / mm/s	P / kJ/mm
3.1	70	890	20	0,173
3.2	70	890	40	0,087
3.3	70	890	15	0,231
3.4	70	890	35	0,099
4.1	70	890	10	0,346
4.2	70	890	50	0,0693
4.3	70	890	25	0,138
4.4	70	890	45	0,077

I_z – welding current, I_f – focusation current, v_z – welding speed, P – specific heat input

Prior to welding, the base material was cleaned from oxides. Consequently, penetration welds according to the parameters shown in Tables 3 and 4 were performed. The penetration welds are shown in Figure 2.

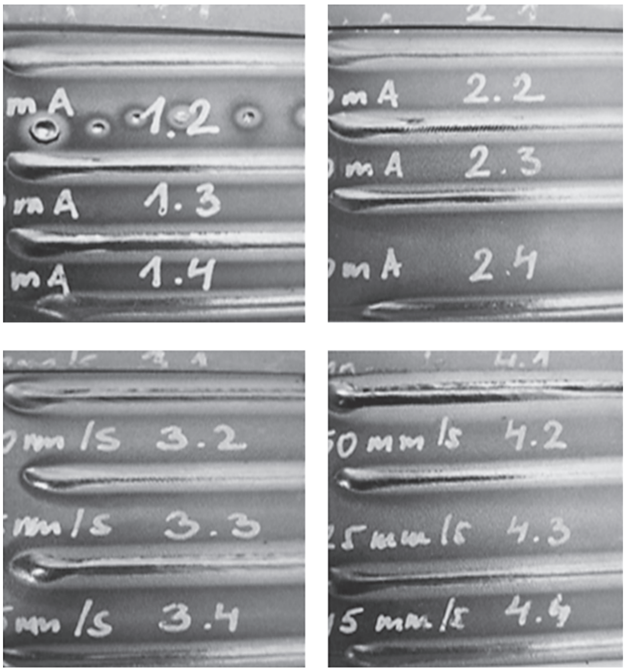

Figure 2 Penetration welds

RESULTS

Visual inspection revealed that the penetration welds were without undesired coloration, i. e. the vacuum provided sufficient protection for the welded materials. Samples 1.2, 2.1, 3.2, 3.4, 4.2 and 4.4 were judged to be satisfactory by visual inspection. In all other samples,

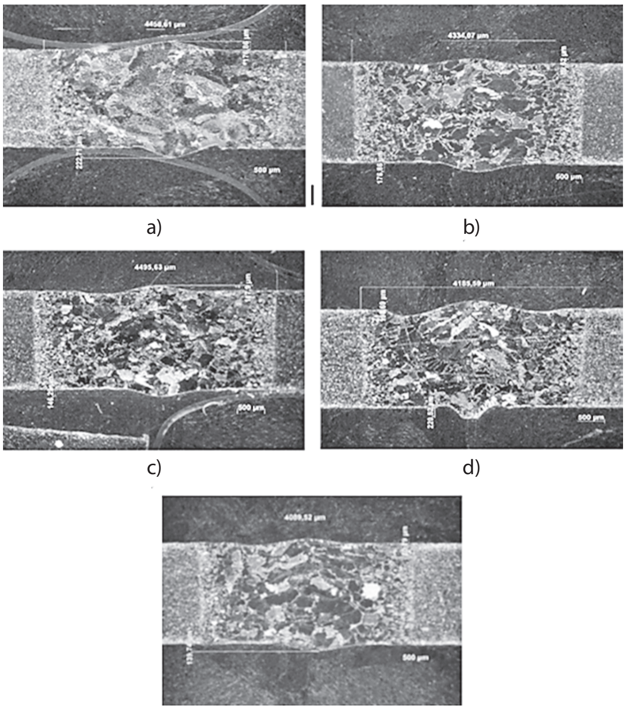
a) b) c) d) e)

Figure 3 Macroscopic analysis
a) 2.1; b) 3.2; c) 3.4; d) 4.2; e) 4.4

the lack of penetration in the weld root was observed. Moreover, the samples 4.3, 4.1, 3.1 exhibited lack of fusion in the weld root and continuous undercut was observed in samples 4.1, 3.3 and 3.1. Based on these defects, all mentioned penetration welds were evaluated by visual inspection as unsatisfactory.

Samples designated by visual inspection as satisfactory were further subjected to macroscopic analysis. Images from the macroscopic analysis showed that the examined samples had a narrow HAZ – typical for electron beam welding. No internal defects such as cracks, cavities or pores had been observed in the welds (Figure 3). The examined samples were therefore indicated as satisfactory.

Microscopic analysis of the samples was carried out by a NEOPHOT 30 light microscope. Given that all samples had a similar microstructure, microscopic analysis was performed only on sample 3.2.

The microstructure of the base metal is shown in Figure 4 and consisted of α titanium with a fine-grained polyhedral structure with a grain size in the range of 10 - 40 µm.

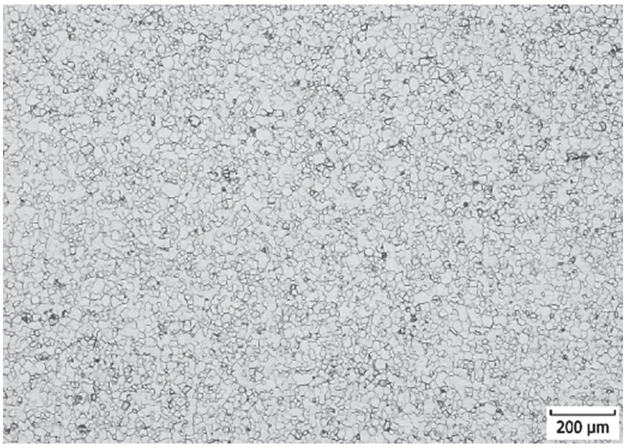

Figure 4 Microstructure of base material

The material had a monophase structure. The transition from base material to HAZ (Figure 5) was narrow and grain coarsening arose here. In the transition region, the grains lost their polyhedral character and grains with acicular morphology were formed. This change was caused by α to β phase transformation at a temperature of approximately 888 °C. This transformation was partly diffuse and partly diffusion-less.

The weld metal (WM) microstructure is shown in Figure 6 and consisted of coarse polyhedral grains with acicular morphology. The Widmannstätten structure and twinning of the grains which is characteristic of the martensitic structure was possible to rarely observe. In this case, martensite was formed by phase β oversaturated with β-stabilizing elements. The dark areas in the weld metal microstructure were acicular grains containing very small (1 µm) polyhedral grains.

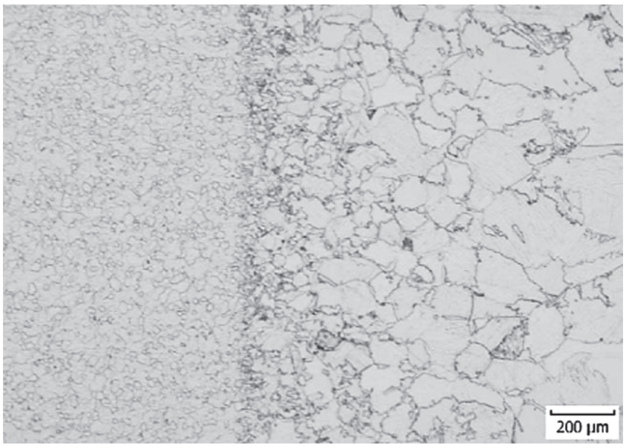

Figure 5 Transition area microstructure

Figure 6 Weld metal microstructure

The microhardness measurement was performed on a Bühler Indentament 1 105 microtest. The test was carried out with a load of 0,98 N. The load time was 10 seconds. The measured values are plotted in Figure 7. The hardness of the weld metal and the HAZ was higher than the hardness of the base metal.

The observed microhardness of titanium alloy Grade 2 was between 135 - 203 HV. Hardness exceeding 200 HV might have been caused due to the presence of martensite or measurement inaccuracy.

The tensile test was performed on a Tinius and Olsen 300 ST instrument. Samples 2.4, 3.2 and 3.4 were used for the tensile test. Three test pieces were made

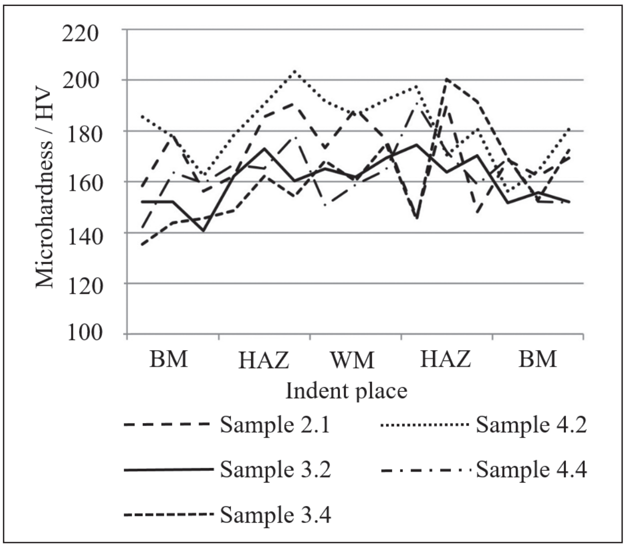

Figure 7 The course of microhardness

Table 5 **Tensile test measured values**

Sample	Test piece	R_m / MPa	A_5 / %	Failure
2.4	1.1	434	17,6	BM
	1.2	451	13,3	Weld
	1.3	451	18,2	BM
3.4	2.1	451	16,4	Weld
	2.2	466	19,9	BM
	2.3	446	17,7	BM
3.2	3.1	442	18,7	BM
	3.2	443	18,4	BM
	3.3	457	20,0	Weld

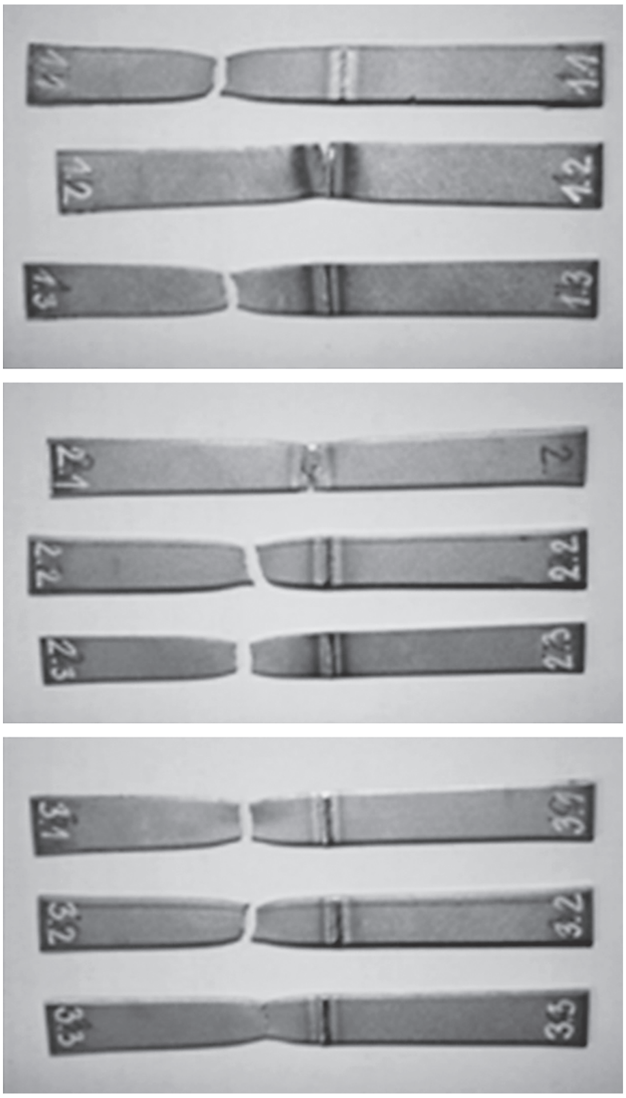

Figure 8 Test pieces made from samples 2.4, 3.4 and 3.2 after tensile test

from each sample. The values obtained by the tensile test for individual test pieces are shown in Table 5.

Most of the test pieces broke in the base metal, only the test pieces marked as 1.2 and 2.1 were broken in the weld. All test pieces after tensile test are shown in Figure 8. Based on the tensile test results, it was found that the most appropriate welding parameters regarding the tensile strength were used in sample 3.2 where the failure occurred in the base metal of all three test pieces.

CONCLUSIONS

The experiment was focused on the set up of the appropriate welding parameters for electron beam welding of titanium alloy Grade 2. The penetration welds produced at the various welding parameters were subjected to visual control, which was judged to be satisfactory for samples 2.1, 3.2, 3.4, 4.2 and 4.4 and therefore subjected to further investigation. Subsequent macroscopic analysis showed that the penetration welds had a narrow HAZ and there were not observed any internal errors such as cracks, cavities or pores.

The microstructural analysis of the penetration welds revealed that the grains of the base metal had polyhedral fine-grained structure. The material had a monophase structure. In the HAZ, the grains due to the temperature approximately 888 °C changed from α phase to β phase. The transformation from polyhedral to acicular grains was observed.

The hardness of the samples continuously rose towards the weld metal, only in some cases it varied. The hardness in welding metal ranged from 150,6 to 219 HV.

The highest average tensile strength 454,3 MPa was observed at sample 3.4. Tensile strength variance was in the range of 345 - 485 MPa, which was typical for titanium alloy Grade 2 titanium.

Based on performed weld joint quality examination, the appropriate electron beam welding parameters of 2 mm thick titanium alloy Grade 2 were: accelerated voltage 55 kV, welding current 70 mA, focusing current 890 mA and welding speed 40 mm/s.

Acknowledgement

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Note: Responsible translator; Martina Šuto, University of Osijek, Osijek, Croatia.