RESEARCH ON THE INFLUENCE OF ELECTRON BEAM WELDING OF TITANIUM ALLOY MICROSTRUCTURE CONNECTION

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Abstract

Microstructures, properties and technical parameters of the welds carried out by the electron beam welding (EBW) process have been investigated in the present paper. Electron beam welding (EBW) is a fusion joining process particularly suitable for the welding titanium. Electron Beam welding is a natural choice for use with materials susceptible to oxidation such as titanium because the EB welding process must occur in a vacuum. During research a two-pass welding technique was developed. In paper there was investigated the electron beam welded joint made of titanium alloy. The weld qualification was carried out by mechanical properties and microstructure evaluations were carried out to ensure the joint integrity. Microhardness measurements of the weld where taken using *Matsuzawa Vickers MX 100* type with applied load 100 g (0.98 N). Light microscopy *Nikon Eclipse MA200* was used for examination of the microstructure and determination of the size of the specific joint zones.

Keywords: Microwelding, electron beam welding, surface engineering microstructure, microhardness

1. INTRODUCTION

The progress observed in the field of materials engineering, surface engineering forces improved quality of the welded joints, superficial layer properties is accompanied by increase of the manufacturing processes. The machining of produced elements, for example, in the aerospace industry is an extremely important. The above requirements require the use of many advanced manufacturing techniques belongs to the non-conventional group of machining methods such as electrochemical machining (ECM), abrasive water jet cutting (AWJ) laser welding and cutting, abrasive flow machining (AFM), electrical discharge machining (EDM) [1] or nonconventional welding processes [2-4]. There are many methods of surface improving processes some of them belong to the group conventional machining: grinding, mechanical polishing, suprefinishing [5, 6]. With progress of titanium industries, many welding methods such as gas tungsten arc welding (TIG), beam welding, resistance welding and diffusion welding have been developed.

The paper is focused on EBW welding effects as a "non-conventional" machining methods of titanium alloys, having wide application in aerospace and energy industry. The aim of research is to study the effects of EBW welding on titanium alloys.

In the article the welding technology, the structures and properties were analysed for titanium sheets. Needless to say that titanium is a unique material, which requires special attention in all the areas of processing, especially in welding. Titanium and its alloys are available in various ranges of high specific strengths and are considered as one of the best engineering material for industrial application [7-9]. The excellent combination of properties such as moderately high specific strength, high fatigue life, toughness, excellent resistance to corrosion and low density makes them attractive for aerospace applications. Titanium alloys are easy to absorb harmful atmospheric gases such as oxygen, hydrogen and nitrogen, because of their high chemical activity. However it influences on lower mechanical properties and causes appearance of unstable structures [10, 11]. While TIG is well known and often used welding method, the laser beam welding (LBW), pulse microwelding, EDM and EDS (alloying) technics are considered as a new welding technologies, characterized by its high energy density and welding speed [12-16]. In turn, using high vacuum electron beam welding (EBW-HV) could protect joints from gaseous contamination. The welding experiments of titanium sheet with 0.5 mm thickness were tested by using the above methods. Titanium exists in two allotropic phases, α phase and β phase. The HCP structured α is stable up to 882 °C and transforms to BCC β thereafter. Ti6Al4V, which is a α-β titanium alloy, is currently the mainly-used titanium alloy of aerospace industry due to is high strength and good capability of being shaped and formed [7]. It contains about 6 wt.% Al for α stabilization and 4 wt.% V for β stabilization. The α-β alloy gives a possibility of varying mechanical and physical properties by controlling the micro-structural development during thermo-mechanical processing. The higher content of interstitial gasses (oxygen and nitrogen) gives slightly higher strength but lower ductility and toughness. At the same time lesser content of gasses would improve ductility, fracture toughness and influence positively on stress corrosion and crack growth resistance. The alloy that contains low interstitial elements is so called Extra Low Interstitial grade (ELI) [8]. The welding technology of titanium is complicated because in molten stage (at temperatures above 1668 °C) it reacts easily with atmospheric gases causing its embrittlement. Also poor preparation and cleaning of the joint along with impurities in the shielding gas could cause contamination [9-11]. That's why joining titanium alloys require special precautions to avoid contamination of the fusion and heat affected zone (HAZ) of the joint. Fusion welding of titanium is performed mainly in inert gas shield, with high energy beam. Electron beam welding (EBW) method is highly suited for joining titanium and it's considered as pure one. The process is carried out inside the high vacuum chamber for it shields hot metal from contamination. Comparing to arc welding processes the joint depth (using EBW method) is achieved with high beam power density and with lower heat input [3]. The Authors focused their studies on the Ti6Al4V alloy, because of its use in the aviation, aerospace, nuclear engineering, civil and chemical industries [17-22]. Forged Ti-6Al-4V popularity increases due to industry-important properties, such as: slow cycle fatigue strength and crack propagation resistance. Ti6Al4V based wrought products (forged, extruded, as cast, or rolled materials) are widely used as structural and engine parts in aircrafts, in life-limit parts for civil aviation engines [18, 19] and fractured critical parts for military engine, such as disks. Current research has confirmed that the mechanical properties of titanium alloys joined by bulk titanium were comparable to those of EBW [23, 24], which was primarily attributed to the characteristic microstructure formed during fast cooling and rapid solidification processes [14, 25, 26]. The mechanical properties of thick weldments, along the thickness direction, vary significantly due to the heterogeneity in microstructure, and were affected the geometry of the actual joints by some welding parameters [27, 28]. Methods for controlling the microstructure and the geometry design are considered to be important factors for achieving high performance thick weldments [29-31].

2. EQUIPMENT AND MATERIAL

2.1. The weld microstructure

All welding experiments were performed using TECHMETA NC model pulsed electron beam welding machine. The degree of vacuum in EBW was 10^{-4} Pa, and the weld parameters of the electron beam are: current - 40 mA, voltage 40 kV. The welded samples were sectioned into metallographic specimens. These metallographic samples with a diameter of 30 mm were prepared using conventional metallographic procedures used for titanium alloys. For structures of the joints illustration, metallographic microscope Nikon Eclipse MA200 with the NIS 4.20 image analysis system was used. The joints samples preparation process included cutting across the weld and mounting in resin. After proper polishing and etching using 4% HF the weld structure was observed on **Figures 1** and **2**.

a) b)

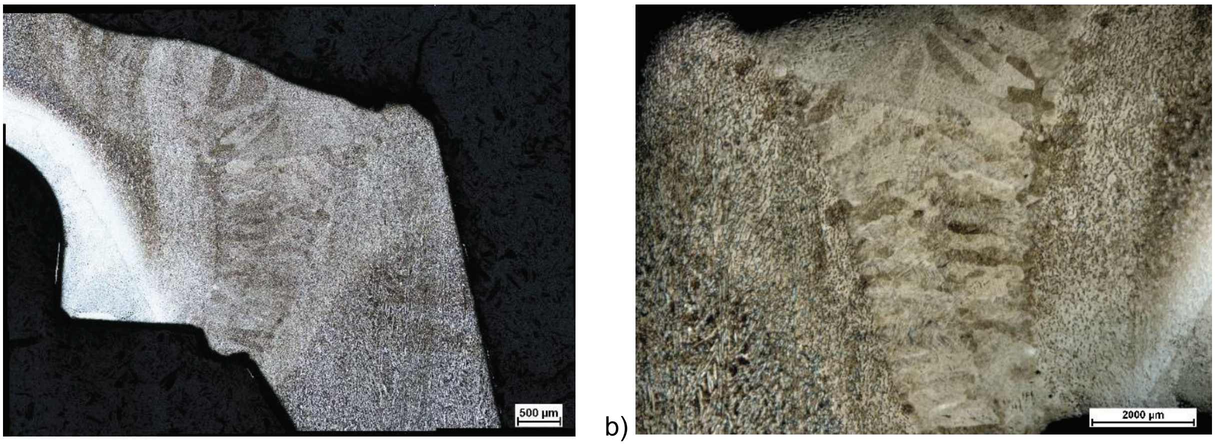

Figure 1 Macrophotography of weld structure

a) b) c)

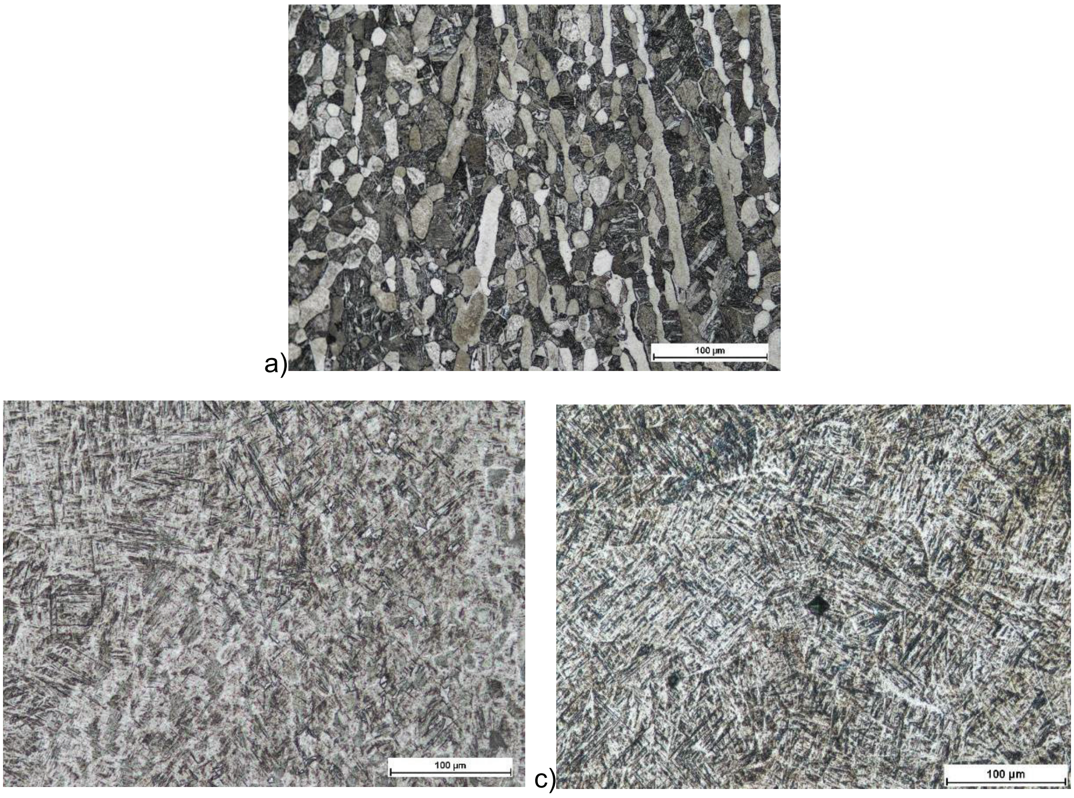

Figure 2 Microphotography of weld structure a) BMZ; b) HAZ c) WZ

2.2. Microhardness of joints

Microhardness tests were carried out by using a Vickers indenter, with an applied load of 0.98 N for 15 s. For investigation there was used Matsuzawa Vickers microhardness MX 100 type, with applied load 0.98 N. The tests were conducted in the heat affected zone, base material and weld.

3. RESULTS AND DISCUSSION

The joints welded by EBW method were smooth, bright sliver with small deformation. Although during the welding process the precautions were carried out, the back of welded joints would also be oxygenated because the samples were thin and easy to deform. The microstructures of the welded joints were observed using SEM

JEOL JSM 7100F microscope The SEM examination of the EBW joints samples showed full-penetration of obtained structures with no observed pores and no defects. The surfaces of the welded joints have typical casting structures composed of similar grains size in the centre and the dendritic grains in the outside of welded seam. **Figure 3** shows the EBW welded joint surface SEM photographs and distributions of elements obtained by EDS method.

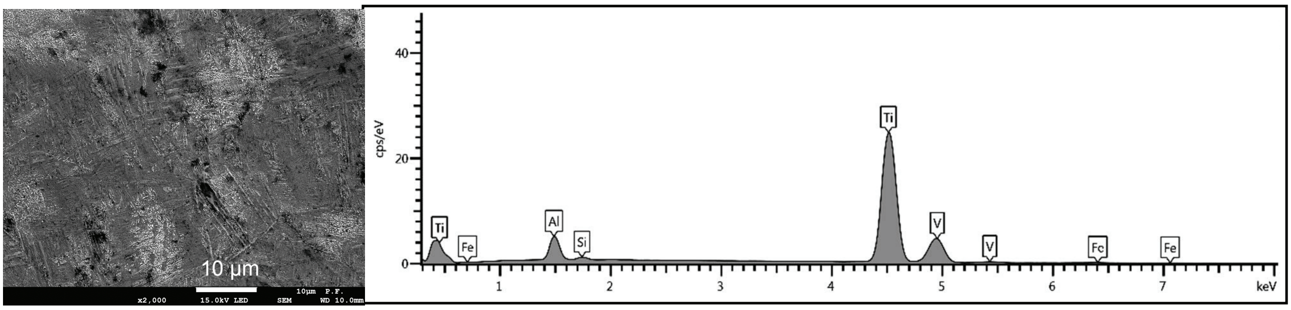

Figure 3 The structure of WZ by EBW methods and EDS

The welded joint is described by: the weld zone (WZ), heat affected zone (HAZ) and base metal zone (BMZ). The WZ is thin, the joint lines on both sides of the weld are almost parallel and the HAZ is very narrow. The welded joint showed the typical characteristic of high aspect ratio, which was characteristic for high energy density of the electron beam welding (EBW). **Figures 1 a)** and **1 b)** is a low-magnification optical micrograph showing a cross-section of Ti6Al4V plate. The microstructure of the base metal zone was studied by optical metallographic observation, as shown in **Figure 2**. It can be seen from **Figure 2 c)** that the microstructure of base metal zone consists of two phases (α, β). For accurate visualization of transformations, XRD testing is required. The microstructure of weld zone (WZ) is shown in **Figure 2 c)**. The weld zone formed a great deal of dispersed acicular martensite α′ phase. The microstructure of the heat affected zone was between the microstructure of base metal zone and the microstructure of weld zone. The microstructure of the base material consisted of same-size grains within a grain boundary network of the β phase, the latter being small in amount on account of the low manganese content in the alloy [10]. The fusion zone (FZ) of EBW was rather narrow, 2-4 mm width. The development of microstructure from the base metal to fusion zone was obvious. The **Figure 2 c)** shows that the fusion zone microstructure was composed of columnar grains oriented perpendicular to the direction of the radial fusion border. An area of 200 µm between the base metal and the fusion zone could be considered as the heat affected zone (HAZ). While weld heat input was increased, the sizes of grains in the fusion zone varied from equiaxed morphology to columnar grain. This dissimilarity could be affected by the difference in temperature gradients and solidification rates at different weld heat inputs. The chemical composition profiles for Ti, V, Al, Fe elements were examined by SEM from the weld to heat affected zone (**Figure 3**). As shown in **Figure 3 b)**, the elements Ti, Al and V, Fe, which are the presumed components of FZ and HAZ, have been identified. A microhardness of the welded joint condition was measured using *Matsuzawa Vickers MX 100* type with applied load 0.98 N. The fusion zone microhardness (407 µHV) increased highly relative to the base metal microhardness of 391 µHV. The hardening of the weld zone with peaking at its centre may be caused by difficulty of slip. At the same time middle welding heat input had not caused heavy grain coarsening, the microhardness distribution was relatively even.

4. CONCLUSION

On the basis of observations and analyzes it can be presumed that the microstructure of the WZ is the martensitic phase α'. The HAZ consists of a fine-grained and coarse-grained zone; the microstructure of the fine-grained zone was the original phase α + phase β + equivalent phase α, and the microstructure of the coarse zone was the original phase α + α' phase. The microstructure of the base metal zone consisted essentially of a long tape and primary α phase and a small amount of the remaining phase of β.

Studies have shown that the welding EBW is an effective method of joining titanium alloy. The metallographic observations, and microhardness measurements shows:

- the proper microstructure connection was obtained with the correct power parameters.
- no cracks were found in the area of the weld and heat affected zones.

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