Materials Science & Engineering A 608 (2014) 199–206

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Mechanical properties of Ti6.5Al2Zr1Mo1V titanium alloy with EBW under different temperatures

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ARTICLE INFO

Article history:
Received 15 September 2013
Received in revised form
11 April 2014
Accepted 15 April 2014
Available online 24 April 2014

Keywords:
Electron beam welding
Oscillation
Titanium alloy
Microstructure
Tensile property
Impact toughness

ABSTRACT

With the development of welding technology, electron beam welding (EBW) is manufacturing the aero parts with heavy thickness. To improve welding quality and mechanical property, we employed EBW with beam oscillation on Ti6.5Al2Zr1Mo1V alloy with 60 mm thickness, and observed the weld microstructures after X-ray NDT, and conducted the tensile and impact tests under different temperatures. The results showed the crystals of the welds were fringe, and the microstructures of the welds were acicular α' martensite. The acicular and isometric crystals existed in HAZ, which were α' martensite mixed with $\alpha+\beta$ structure. With the increase of the temperatures, tensile properties of the top and bottom joints gradually lowered, and the strengths were almost equal to base metal, and the percentage elongations after fracture were lower than those of base metals. The strength overmatching of the joints resulted in the inhomogeneous elastic–plastic deformations, and tensile specimens of the joints ruptured in base metal. The impact toughnesses of top welds were equal to the bottoms under different temperatures, which were lower than those of base metals. Electron beam oscillation improved the uniformity of the microstructures, which contributed to the homogeneity of mechanical properties from the top to bottom joints.

1. Introduction

The material of Ti6.5Al2Zr1Mo1V is one of near α titanium alloy, which aluminum enhances mechanical strength, and zirconium and vanadium improve the stability of manufacturing processing. The engineers widely investigated on the microstructures and mechanical properties of the materials in China [1–17], which exhibited high strength, high stabilization and excellent tenacity. Laser beam welding (LBW), electron beam welding (EBW) and argon-arc welding were applied to aero parts, and EBW was suited to welding the materials with medium and heavy thickness [18–20].

Because of high power density, low deformation and great depth-to-width radio, EBW is capable of large components instead of the conventional welding and bolting technology, especially full penetration welds of heavy thickness by single pass [21,22]. EBW was employed to weld the Fwd and Aft booms of Ti–6Al–4V ELI alloy for F-22 Raptor, which the booms were welded with 6.4–25 mm thickness and 87.6 m length [23]. The wing boxes of titanium alloy were EB welded with 12–57.2 mm thickness for F-14 TOMCAT, and the weight cut 270 kg compared with the bolting [24].

The processes and mechanical properties of titanium alloy with EBW were studied in India, Germany, Russia and USA. Barreda et al. [25] investigated the behaviors of a 17 mm Ti6Al4V weld with a filler titanium alloy of similar and different composition to the base plate with a 3 kW electron beam welder. Saresh et al. [26] investigated the microstructure and mechanical properties of single-pass and two-pass double side joints of Ti6Al4V alloy with 21 mm thickness, and qualified all the tests requirements of aerospace applications. Huez et al. [27] welded Ti6Al4V alloy plates with 10 mm thickness in different processing routes by EBW, the configurations of α' martensite in the welds were entire different after PWHT, which resulted in the difference of the mechanical properties. The investigations were focusing on Ti6Al4V alloy, and the materials of Ti6.5Al2Zr1Mo1V alloy were seldom studied. In China, Zhang [19] observed and studied weld shape and the microstructure of medium thickness Ti6.5Al2Zr1Mo1V alloy with EBW. Ji [18] and Li [20] investigated fatigue properties of Ti6.5Al2Zr1Mo1V alloy joints with EBW, and discussed the influence of the microstructures on mechanical properties.

From the literatures review, mechanical properties of EBW joints under different temperatures were not reported in detail for titanium

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http://dx.doi.org/10.1016/j.msea.2014.04.048
0921-5093/

alloy with heavy thickness, which would be very essential to the aero application. EBW with beam oscillation was investigated on Ti6.5Al2Zr1Mo1V titanium alloy with 60 mm thickness, and the morphology and microstructure of the welds were observed in the paper. The tensile and impact tests were conducted under different temperatures, and mechanical properties of the joints were investigated. The influences on mechanical properties of the joints were discussed.

2. Experimental procedures

The materials were Ti6.5Al2Zr1Mo1V alloy with forging and annealing, whose chemical compositions (weight percent) were Al6.91%, V2.19%, Zr2.21%, Mo1.66% and Ti balance. The microstructures of base metal were $\alpha+\beta$ (shown as Fig. 1), and the boundaries of β crystals were entirely cracked. The proportion of primary α was less than 10%, and the length of lathy α was lower than 0.25 mm. The samples with 300 mm × 200 mm × 60 mm, were grinded the oxidation surface and cleaned by ethanol before welding.

The welds were accomplished along the length of the samples by ZD30CCV85M EB welder. To improve welding quality, beam oscillation was employed during EBW (Fig. 2), where electron beams oscillated and rotated with high frequency. Electron beam oscillation brought about an intense stir to molten pool, and enhanced the keyhole effect, which allowed gas porosity to rise and escape from the weld pool [21]. The root spikings of the welds were also reduced by EBW with beam oscillation.

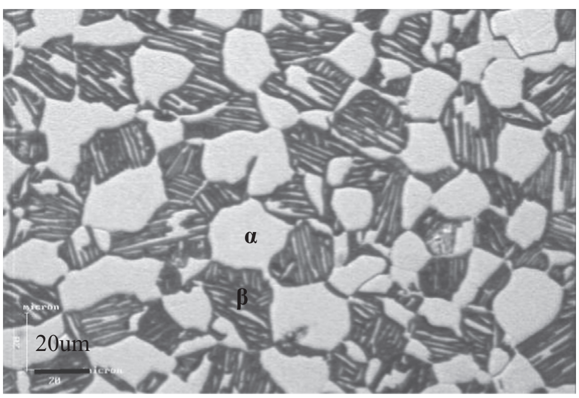

Fig. 1. Microstructure of base metal.

The welding parameters are shown in Table 1, and the function wave of beam oscillation was circular, and the amplitude (*Bx*) was 0.5 mm. The spot of beam oscillation was observed by CCD (Fig. 3), and the energy was convergent and steady.

The appearance of the weld was uniform and smooth without undercuts (Fig. 4), and the reinforcement of the weld was narrow. The samples were annealed at 800 °C with 2 h after EBW.

The samples were inspected by X-ray NDT, and all the welds were eligible for the standard without the porosities and cracks. The metallographic, tensile and impact specimens were prepared from the samples, and the tensile and impact tests were conducted under different temperatures.

3. Results and discussions

3.1. Microstructures and microhardnesses

The widths of the frontal and rear welds were 8.5 mm and 2.3 mm respectively, and the weld morphology was parallel (Fig. 5).

The welds were observed by an optical microscope (Fig. 6). The crystals of the welds were fringe (shown as Fig. 7), which gradually thinned along weld penetration. Acicular and isometric crystals existed in HAZ, and were similar to base metal. The crystals were inclined to be uniformity along weld penetration.

Because of the rapid cooling velocity, the microstructure of EB welds were acicular α' martensite (shown as Fig. 8). With the increase of weld penetration, the configuration of α' martensite did not change. The microstructures of HAZ were α' martensite mixed with $\alpha+\beta$ structures, and the dimensions were consistent from the top to bottom. The homogeneity of the crystals and microstructures was attributed to beam oscillation.

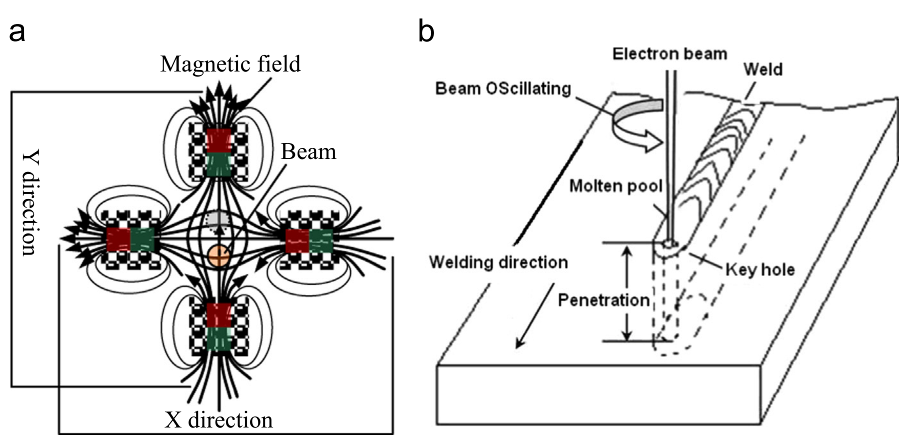

Fig. 2. EBW with beam oscillation. (a) Beam oscillation by deflecting, (b) beam oscillation welding.

Table 1
Parameters of EBW with oscillation.

Process	Voltage U_a/kV	Current I_b/mA	Focusing I_f/mA	Velocity $v/(mm\ min^{-1})$	Scanning
	150	2158	180	600	Circle, $Bx=0.5$ mm, $f=500$ Hz