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Effect of beam offset on microstructure and mechanical properties of dissimilar electron beam welded high temperature titanium alloys

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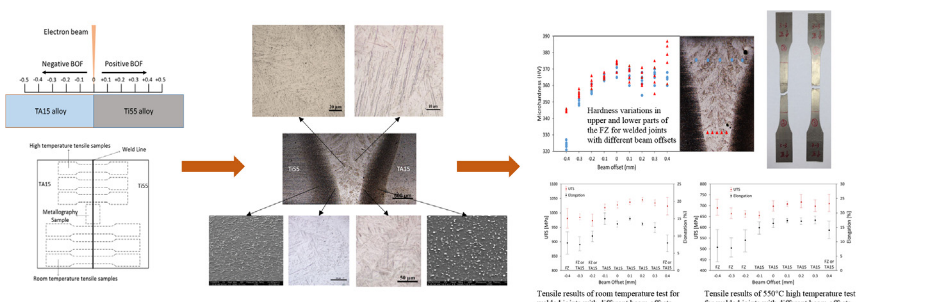
HIGHLIGHTS

- Dissimilar EB welding of Ti55-TA15 is investigated for the first time.
- The Effect of beam offsetting on microstructure and mechanical properties of welded joint is studied.
- The higher reinforcement of the weld is found in the welded joints with beam offset towards Ti55.
- Tensile test and microhardness results are in accordance with chemical composition and microstructure observations.
- The porosities are found in high beam offset welded joints in both directions.

GRAPHICAL ABSTRACT



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ABSTRACT

Electron beam welding was used to join dissimilar Ti55 to TA15 titanium alloys. The aim of this study was to investigate the effect of the beam offset on microstructure and mechanical properties of the welded joints. Microstructural characterization was investigated by optical microscopy, scanning electron microscopy and X-ray diffraction. Tensile test was conducted at room temperature and 550 °C. Results indicated that the fusion zone consisted of martensite α' and acicular α. Heat affected zone (HAZ) in both Ti55 and TA15 sides consisted of two regions; Low temperature HAZ (LT-HAZ) was composed of primary α, secondary α and prior β and high temperature HAZ (HT-HAZ) was composed of martensite α' and acicular α. The hardness of fusion zone was lower than HAZ of both Ti55 and TA15 alloy. Energy-dispersive spectroscopy was applied to display microstructure evolution inside the fusion zone. Tensile results showed that offsetting the beam position towards Ti55 alloy led to higher values of joint strength. Beam offsetting towards TA15 alloy lowered the hardness and strength of welded joints. Increasing the beam offset to the values >0.3 mm towards Ti55 or TA15 resulted in premature fracture due to increasing the possibility of porosity formation inside the weld metal.

1. Introduction

Titanium alloys have a growing application in aerospace, automotive and nuclear industry due to their significant characteristics such as corrosion resistance, good fatigue behaviour and low density to strength [1–5]. Near-α titanium alloys are well known as high temperature service alloys. They can undergo up to 600 °C depending on the alloying

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elements and heat treatment [6–11]. Owing to the fact that hexagonal crystal structure α possesses higher creep resistance in comparison with bcc structure β, the amount of α stabilizers such as Al are relatively high in near-α titanium alloys, however the β stabilizers such as Mo, V and Nb are frequently found in these alloys to improve processing characteristics [12].

So far, several works have been performed on dissimilar welding of titanium alloys. They mainly focused on microstructure and mechanical properties such as tensile and notch tensile strength, [13–15], strain hardening behaviour [16], cyclic deformation [17] and fatigue properties [18–22]. A number of previous studies showed that the hardness and strength of the fusion zone exhibited low values owing to formation of soft phases. For example Lei et al. [23] studied on laser welded Ti–22Al–27Nb/Ti–6Al–4V dissimilar alloys. They found that fusion zone exhibited lowest hardness value in the welded joint owing to presence of soft phase B2. Li et al. [24] revealed similar softening in the fusion zone of laser welded joints of dissimilar Ti–22Al–25Nb/TA15 titanium alloys. Zhang et al. [25] studied on laser-TIG hybrid welded dissimilar joints of Ti–22Al–27Nb and TA15 and also found soft B2 phase inside fusion zone. Wang et al. [18] focused on dissimilar EB welding of Ti–6Al–4V and BT9 titanium alloys and showed that two hardness sub-regions could be identified inside the fusion zone.

Offsetting the beam position changes the contribution of base metals in chemical composition of the weld metal in dissimilar beam welding processes and consequently results in different mechanical properties of welded joint. In case of titanium alloys, previous researches on beam offsetting mostly regarded to dissimilar welding of titanium alloys to another metals such as aluminium alloys in order to suppress formation of undesirable intermetallic compounds in the fusion zone [26–28]. However, few works have been performed on the effect of beam offset on weld joint properties of dissimilar titanium welds. Zhang et al. [29] revealed that the microstructure and the mechanical properties of the weld metal were influenced by the beam offset in pulsed laser welded BTi-6431S/TA15 dissimilar titanium alloys. Liu et al. [30] showed that offsetting of the laser beam position could be utilized to control the chemical composition of fusion zone in laser beam welding of Ti–6AI–4V to Beta-C titanium alloy.

Ti55 titanium alloy was firstly introduced by Chinese producers with the nominal chemical composition of Ti–5.5Al-4Sn–2Zr–1Mo–0.25Si–1Nd [31,32]. In order to improve weldability and to extend the range of application, recently the rare earth element Nd has been replaced by Ta and Nb elements in new generation of Ti55 alloy. Hereinafter the Ti55 alloy refers to the new generation of Ti55 with chemical composition presented in Table 1. Ti55 alloy is extensively applied in manufacturing of aerospace components such as compressor, drum and blade parts of high-pressure sections in aero-engines owing to long-term durability for service up to 550 °C [33–35]. TA15 alloy is extensively used to manufacture structure components in aerospace industry due to moderate room temperature and high temperature strength, good thermal stability and welding performance [7,36,37]. Although both Ti55 and TA15 alloy are known as high temperature titanium alloys for service up to 550 °C, but Ti55 alloy is preferred to use at higher temperature services due to longer thermal durability. Electron beam welding of dissimilar Ti55 to TA15 titanium alloy is used in structural components with different working temperatures in aerospace industry. For instance, the higher temperature of inlet of aero-engine, inevitably leads to using the materials with higher temperature resistance such as Ti55 alloy for inlet part along with joining to the inner structure which is made from TA15 alloy. Few number of researches on the beam offset of titanium alloys along with the fact that literature on welding properties of new generation of Ti55 alloy is rare, encouraged the authors to focus on dissimilar electron beam welding of Ti55–TA15 alloy. Beam offsetting was applied to control chemical composition and mechanical properties of weld metal in room temperature and high temperature services.

Table 1
Chemical composition of Ti55 and TA15 base metals.

Element [wt%]	Al	Mo	Zr	Si	Nb	Ta	Sn	V	Ti
Ti55 alloy	5.13	0.99	2.98	0.31	0.39	0.4	3.48	–	Bal.
TA15 alloy	6.5	1.2	1.96	–	–	–	–	1.4	Bal.

2. Experimental procedure

Ti55 and TA15 alloys with chemical compositions presented in Table 1 were used in this study. As shown in Fig. 1, both the base metals are near-α titanium alloy, consisting of equiaxed primary α along with prior β on boundaries and triple points of α grains. Ti55 and TA15 sheets were cut into the dimensions of 140∗80∗2 mm. Before welding, all the sheets were cleaned by acetone and alcohol in order to prevent weld metal contamination. Electron beam welding process was conducted by SEBT W800 machine with welding parameters as shown in Table 2. The welded joints were prepared with different beam offsets (BOFs) from 0.5 mm towards TA15 alloy to 0.5 mm towards Ti55 alloy and with interval of 0.1 mm. The beam offsets towards Ti55 alloy were considered as positive and those towards TA15 alloy as negative BOFs. Fig. 2 shows beam offset positioning in present study.

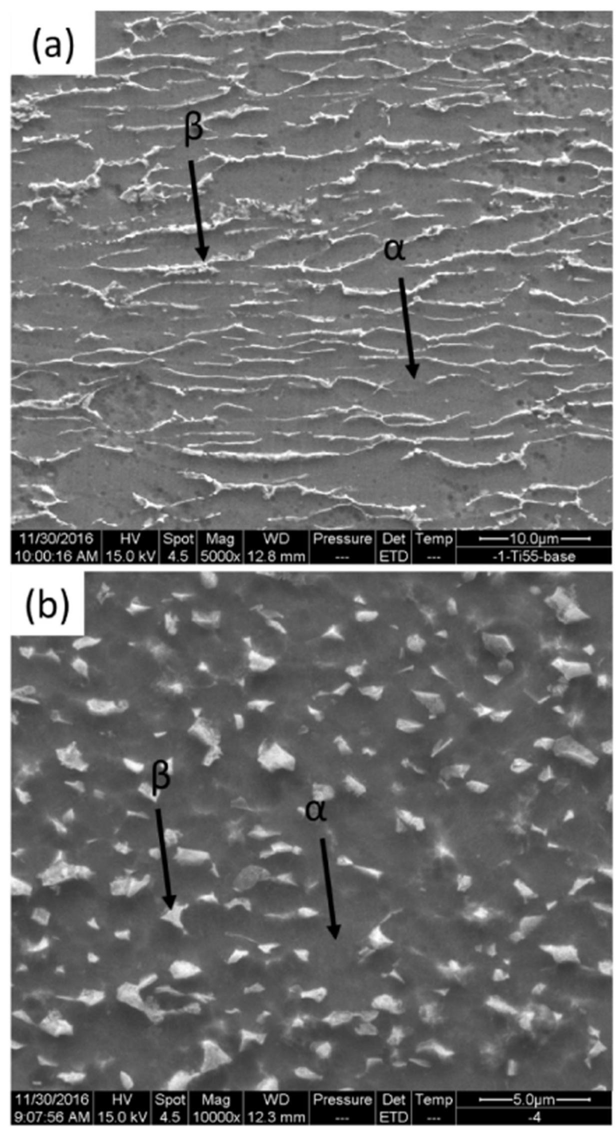

Fig. 1. Microstructure of: (a) Ti55 base metal, (b) TA15 base metal.