



Microstructure and mechanical properties of Ti-6Al-4V welds using α , near- α and $\alpha + \beta$ filler alloys



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ABSTRACT

Effects of filler metal on the microstructure and mechanical properties of Ti-6Al-4V joints were investigated. Three specimens were prepared using α , near- α and $\alpha + \beta$ type filler materials and one specimen was welded without filler metal. The microstructural characterizations, hardness and tensile tests were applied to study the welded specimens. For the specimen welded without filler material, a coarse-grained structure of $\alpha + \beta$ was found in the microstructure of weld metal. Although this specimen showed lower hardness values compared to the base metal; the hardness of other weld metals was higher than that of the base material. The microstructure of other welds was a mixture of α , β and some amount of α' -martensite. Both acicular and basketweave morphologies of α' were found in the weld metal. The α colonies were grown from the α lamellae which were formed at the β grain boundaries. The highest tensile strength was obtained for the specimen welded with the matching filler metal (about 91% of the base metal).

1. Introduction

Titanium alloys have high specific strength and good toughness at high temperatures [1]. Different strength levels can be obtained by heat treatment in the class of $\alpha + \beta$ titanium alloys. They have been widely used in aerospace industries, medical devices and marine components [2]. Welding is usually applied to join the structural parts.

Several factors could affect the mechanical and corrosion properties of weld, such as microstructural components, welding process, chemical composition of weld zone, etc. According to Liu et al. [3], the cooling rate dependent mechanism of $\beta \rightarrow \alpha$ transformation could change the morphology of weld zone. Jicai et al. [4] showed that the increased cooling rate could change the cellular structure of weld to the dendritically columnar morphology. Also, it has been claimed that the grain size of heat affected zone (HAZ) affects the grain size of weld metal due to epitaxial growth [5].

Researchers have also investigated the effect of morphology and microstructural constituents on the mechanical properties of titanium welds. Mohandas et al. [6] claimed that both strength and ductility could be promoted by distribution of finer prior β grains in $\alpha + \beta$ titanium weldments. It has been proposed that a thin α plate in the microstructure enhanced tensile properties of the weld [7]. Liu et al. [8] reported that distribution of fine α phase in the microstructure could also increase hardness.

The effect of post-weld heat treatment (PWHT) on the $\alpha + \beta$

titanium welds was studied by Mohandas et al. [6]. They showed that PWHT in high temperatures deteriorated ductility of the weldments and different morphologies of α could be formed in the microstructure. Meshram and Mohandas [9] reported that PWHT reduced the impact properties of near- α Ti joints. Although it has been shown that stress relieving could be useful for mechanical properties of titanium welds, it has a negative effect on the impact toughness [10]. However, Wang et al. [11] reported that the improved ductility could be obtained for the Ti-23Al-17Nb joints by application of proper PWHT. The heat treatment at high temperatures could minimize the anisotropy of tensile properties in the TiAl layer deposited on the titanium substrate [12].

The welding technique is a major factor affecting the mechanical properties of the weld. Sundaresan et al. [13] used pulsed current welding to join $\alpha - \beta$ titanium alloys and reported the increased ductility of weld due to the grain refinement. According to Yung et al. [14], tensile strength and ductility of Ti welds was decreased by increasing the welding heat input. Generally, it has been claimed that the welding speed and current have major effects on the tensile strength of the weld [15]. Lathabai et al. [16] applied keyhole gas tungsten arc welding (GTAW) to join commercially pure (CP) titanium without filler material and obtained the tensile and hardness properties comparable to the welds with matching filler metal. Yang et al. [17] improved ductility of the Ti-6Al-4V joints using ultra high pulse frequency GTAW with low duty cycle. Liming et al. [18] found that the increased number of welding passes reduced fatigue strength and hardness of the joints

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Table 1

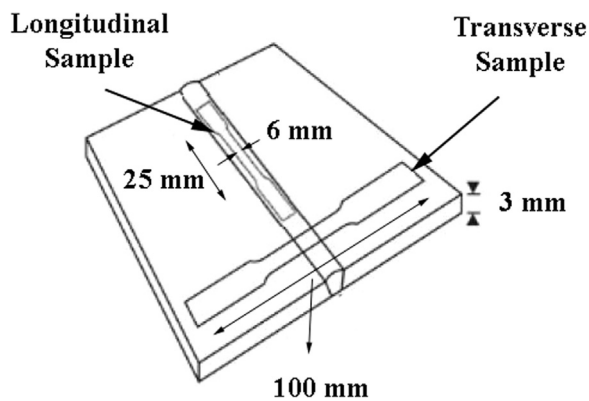
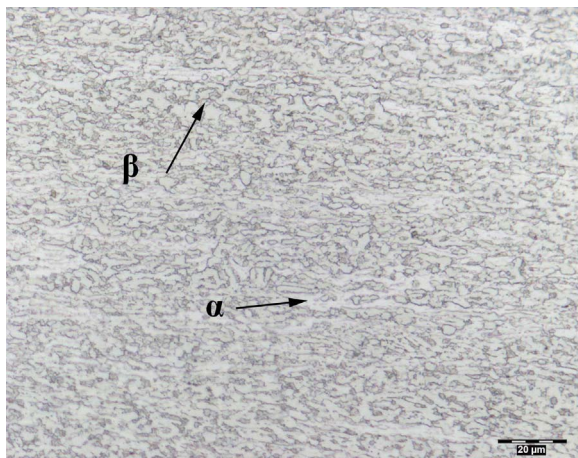
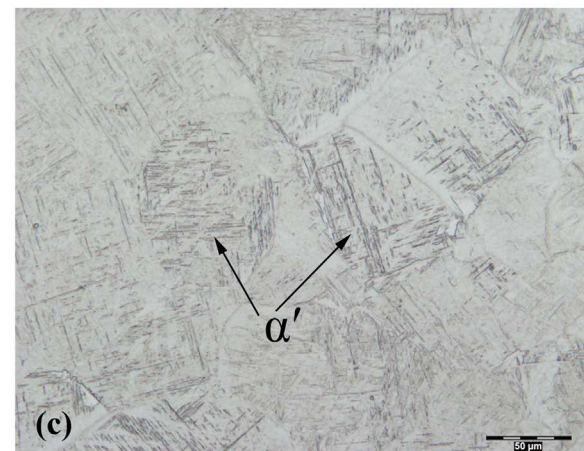
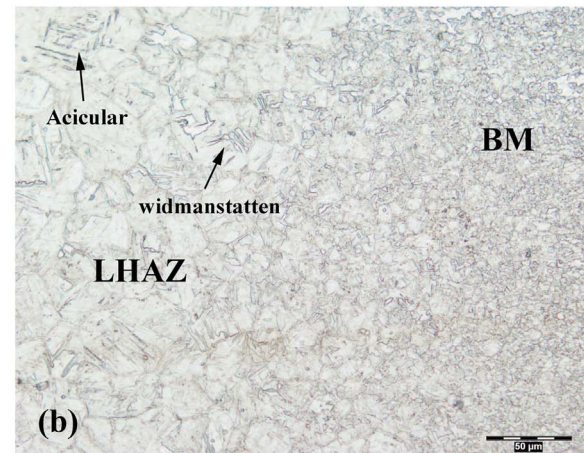
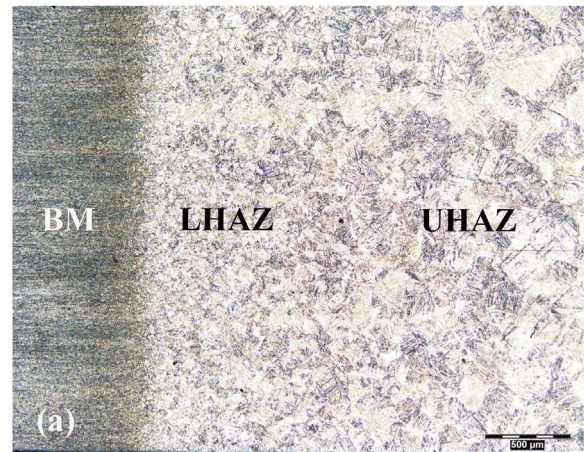
The chemical composition of Ti-6Al-4V alloy and filler metals.

Element (wt%)	Ti	Al	V	Zr	Fe	Sn	Mo	Nb	Si
Base Metal	Rem.	6.5	4.2	0.03	0.06	–	0.005	0.02	0.03
ER Ti-6Al-4V	Rem.	6	4	–	0.12	–	–	–	–
ER Ti-5Al-2.5Sn	Rem.	5.2	–	–	0.4	2.5	–	–	–
ER Ti-8Al-1Mo-1V	Rem.	7.9	1.2	–	0.25	–	1.1	–	–

Table 2

The welding parameters.

Current (A)	Welding Speed (mm/min)	Tungsten Electrode	Shielding Gas	Trailing Gas	Backing Gas
85 (DCEN)	~ 180	EWTh-2 (Φ 2.4 mm)	Ar 99.999% (12 l/min)	Ar 99.999% (25 l/min)	Ar 99.999% (4 l/min)

**Fig. 1.** Schematic of the tensile samples.**Fig. 2.** The microstructure of base material.**Fig. 3.** (a) The macrograph of BM/LHAZ/UHAZ; (b) the microstructure of LHAZ containing widmanstatten α , β and small amount acicular α ; (c) the microstructure of UHAZ containing large grains of β , α and α' -martensite.

during repair of TA15 titanium alloy parts.

Alloying elements can affect the properties of $\alpha + \beta$ titanium welds. It has been shown that the absence of alloying elements facilitated the columnar growth in the weld zone [19]. The addition of β -stabilizers (V, Mo, Nb, etc) could promote toughness of a Ti-Al-Nb alloy [20]. Xiong et al. [21] welded Ti6321 alloy using matching filler metal and obtained a mixture of acicular α , massive α and widmanstatten $\alpha + \beta$ in the microstructure of weld zone with a ductile fracture after tensile testing.

Although the effect of alloying elements on the properties of titanium alloys has been known for many, it seems that more investigations

are necessary to find the influence of alloying elements on properties and microstructural evolution of titanium weldments. The present work was carried out to compare the effect of different filler metals on the mechanical properties and microstructural characteristics of Ti-6Al-4V joints.

2. Materials and methods

The mill-annealed plates of 3 mm-thick Ti-6Al-4V alloy (conforming to ASTM B265 Grade 5) were used as the base material to fabricate the joints. Different filler metals were applied to study the effect of weld

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