

Influence of welding processes on microstructure, tensile and impact properties of Ti-6Al-4V alloy joints

T. S. BALASUBRAMANIAN¹, M. BALAKRISHNAN², V. BALASUBRAMANIAN², M. A. MUTHU MANICKAM¹

1. Combat Vehicle Research and Development Establishment (CVRDE), Avadi, Chennai- 600 054, India;

2. Center for Materials Joining Research (CEMAJOR), Department of Manufacturing Engineering,
Annamalai University, Annamalai Nagar 608 002, Tamil Nadu, India

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Abstract: Titanium alloys have been successfully applied for aerospace, ship and chemical industries because they possess many good characteristics such as high specific strength, superior corrosion resistance and excellent high temperature resistance. Though these alloys show reasonable weldability characteristics, the joint properties are greatly influenced by the welding processes. Weld thermal cycle of the processes will control the weld metal solidification and subsequent phase transformation and resultant microstructure. The welded joints of Ti-6Al-4V alloy were fabricated by gas tungsten arc welding (GTAW), laser beam welding (LBW) and electron beam welding (EBW) processes. The joints fabricated by EBW process exhibit higher strength compared with the GTAW and LBW joints; but the joints by GTAW process exhibit higher impact toughness compared with the LBW and EBW joints. The resultant tensile and impact properties of the welded joints were correlated with the weld metal microstructures.

Key words: titanium alloy; gas tungsten arc welding; laser beam welding; electron beam welding

1 Introduction

Titanium alloys have been successfully applied for aerospace, ship, desalination of sea water, biomechanics and chemical industries because they possess many good characteristics such as high specific strength, corrosion resistance, and toughness, low thermal expansion rate, high temperature creep resistance [1]. Presently, Ti-6Al-4V is one of the most widely used titanium alloys, accounting for more than half of all titanium tonnage in the world, and no other titanium alloys threaten its dominant position [2–3]. The Ti-6Al-4V alloy is commonly used in nuclear engineering, civil industries and medically implanted materials, transportable bridge girders, military vehicles, road tankers, and space vehicles, for its above said significant properties [4–5].

The welding technology of titanium is complicated due to the fact that at temperatures above 550 °C, and particularly in the molten stage, it is known to be very reactive towards atmospheric gases such as oxygen, nitrogen, carbon or hydrogen causing severe embrittlement. Gas tungsten arc welding (GTAW) is the most preferred welding method for reactive materials

like titanium alloy due to its comparatively easier applicability and better economy [6]. However, it is widely understood that the GTAW of titanium alloy exhibits columnar grains in the weld pool, which often results in inferior mechanical properties and may lead to hot cracking [6]. To overcome these problems, the high energy beam welding process like laser beam welding (LBW) and electron beam welding (EBW) is considered in this work.

Numerous experiments have demonstrated that laser welding permits the manufacture of precision welded joints with a high depth-to-width ratio and a high welding speed. Laser welding has been used as one of the major manufacturing processes in the medical device industry because it offers number of advantages such as precision and noncontact processing, with a small heat affected zone (HAZ), consistent and reliable joints [7]. Owing to these advantages, laser beam welding has been widely applied in industrial production [8]. EBW is highly suited for joining titanium, as the high vacuum inside the chamber where the process is carried out, shields hot metal from contamination. Moreover, joint depth can be achieved with high beam power density and low heat input, when compared with arc welding

processes [9].

MOHANDAS et al [10] investigated the fusion zone microstructure and porosity in electron beam welds of $\alpha + \beta$ titanium alloy and reported that the porosity at low welding speed was low and the scale of martensite lath depended on the welding speed. The early work by SUNDERASAN et al [11] showed the influence of DC and AC pulsing on the solidification structure of $\alpha + \beta$ titanium alloy welds and the effect of grain refinement on tensile behaviour. QI et al [1] studied the microstructure, properties and technical parameters of welding of 0.5 mm-thick sheets of commercial pure titanium by GTAW, LBW and EBW processes. The influence of temperature below 450 °C on the tensile properties of LBW of dual phase Ti-6Al-4V titanium alloy was investigated by WANG et al [12]. WU et al [13] investigated the microstructure evaluation and fracture behavior for EBW of Ti-6Al-4V and reported the disordered and short needle morphology of weld microstructure makes the fracture mechanism complex. SARESH et al [9] investigated the effects of electron beam welding on thick Ti-6Al-4V titanium alloy and found that the joint quality of single sided partial penetration welds can be improved by using two passes double side welding technique with lesser beam power. BALASUBRAMANIAN et al [14] developed mathematical models to predict the tensile properties of pulsed current gas tungsten arc welded Ti-6Al-4V alloy. CAO and JAHAZI [15] reported the effect of welding speed on surface morphology and shape, welding defects, microstructure, hardness and tensile properties of Ti-6Al-4V alloy welded using a high-power Nd:YAG laser.

From the literature review, it is understood that the extensive research work has been carried out on welding of Ti-6Al-4V alloy. However, most of the published information is focusing on any one of the welding process. There is no literature available comparing the tensile properties and microstructural features of GTAW, LBW and EBW joints of Ti-6Al-4V alloy. Hence, the present investigation is carried out to compare the tensile properties and microstructural characteristics of GTAW, LBW and EBW joints of Ti-6Al-4V alloy.

2 Experimental

The rolled plates of 5.4 mm-thick Ti-6Al-4V alloy were used as base material to fabricate the joints. The chemical composition and mechanical properties of the base metal (BM) are presented in Tables 1 and 2, respectively. The base metal contains elongated grains of α (light etched) and transformed β (dark etched) containing some amount of acicular α . The β phase is distributed at the boundaries of the α phase. Single ‘V’

butt joint configuration was prepared to fabricate the joints using GTAW process. Square butt joint configuration was prepared to fabricate the joints using LBW and EBW processes. The optimized welding parameters were obtained by trial experiments. Few welding trials were carried out on 5.4 mm-thick rolled plates of Ti-6Al-4V alloy. The welding parameters were varied to get defect free and full penetration joints. The welding parameters, which resulted in defect free and full penetration joint, were taken as optimized welding parameters. The optimized welding parameters (presented in Table 3) were used to fabricate the joints. Necessary care was taken to avoid joint distortion during welding. The welding was carried out normally to the rolling direction of the base metal.

Table 1 Chemical composition of base metal (mass fraction, %)

Al	V	Fe	O	N	C	Ti
6.38	4.07	0.19	0.17	0.008	0.012	Bal.

Table 2 Mechanical properties of base metal

Yield strength/ MPa	Ultimate tensile strength/ MPa	Elongation/ %	Reduction in cross sectional area/%
969	1 002	12.7	34.55
Notch tensile strength/MPa	Notch strength ratio	Impact toughness/J	HV _{0.5}
1 236	1.23	16	372

The welded joints were sliced using wire-cut electric discharge machining (WEDM) as shown in Fig. 1 to prepare the tensile and impact test specimens. Two types of tensile specimens (smooth and notch) were prepared to evaluate the transverse tensile properties. The smooth (unnotched) tensile specimens were prepared to evaluate yield strength, tensile strength, elongation and reduction in cross sectional area. The notched tensile specimens were prepared to evaluate notch tensile strength and notch strength ratio of the joints. The notched bar impact specimens were prepared to evaluate the impact toughness of the base metal and joints. The tensile and impact specimens were prepared according to the ASTM E8M—04 and ASTM E23—04 standards, respectively. Tensile testing was carried out using 100 kN electro mechanically controlled universal testing machine (Maker: FIE-Blue Star, India; Model: UNITEK—94100). The 0.2% offset yield strength was derived from the load displacement curve. The specimens for metallographic examination were sectioned to the required sizes from the joint comprising weld metal, HAZ and base metal regions and polished using different grades of emery papers. Final polishing was done using the diamond compound (1 μ m in particle

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