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TENSILE PROPERTIES OF GAS TUNGSTEN CONSTRICTED ARC WELDED TI-6AL-4V ALLOY JOINTS

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ABSTRACT

Titanium and its alloys have been considered as one of the best engineering materials for industrial applications. Excellent combination of properties such as high strength to weight ratio, excellent resistance to corrosion makes them attractive materials for many industrial applications. Recently, considerable research has been performed on Gas Tungsten Constricted Arc welding (GTCAW) process and reported advantages include, lower heat input, reduced residual stresses and distortion. In this investigation, tensile properties of GTCA welded Ti-6Al-4V alloy joints were evaluated. Single pass, autogeneous welds free from volumetric defects were fabricated using optimized GTCAW parameters. The joints were characterized using optical microscopy, scanning electron microscopy and microhardness, survey. Tensile properties of the joints were overmatching with the base metal. The alpha and granular beta grains in the base metal were changed into short acicular alpha martensitic structure in the fusion zone as a result of GTCAW.

Keywords: *Titanium alloy, Gas Tungsten Constricted Arc welding, Tensile properties and Microstructure.*

1. Introduction

Ti-6Al-4V alloy is one of the most important non ferrous metals and this alloy serve as bridge between the ideal properties of aluminium and steel. Ti–6Al–4V alloy has excellent specific tensile and fatigue strength and corrosion resistance and hence mainly used for aircraft structural and engine parts, petrochemical plants and surgical implants [1-4]. The frequently preferred welding process for joining titanium alloys is Gas Tungsten Arc Welding (GTAW) process. This is due to comparatively easier applicability and better economy. In case of single pass welding of thinner section of this alloy, pulsed current was found beneficial due to its advantages over the conventional continuous current process [5-8]. However, GTA welding of titanium alloys leads to grain coarsening at the fusion zone and heat affected zone (HAZ). Weld fusion zones typically exhibit coarse columnar grains because of the prevailing thermal conditions during weld metal solidification. This often results in inferior weld mechanical properties and poor resistance to hot cracking [9-10].

Under fill and porosity were the two main defects as observed in the laser welding of Ti-6Al-4V. The main concern related to the presence of porosity is a reduction in the weld cross-sectional area, especially when a large number of pores concentrated in one region can coalesce into large pores. Inevitably, the presence of porosity degrades the mechanical properties of the joints, usually affecting the ductility to a greater extent than the tensile strength [10-12]. Fusion zone grain refinement are mostly attained by current pulsing techniques by physically disturbing the arc in the molten weld pool which is agitated violently so optimum frequency reduces the prior beta grain boundary which improves the tensile ductility [13-15].

The process chosen for this investigation is the gas tungsten constricted arc welding (GTCAW) developed by Vacuum Brazing Company (VBC), UK. The GTCAW operates at 20 kHz and produces a magnetically constricted columnar profile arc, like that of a plasma arc. The arc is constricted by the magnetic field around the arc. The GTCAW machine generates high frequency pulse, the relationships of which are programmable to alter the magnetic field of the arc, thus enabling the control of the constriction of the arc as shown in Fig 1. The constriction of the arc produces

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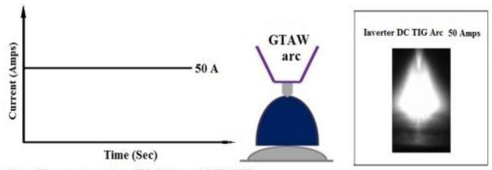
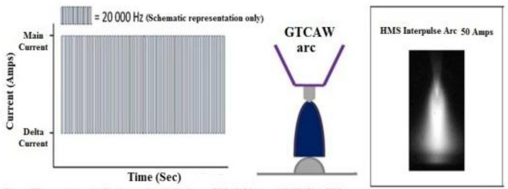
narrow but deeper weld beads along with narrow heat affected zone [16-19].



Gas Tungsten Arc Welding (GTAW)

(a)



Gas Tungsten Constricted Arc Welding (GTCAW)

(b)

Fig.1 Schematic diagram showing the difference between (a) GTAW and (b) GTCAW

There are many reports available on tensile properties of constant current and pulsed current GTA welded Titanium alloys. However, to the authors' best knowledge, no work has been reported so far on tensile properties of GTCA welded Ti-6Al-4V alloy joints. Hence the present investigation was aimed to evaluate the tensile properties of GTCA welded Ti–6Al–4V alloy joints and compare with the unwelded alloy properties.

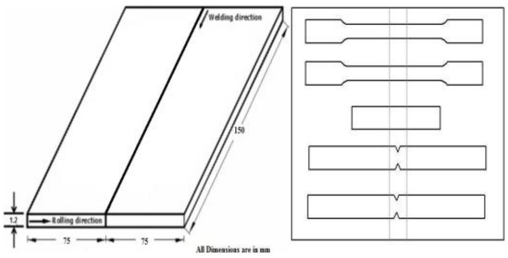
2. Experimental Procedure

The as-received base material (BM) used in this investigation was 1.2 mm thin Ti-6Al-4V alloy sheets. The chemical composition of the base alloy is given in Table 1.

Table 1 Chemical Composition (wt%) of base material

Al	V	Fe	C	Si	Ti
6.181	3.745	0.266	0.029	0.025	Bal

A square butt joint configuration, as shown in Fig. 2 (a), was prepared to fabricate the joints. A single pass autogenous welding procedure was used to fabricate the joints. The joints were fabricated by Interpulse TIG (IE175i) Welding machine (Make: VBC, UK). Argon (99.99 %) was used as the shielding and purging gas.



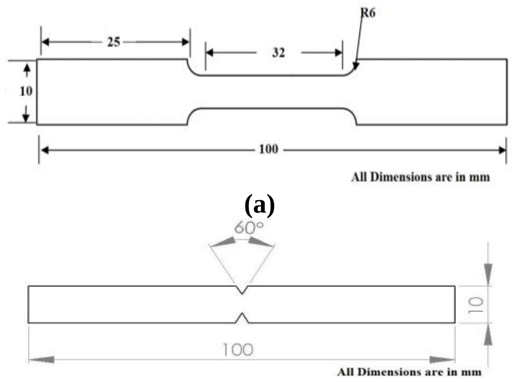
(a) (b)

Fig 2 (a) Joint Configuration (b) Scheme of specimen extraction

Table 2 Optimized welding parameters used to fabricate the joints

Process	**GTCAW**
Electrode Material	**Tungsten (Lanthanated)**
Tungsten electrode diameter (mm)	1.6
Polarity	DCEN
Voltage (volts)	9
Main Current (amps)	50
Delta Current (amps)	30
Delta Frequency (kHz)	20
Welding Speed (mm/min)	60
Shielding Gas	Argon
Back Purging Gas	Argon
Gas Flow Rate (lpm)	15
Heat Input (J/mm)	216

The welding parameters used in this investigation are presented in Table 2. The welded joints were sliced in transverse direction using wire cut EDM process to the required dimensions. American Society for Testing of Materials ASTM E8M-05 standard for sheet type material (i.e., 25 mm gauge length and 6 mm gauge width) was followed to prepare tensile specimens. Two different tensile specimens were prepared to evaluate the transverse tensile properties. The smooth (unnotched) tensile specimens were prepared to evaluate yield strength, tensile strength, and elongation. Notched tensile specimens were prepared to evaluate notch tensile strength (NTS) and notch strength ratio (NSR) of the joints.



(b)

Fig. 3 Dimensions of tensile specimen: (a) un-notched tensile specimen (b) notched tensile specimen

Tensile test was carried out using 50 kN universal testing machine (UTM) with the strain rate of 1 mm/min (Make: Tinius Olsen; Model: 50 ST). The 0.2% offset yield strength was derived from the load-displacement diagram. Vicker's microhardness tester (Make: Shimadzu, Japan and Model: HMV-2T) was used to measure the hardness across the joints with a 0.2 kg load. Microstructural examination was carried out using a light optical microscope (Make: Huvitz, Korea; Model: MIL-7100) incorporated with an image analyzing software. The specimens for metallographic examination were sectioned to the required dimensions 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 µm particle size) in the disc polishing machine. Specimens were etched with a standard reagent made of 2% HF and 3% HNO3 in 95% distilled water to reveal the micro and macrostructure.

3. Results

3. 1 Tensile properties

The transverse tensile properties such as yield strength, tensile strength, percentage of elongation, notch tensile strength, and notch strength ratio of Ti-6Al-4V alloy joint were evaluated. In each condition, three specimens were evaluated, and the average results are presented in Table 3. The yield strength and ultimate tensile strength of unwelded parent metal are 977 MPa and 1010 MPa, respectively. However, the yield strength and ultimate tensile strength of GTCAW joints are 989 MPa and 1030 MPa, respectively. This indicates that there is a 2 % higher in strength values due to GTCAW. Since the tensile specimens involving the entire joint shown in Fig. 4 fractured in the base metal region.

(a) Un notched

(b) notched

Fig. 4 Photographs of tensile specimens (after testing)

Elongation of the unwelded parent metal is 15%. However, the elongation of GTCAW joints is 11%. This suggests that there is a 27 % reduction in ductility due to GTCA welding shown in Fig. 5. Notch tensile strength (NTS) of unwelded parent metal is 1230 MPa. However, the notch tensile strength of a GTCAW joint is 1140 MPa. This reveals that the reduction in NTS is approximately 7 % due to GTCA welding. Another notch tensile parameter, NSR, is found to be greater than unity (>1) for GTCAW joints. This suggests that the Ti-6Al-4V alloy is insensitive to notches and it is a "notch ductile materials". The NSR is 1.21 for unwelded parent metal, but it is 1.12 for GTCAW joints.

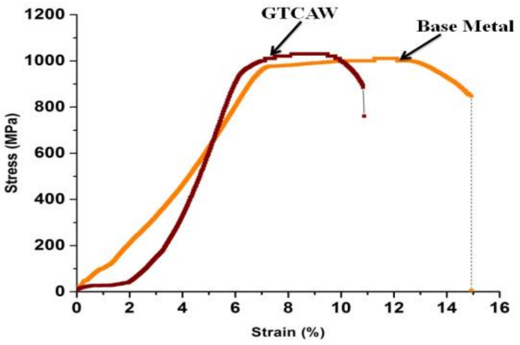


Fig. 5 Load displacement curves of tensile test results.

3.2 Hardness

The microhardness variation across the mid thickness of the welded joint was measured and presented in Fig. 6. The hardness of the as-received base metal is approximately 375 Hv. The hardness of the fusion zone varies from 430 Hv to 440 Hv, depending on the grain size and phases sampled by each indentation.

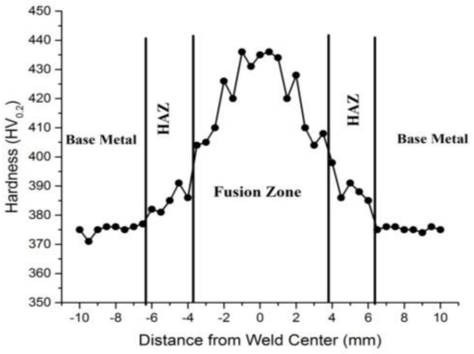


Fig. 6 Hardness profile at mid cross section

4. Macrostructure

Macrostructure of the gas tungsten constricted arc welded Ti-6Al-4V alloy joint is shown in Fig. 7. The weld cross section has no volumetric defect. The macrostructure of the joint clearly reveals four distinct regions such as fusion zone (FZ), high temperature heat affected zone (HTHAZ), and low temperature heat affected zone (LTHAZ) and the base metal (BM).

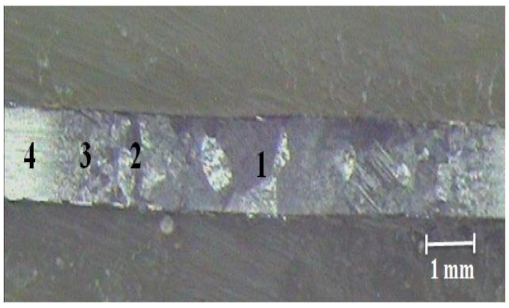


Fig. 7 Macrostructure of Gas Tungsten Constricted Arc Welded Ti-6Al-4V alloy 1-Fusion zone; 2-Higher temperature heat affected zone; 3-Low temperature heat affected zone; 4-Base metal.

Table 3 Tensile properties of Base metal and GTCAW joints.

Material	0.2 % Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (25 mm gauge length) (%)	Notch Tensile Strength (MPa)	Notch Strength Ratio (NSR)	Joint Efficiency (%)	Fracture Location
Base Metal	977	1010	15	1230	1.21	-	-
GTCAW Joint	989	1030	11	1140	1.12	102	BM

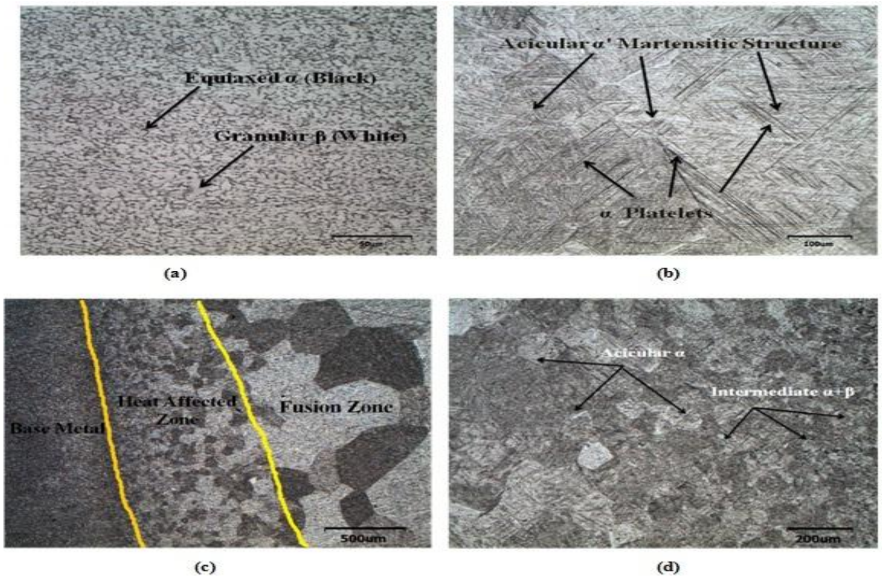
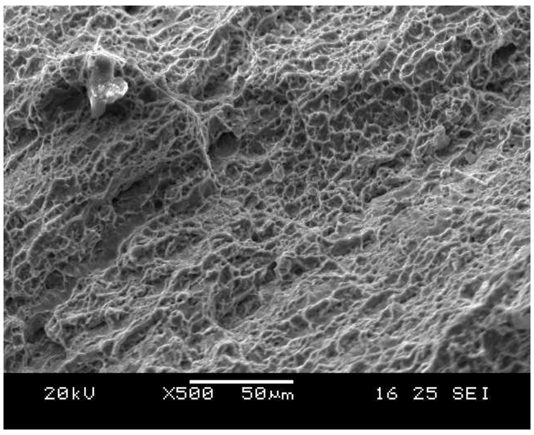
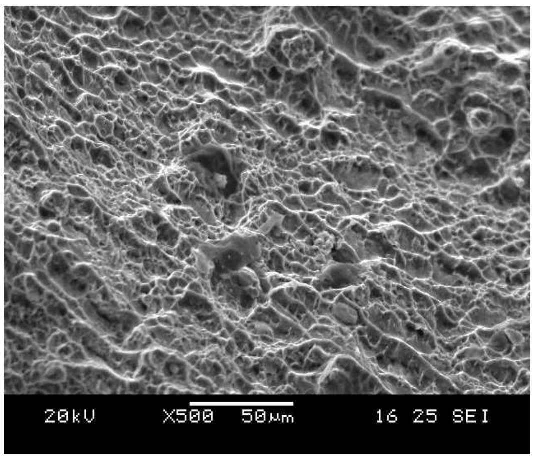


Fig. 8 Optical micrographs of Gas Tungsten Constricted Arc welded joint (a) Optical Microstructure of Base Metal. (b) Fusion Zone (c) Base metal to Fusion Zone interface (d) Heat Affected Zone.



(a) Base metal



(b) GTCAW Joint

Fig.9 SEM fractographs of tensile tested specimens

4.1 Microstructure

Optical micrographs of base metal and different regions of GTCAW joint are displayed in Fig. 8. The base metal consists of equaixed alpha (dark) and granular beta phase (white) (Fig. 8a) and the average grain size is approximately 6 µm. The fusion zone (Fig 8-b) consists of acicular alpha martensitic structure with in prior-β grains HAZ region (Fig 8-d) consists of intermediate α+β, primary α and β.

4.2 Fractographs

Fig. 9 displays the fractographs of tensile tested specimens of base metal and GTCAW joint. The displayed fractographs invariably consist of dimples, which indicate that the specimens failed in ductile mode under the action of tensile loading. However, finer dimples were observed in the joint compared to the base metal and this may be due to the grain refinement caused by GTCAW process.

5. Discussion

Transverse tensile properties of the base metal and welded joint are presented in Table 3. The joint exhibits higher ultimate tensile strength and yield strength, and lower elongation than the unwelded base alloy. The transverse tensile specimen of the joint fractured away from the fusion zone, at the BM region, because the BM had the lowest hardness, (Fig. 8). The strength is roughly proportional to hardness, so that the BM region would preferentially yield and then fail during transverse tensile test. The overall mechanical properties of a joint are determined by the characteristic features of the individual microstructures present in the fusion zone and the heat-affected zone of GTCAW joint. The fusion zone of the GTCAW consists of acicular alpha martensitic structure with clear visible of alpha in beta grain boundary [Fig. 8 (b) and (d)]. The absence of alpha phase in the β grains indicates moderate cooling rate [8]. Interface region (Fig 8-d) consists of some acicular with intermediate α+β, primary α and β. HAZ region undergoes the β-transus temperature below 985°c[17]. The fusion zone and high temperature heat affected zone (heated above about 1400°C) reaches the a beta phase and considerable grain growth takes place at high temperatures in case of conventional arc welding [7]. However, the characteristic feature of the GTCAW titanium alloy welds is the presence of grain growth in the HAZ. The grain size in the HTHAZ of the GTCAW welds was found to be very similar to that of the fusion zone but it has some acicular alpha with intermediate α+β [13]. This phenomenon is due to the relatively moderate heat input associated with GTCAW process compared to conventional GTAW process [17].This wider low temperature heat affected zone originated when the material was heated to temperatures (800°c to 1100°c). The maximum amount of intermediate α+β and primaryα and primary β were formed at the point in this zone at which the longest time was spent during welding and at the temperature of 1030°'C. The presence of hard un-tempered martensite might have reduced the ductility of the joint and acted as stress raisers and crack initiation points [6,7].

6. Conclusions

1. Tensile strength of GTCAW joint is found to be 2 % higher compared to the tensile strength of base material. Similarly, ductility (elongation) of GTCAW is found to be 26 % lower compared to the base material.

2. The average hardness of the fusion zone is 435 Hv , which is higher than the base material (375 Hv). This is mainly due to the presence of acicular alpha martensitic structure in the fusion zone.
3. The equiaxed alpha and intergranular beta in the base material are changed in to acicular alpha martensitic structure with prior beta grain boundary in the fusion zone of GTCAW joints. This may be the reason for increase in fusion zone hardness, decrease in ductility and increase in tensile strength of GTCAW joints.

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