



Investigation of the Mechanical and Microstructural Properties of TIG Welded Ti6Al4V Alloy

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Abstract. The joint integrity of 1 mm thick sheets of Ti6Al4V alloy welded autogenously using TIG welding was investigated in this article. The current and gas flow rate were varied and their effects on the mechanical properties and microstructure of the weld were analyzed. Results show that the microstructure within the weld zone consists of α' martensitic phase and are coarse, which results in higher microhardness within the weld zone compared to the base metal. The samples with a higher gas flow rate were observed to also improve the tensile strength, while samples with a lower gas flow rate resulted in tensile strength below that of the base metal.

1 Introduction

Titanium is one of the most used metals in industries such as aerospace, ship and chemical, due to its unique mechanical properties of good strength to weight ratio and high corrosion resistivity [1]. Joining titanium alloys could pose adverse effects on the mechanical properties if not properly welded in a controlled environment since titanium alloy is adversely affected in atmospheric gases such as nitrogen, oxygen at a temperature of 350 °C [2]. Several welding techniques have been employed in joining of Ti6Al4V alloy sheets, some of which are; gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG), gas metal arc welding (GMAW), electron beam welding (EBW), friction stir welding (FSW), laser beam welding (LBW) [3, 4]. Each of these techniques have their unique advantages and disadvantages. The EBW is laborious due to the vacuum needed to be created within the working chamber, LBW is expensive to set up, FSW has its

limitation to specific applications and GMAW creates a wider heat affected zone (HAZ) due to the enormous heat input and it is associated with spatter formation. Therefore TIG welding which uses inert gases as a shield from environmental contamination is preferred compared to other welding techniques due to its arc stability, better economy and easier applicability [5–8].

Analysis of research works shows that quite many researches have been done on TIG welding of Ti6Al4V alloy and some advantages and disadvantages have been highlighted. One of the major problems with titanium alloy highlighted by Balasubramanian et al., [6] was the coarsening of grains within the HAZ and fusion zone (FZ) during TIG welding, which is as a result of the heat input and could cause embrittlement of the material. Babu and Rahman [9] also attributed this embrittlement to decreasing size of the α colonies, which controls the maximum dislocation slip length. The decrease in the α colonies are caused by thermomechanical activities during welding. The ductility within the weld zone (WZ) is also attributed to the acicular and martensitic intragranular microstructure and a large prior β grain size. Therefore, controlling the input current and gas flow rate will improve the mechanical properties of the WZ as reported by some works of literature where pulsed current TIG [9, 10] have been used to control the heat input during TIG welding. Even though, it is of less economic advantage and no change in mechanical properties, compared to the manual TIG welding as reported in [11]. Columnar grains have also been reported to be observed in both pulsed and unpulsed TIG welding [12]. Some researchers have identified current, welding speed and voltage as the most important parameters in TIG welding [13, 14]. Thus, it is crucial to control the heat input during welding and the level of gas shielding so as to avoid contamination of the weld.

Therefore, this article investigates the joint integrity of Ti6Al4V alloy using TIG welding. It focuses on the effect of welding parameters such as current, voltage and gas flow rate on the microstructure, tensile and microhardness properties of Ti6Al4V alloy.

2 Methods

Ti6Al4V grade 5 of $100 \times 60 \times 1$ mm was joined autogenously using TIG welding technique with argon gas (99.999% purity) as a shield to prevent contamination and oxidation of weld. The parameters used for welding were chosen based on the range of optimum parameters given in [15]. Before the welding process, the samples were cleaned with acetone to remove oxide films and welding was done along the 100 mm length. The elemental composition and mechanical properties of the alloy in accordance with ASTM B265 [16] are presented, Table 1 and 2 respectively. Four welds were carried out by varying current and gas flow rate Table 3.

Table 1. Chemical composition of Ti6Al4V alloy

Element	Ti	Al	V	Fe	C	N	H	O	Others
Weight (%)	Remainder	6.10	4.0	0.15	0.03	0.018	0.002	0.13	Each < 0.10

Table 2. Mechanical properties of Ti6Al4V (grade 5) alloy

Parameters	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Microhardness (HV)
Values	895	825	10	362

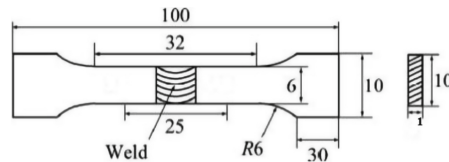
Table 3. Experimental process parameters

Sample no	Current (A)	Gas flow rate (L/min)
T11	40	9
T12	30	9
T13	30	7
T14	40	7

The welded plates were cut into $25 \times 10 \times 1$ mm for microstructure analysis, each sample was gradually grinded using grinding papers from 320 to 1200 grit size, they were then polished and etched using Kroll's Reagent. The microstructure of the samples was taken using Olympus DP 25 optical microscope at 50x magnification. Each sample was analyzed at the FZ, HAZ and base material/metal (BM).

Microhardness testing was done using the Indentec digital Vickers microhardness tester. A force of 4.9 N was applied with a dwell period of 15 s. A minimum of twenty indentations was done on each sample across the sample at a distance of 1 mm.

Tensile test samples were cut using the ASTM E8 standard [17] Fig. 1. The tensile samples were pulled using universal testing machine Zwick Roell 2250.

**Fig. 1.** Tensile sample

3 Results and Discussion

3.1 Microstructure

The microstructure of welded metals is classified into three zones, the BM, HAZ and FZ. Figure 2(a) shows the microstructure of the BM, which is made of the white α and black β phase, as observed in [18]. The HAZ Fig. 2(b) is characterized by the equiaxed α , transformed β and elongated α grains. The FZ Fig. 2(c), which undergoes melting and

solidification is observed to have the widmanstatten structure, martensite (α' phase) and recrystallized β phase together with secondary acicular α phase and β phase, which was similar to what was observed in [19].

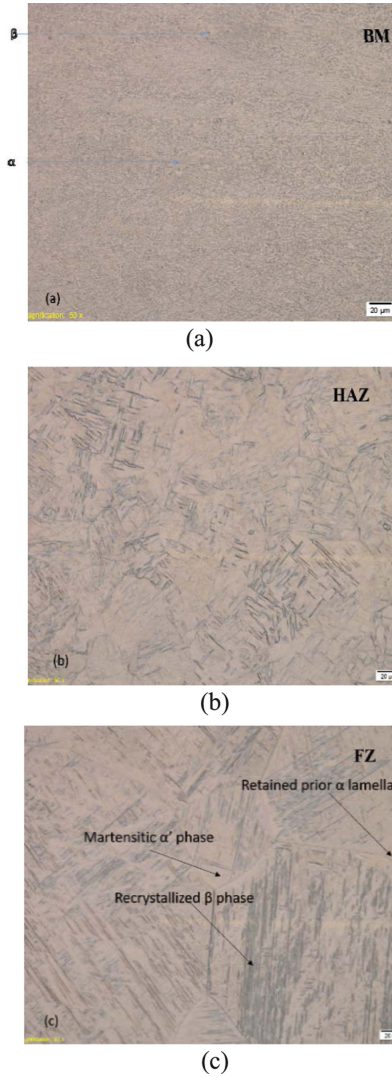


Fig. 2. (a) Optical micrograph of BM (b) Optical micrograph of HAZ (c) Optical micrograph of FZ.

3.2 Microhardness

The microhardness profile is shown in Fig. 3 and it was carried out in accordance with ASTM E384 [20]. The hardness is observed to generally be highest at the FZ for all

samples, due to the increment of β grains and extensiveness of the grains within the FZ. The BM was observed to exhibit hardness of the range of 362 ± 4 HV, the HAZ and FZ has an average hardness of 366.4 ± 5 HV and 378.86 ± 5 HV respectively. There is a relationship between the hardness profile and the microstructure, the primary α is lower in hardness and higher in ductility than the β phase, while the α' martensitic shows a higher hardness than the β phase as also reported in [19] and [21]. The higher hardness within the WZ can also be attributed to oxygen pickup during welding, which causes a hardening effect as observed in [22] hence, the FZ has a higher hardness than the BM.

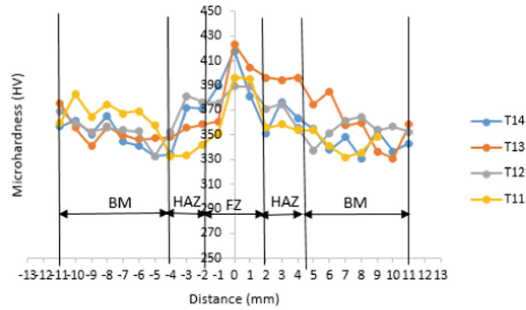


Fig. 3. Microhardness profile of TIG welded samples

3.3 Tensile Strength

Tensile strength was conducted in accordance with ASTM E8 [17]. Figure 4(a) shows the tensile failure points of each sample, while Fig. 4(b) shows the tensile strength of each sample. The maximum tensile stress of 913.67 MPa was observed in sample with current and gas flow rate combination of 30 A and 9 L/min respectively, compared with the tensile strength of the base metal 895 MPa in Table 2. The increase in tensile strength is attributed to the ductility nature of the α' martensitic microstructure observed in the FZ as observed in [23], even though the failure occurred at the HAZ, It could further be attributed to the higher gas flow rate which provided a sustainable inert environment during the cooling of the weldments. Samples with lower tensile strengths below the values of the BM, which were welded with gas flow rate of 7 L/min were observed to fracture at the FZ, irrespective of the current used. This can be attributed to contaminations such as oxygen picked up during welding as a result of lower gas flow rate. Table 4 shows the joint efficiency of the welds, all welds shows a joint efficiency above the standard 70% for butt joint [24], except welds with parameter combination of 30 A and 7 L/min current and gas flow rate respectively, which is weaker as a result of lower heat input and gas flow rate.

Table 4. Joint efficiency of TIG welded samples

Sample no	Joint efficiency (%)
T11	98
T12	102
T13	58
T14	77

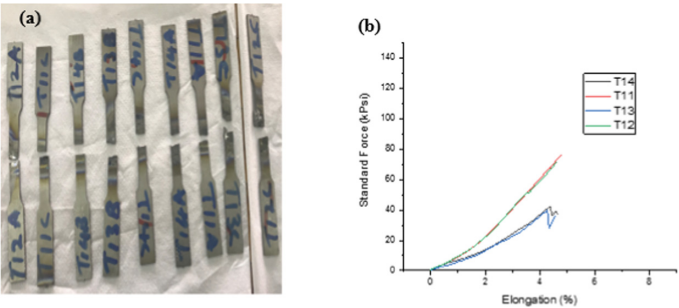


Fig. 4. (a) Joints of welded samples (b) Tensile properties of TIG welded samples

4 Conclusions

TIG welding of Ti6Al4V alloy autogenously has been carried out and the following conclusions are drawn from the results of the characterizations done.

1. The microstructure within the HAZ and FZ is made up of α' martensitic phase which results in higher hardness with the WZ.
2. The microhardness was observed to increase from the BM towards the FZ.
3. The gas flow rate, has a significant effect on the tensile strength of welds, samples with 9 L/min gas flow rate exhibited an improved tensile strength.
4. Irrespective of the welding current, gas flow rate of 7 L/min exhibited lower tensile strength.

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