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Flow Rate Effects on Microstructure and Mechanical Properties for Titanium Weld Joint

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Abstract

Titanium is a metal with a low density, has good heat transfer, and a high melting point; hence widely used for various purposes, such as petrochemicals, aerospace, medical, and reactors. The titanium welding process is complicated because no absence of protection against air during the welding process results in the high absorption of oxygen from free air. In this work, ASTM Gr-1 Titanium is joining using Tungsten Inert Gas (TIG) welding method. The effect of argon flow rate on the mechanical properties of titanium welding and its microstructures is investigated by hardness and tensile tests. Then, microstructure observation to explore the fusion zone and heat-affected zone. Furthermore, phase formation during the welding process is analysed using the X-ray diffraction (XRD) method. The tensile test revealed that maximum tensile strength was obtained at a 60 l/m argon flow rate while minimum tensile strength was received at 25 l/min. The hardness test shows that maximum hardness was obtained at 25 l/min on the fusion zone.

***Keywords**: CP Titanium; Argon flow rate; mechanical properties; microstructure*

1. Introduction

Welding is a technique of joining two metal pieces permanently, in contrast to connecting using bolts and nuts that can be removed or not permanent. According to Deutsche Industrie Normen (DIN), welding can be defined as a metallurgical bond in metal or metal alloy joints carried out in a melted or liquid state [1]. The need in the fertilizer industry today cannot be separated from welding techniques as a method of joining component structures. Many factors are considered in choosing the material to be welded and the welding method, such as strength, toughness, lighter mass, and corrosion resistance of materials.

Welding is the process of joining two or more metals using heat energy, so the metal around the weld area experiences changes in its metallurgical structure, deformation, and thermal stress [2]. Liquid welding is a method of welding in which the joint is heated until it melts using a heat source with added materials or fillers. Types of liquid welding that are often used are shield metal arc welding (SMAW) and gas tungsten arc welding (GTAW) [3,4]. For this case, discuss the liquid welding type of GTAW.

Process GTAW or tungsten inert gas (TIG) is used non-consumable electrodes to be used in autogenous welding, i.e., welding without filler metal. GTAW welding, a shielding gas is used, i.e., an inert gas (argon, helium) or an active gas (CO_2). The working principle of GTAW is to melt and combine metals by heating them by an electric arc obtained from the potential difference between the non-consumable tungsten electrode and the metal. The weld pool is protected by a shielding gas supplied by the shield gas cylinder. The main parameters of GTAW welding are arc length, welding current, welding travel speed, and shielding gas [5]. Figure 1 is a schematic of GTAW process welding.

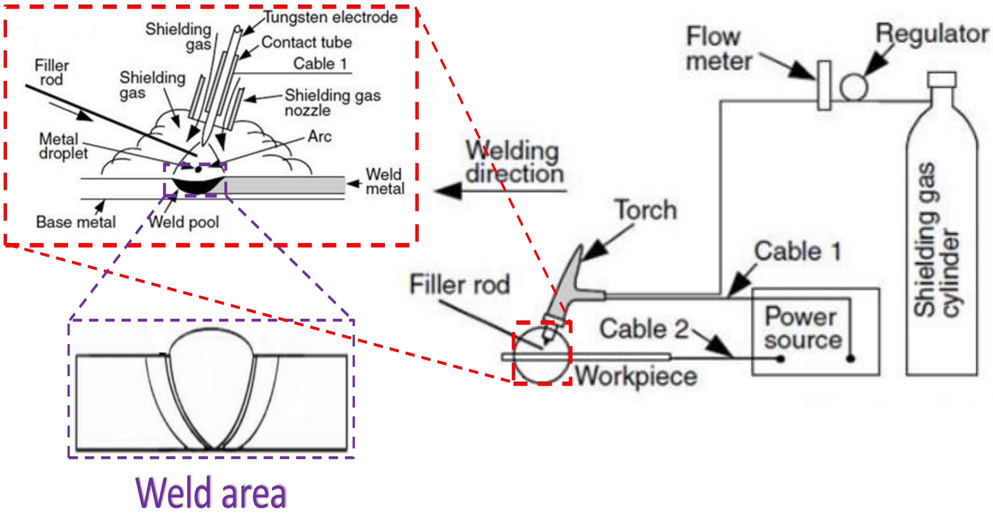

Figure 1. Schematic of the GTAW equipment used

From Figure 1, metal will experience the effect of heating the welding result and changing the weld area's microstructure. The shape of the microstructure depends on the temperature achieved in the welding, the welding speed, and the welding cooling rate. Metal areas that experience changes in microstructure due to welding (heating) are called the Heat Affected Zone (HAZ) [6].

Welding TIG works with high-alloy steel and metals (non-ferrous) such as aluminium, copper, titanium, and alloys thereof; because of the high arc stability, TIG welding is the best of modern electric welding due to its high heat dispersion. Excess on the workpiece is reduced by adding an inert shielding gas also a cooling gas [1].

Titanium is a metal with a low density where it is 60% lower than the density of steel and can be strengthened again by adding alloys and special treatment. Titanium has good heat transfer properties with a conductivity value of 11.4 W/m·K and a thermal coefficient (8.41 µm/m·K), which is lower than steel and non-magnetic. Titanium is generally silver with a density of 4.51 g/cm^3 (0.163 lb/in^3), a melting point of 1668 ± 10 °C (3035 °F), and a boiling point of 3260 °C (5900 °F). Titanium at a temperature of less than 882.5 °C has a close-packed hexagonal (α phase) crystal form, whereas when it is above 882.5 °C, it has a body-centred cubic (β phase) crystal form [7].

Titanium and its alloys have a higher melting point than steel, but temperatures useful for structural applications generally only range from 427 - 595 °C. Titanium with aluminide alloys can be used for applications up to 760 °C, where it is widely used for various purposes, such as petrochemicals, spacecraft, medical devices, and reactors [8].

Commercially pure (CP) titanium is ductile enough (15-25% elongation) and has an ultimate tensile strength of 30 ksi (207 MPa) at room temperature. Adding the elements nitrogen and oxygen will strengthen the titanium (interstitial solid solution) but will cause embrittlement due to the dissolution of these elements. Carbon is also an impurity in titanium, but its effect does not exceed oxygen and nitrogen. Hydrogen can cause embrittlement if it is over the limit. These elements will naturally dissolve during the welding process [9]. The addition of the aforementioned alloys causes the tensile strength to increase and the ductility to decrease; the combination of high tensile strength and light density is needed in various work structures and good corrosion resistance properties up to temperatures below 650 °C [7].

Hydrogen, oxygen, carbon, and nitrogen in pure titanium and its alloys are impurities. The mechanical properties quality of CP titanium without alloy is seen from many interstitial elements, especially the amount of oxygen. The interstitial element is contaminated by oxygen which can cause impurities during the welding process. The absence of protection against air during the welding process results in the high absorption of oxygen from free air. Hydrogen, nitrogen, and oxygen are absorbed in humid and wet conditions during the welding process. Residual cleaning material, oil, and other material contamination to be welded cause carbon and hydrogen contamination [10]. Therefore, this study investigates the effect of argon flow rate on mechanical properties and microstructures in titanium welding.

2. METHODS

Chemical element composition on CP titanium material has been obtained by doing XRF testing at a fertilizer plant. Table 1 is the chemical composition element of CP titanium (ASTM Gr-1 titanium). Table 1 indicates that the material is a commercially pure titanium ASTM Grade 1.

Table 1. Composition of ASTM Gr-1 Titanium

Element	Composition (%)
Titanium (Ti)	99.38
Iron (Fe)	0.548
Tin (Sn)	0.065

The TIG machine used for CP titanium (ASTM Gr-1 titanium material) welding is the PANA-TIG TSP 500 with ERTi-1 filler rods. Before welding, the titanium is cleaned using acetone so that the impurities that stick to the material disappear and do not diffuse when the welding process. Furthermore, the titanium metal is placed on the backing shield. The welding process is carried out in an open space. The details on TIG welding parameters can be seen in Table 2. After all, preparations have been completed, welding can be carried out according to a predetermined procedure. The welding procedure to be carried out refers to the welding procedure specification (WPS). GTAW welding process on titanium can be seen in Figure 2.

Table 2. GTAW welding parameters on titanium

Specimens	Argon flow rate (l/min)	Current (A)	Voltage(V)		Inert Gas
			Root	fill and cap	
A	15	120	100	110	Argon UHP 99.99%
B	25				
C	60				

Figure 2. GTAW welding process on titanium

Then, the hardness test was carried out using the Vickers hardness method with the diamond as the indenter. Tensile strength was determined through the universal testing machine (Hung Ta Type HT 9502). The surface morphology of the sample fracture was observed using an optical microscope.

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3. Result and Discussion

From Figure 3, an increase in the hardness in the fusion zone area of each sample was obtained. The hardness increased for a 25 l/min argon flow rate of 162 VHN and 15 l/min of 146 VHN. The hardness increase is suspected because of the maximum protection from inert argon gas during the welding process. From Figure 3, the hardness in the base metal area tends to be stable at 118 VHN, and in the HAZ area, there is a decrease in the hardness by an average of 108 VHN.

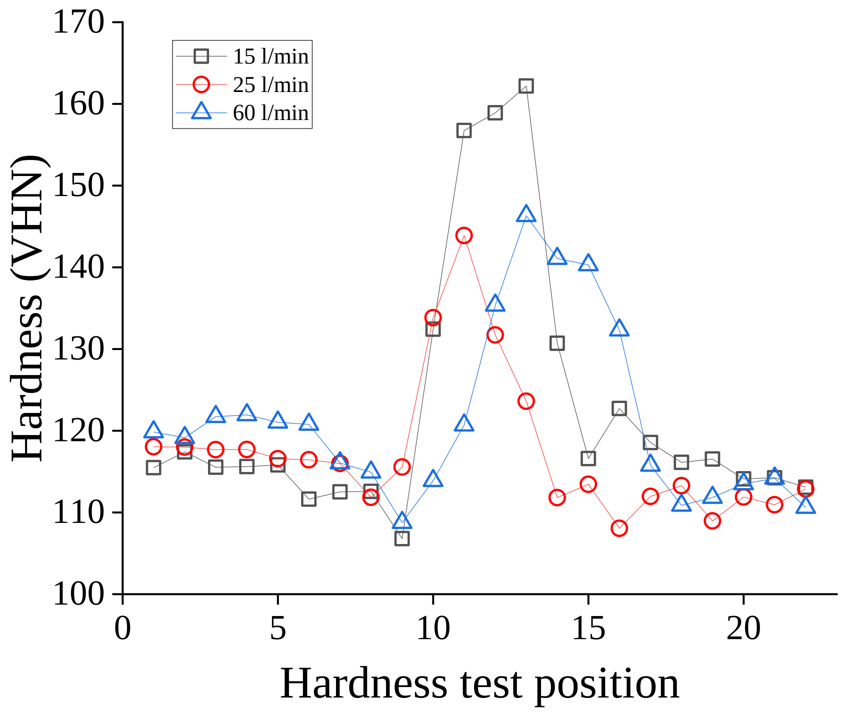


Figure 3. Hardness profile on welded joints

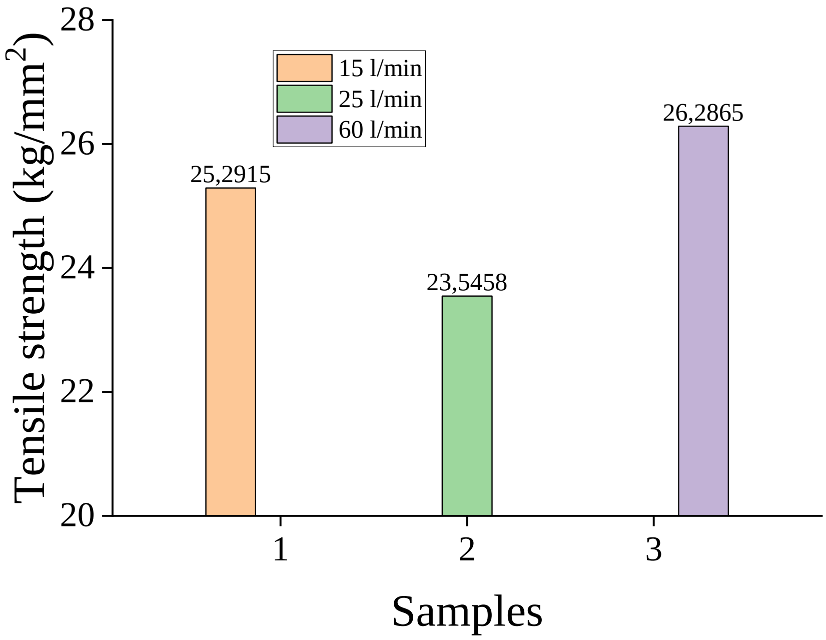
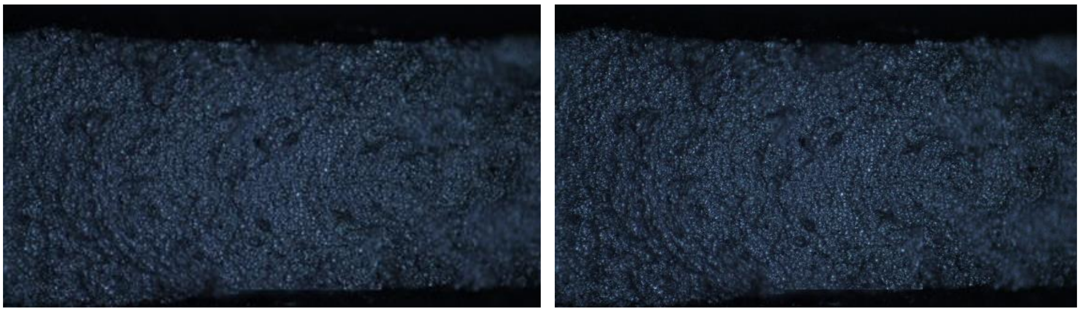


Figure 4. The profile of the tensile strength

Figure 4 shows the tensile strength of samples A, B, and C. Based on Figure 4, the lowest average tensile strength obtained in sample B of 23.5485 kg/mm^2. Based on Figure 4, the lowest average tensile strength obtained in sample B of 23.5485 Kg/mm2; the lowest tensile strength occurred allegedly because of minim protection in welding when the temperature is above 800 °C so that the outside air (oxygen, hydrogen, and nitrogen) enters and cause embrittlement. Consequently, it affects the welding strength of the titanium material; this condition is proportional to the hardness profile in sample B, which tends to increase in the area of base metal and weld metal [11].

Figure 5 shows the morphology fracture of samples B and C. From Figure 8-a, the fracture surface of the tensile test specimen C undergoes plastic deformation; it is characterized by fractures that form a uniform dimple caused by crack propagation in the grain boundaries (intergranular) on the fracture surface; this indicates ductile fracture characteristics. From Figure 8-b, the surface fractures in specimen B are mortar tends to be wider and has a fracture that tends to be smooth and has little plastic deformation; this indicates that the fracture is less ductile in the material.



(a) (b)

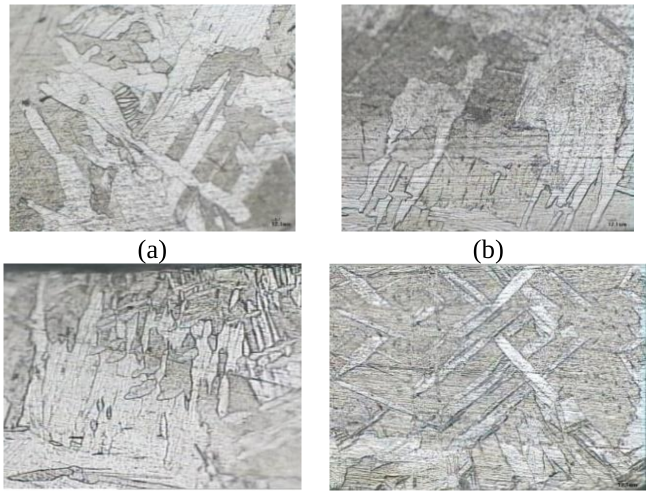
Figure 5. Morphology of fracture: (a) The fracture surface is ductile, (b) The broken surface is less ductile

Figure 6 shows the microstructure of the parent metal. The microstructure of pure titanium in the base metal consists of a fine equiaxed α grain structure and tends to be uniform / hexagonal closed packed (HCP) phase (Figure 6). The microstructure is generally formed at room temperature or below 882.5 °C [10].

Figure 6. Parent metal microstructure

Figure 7-a is the microstructure of the HAZ where there is the deformation of item α. Initially uniformly turns into coarse serrated and acicular α. Figure 7-b is the microstructure of the fusion zone for welding with a flow rate of 15 l/min. From Figure 7-b,

the microstructure changes from serrated α coarsely transforming into serrated α fine. The transformation is caused in the welding process the rapid cooling and oxygen diffusion occur [12]. Figure 7-c is the microstructure for sample 25 l/min. From Figure 7-c, the growth of acicular and alpha platelets is increasingly dominant; this is proportional to the hardness testing results in the FZ area. Figure 7-d is the area of the fusion zone for the C sample (60 l/min), where the arrows that serrate and platelet alpha are more dominant, with the least acicular alpha being formed; this is due to high protection from extensive air contamination by argon during the welding process.



(a) (b)

(c) (d)

Figure 7. The microstructure of titanium welding: (a) HAZ is formed by serrated and acicular alpha, (b) FZ for welding with a flow rate of 15 l/min, (c) FZ for welding with a flow rate of 25 l/min, and (d) FZ for welding with a flow rate 60 l/min

From Figure 8, form Ti 90 phases are formed in the base metal area, HAZ, and weld metal; no other phases are formed. This indicates that the welding procedure is correct and meets welding standards titanium. The welding of specimen C using the argon discharge of 60 l/min, the maximum protection against outside air contamination is when welding is carried out so that there is no $Ti0_2$ phase or titanium oxide (easily formed when titanium is heated to 882 °C), and other phases are formed [13].

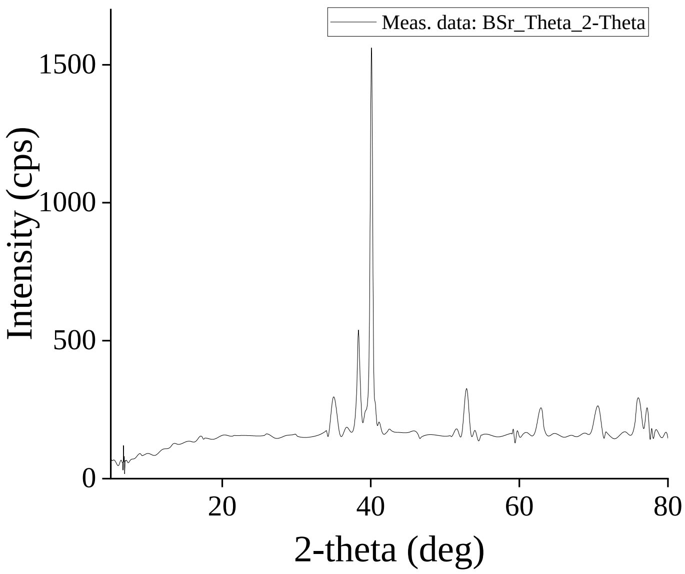


Figure 8. XRD results at HAZ and Fusion Zone

4. CONCLUSION

Testing the mechanical properties in this research includes hardness and tensile testing. They are testing the hardness of the Vickers using a load of 20 Kgf. Based on the results, the argon flow significantly affects the welding results; a high UHP argon flow rate protects the welding from oxygen so that the hardness is not too high increased compared to low flow rates. Furthermore, it increases the hardness and decreases the strength of the material and ductility when fractured. The results show that the C specimen obtained by TIG welding treatment using the 60 l/min argon flow rate experienced the lowest hardness addition of 144 VHN. In contrast, the B sample experienced the highest average addition of the hardness of 162 VHN (25 l/min), the A sample of 146 VHN (15 l/min). Based on the tensile test, the C sample is the highest tensile strength C with an average of 26.2865 kg/mm2, while the lowest is the B sample B of 23.5485 kg/mm^2.

Based on metallographic testing, the main metal area of commercially pure titanium has a uniform grain size with a hexagonal closed packed (HCP) phase. In contrast, the grain forms become elongated like straw, called platelet and acicular alpha in the HAZ and weld metal.

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