Investigation into the TIG welded joint of titanium G-5 alloy sheet

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Abstract. In TIG (Tungsten Inert Gas) welding process Welding Current and Speed are important parameters. This paper investigates into microstructure and some mechanical properties of TIG welded Ti-6Al-4V Titanium alloy. Welding was carried by varying welding current and speed while keeping other parameters constant. It investigates into microstructures of different zone around the welded joint and found that microstructures become coarser near the Fusion Zone (FZ) and Heat Affected Zone (HAZ) and β-Phase predominant at FZ. The analysis of microhardness shows that as we move from base metal to weld centreline hardness value increases and maximum value of hardness was found at Fusion Zone. Highest value of hardness was found to be 472 HVN which is very high compare to base metal which is at low speed and high current i.e. of Sample S3.

1. Introduction
Titanium being light in weight and unique combination of corrosion resistance and strength has been encouraged to wide research activity and a great deal of interest is currently focused by industries towards joining process of these materials. Titanium is a very robust material. It has high strength to weight ratio. Joining of such metal is very important. Ti-6Al-4V Titanium alloy is an alpha-beta alloy. These alloys are sensitive to heat treatment, solution treatment and ageing which increases the strength by 50% compared with annealed condition. Unalloyed titanium has two allotropics forms. The low temperature form, α, exist as an HCP (Hexagonal Close Packing) crystal structure upto 882°C above which it transform to β which is BCC (Body Centred Cubic) crystal structure.

The elements which stabilize α-Phase are α Stabilizers like Aluminium, Tin, and Zirconium. The elements which stabilize β-Phase are β stabilizers like molybdenum, Vanadium and Iron. Ti-6Al-4V is α-β alloy. During welding, a small portion of titanium is melted and rapidly cooled. The complexities of the resultant microstructure can be compounded by contamination with impurities from the ambient environment. They don’t change the crystal structure but they significantly increase the hardness and strength. The fundamental problem in welding titanium alloy is the elimination of atmospheric contamination. Most likely the contaminants are oxygen and nitrogen.
This absorption of gases results in increasing brittleness and hardness. So to minimize these issues an appropriate shielding medium should cover the weld area [1-3].

At present, Ti-6Al-4V is one of the most widely used alloys of titanium, and it accounts for more than half of all the world’s titanium tonnage [4, 5]. Due to its high strength and low density, along with good tensile and creep properties up to about $300^\circ C$, it 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 [6, 7]. Conventionally, TIG, plasma arc [8], and electron beam welding [9] have been used to weld titanium alloys. But TIG welding is one of the most widely used welding methods for titanium alloy, particularly in sheet form [10]. A main drawback of TIG welding is its high heat input and the resulted greater distortion and higher risk of contamination [11]. Sundaresan et al. indicated that the microstructure of the HAZ undergoes both rapid heating and cooling that cause significant growth of the prior $\beta$ grains [12]. Chen and Devletian observed a lamellar ($\alpha + \beta$) structure within coarse prior- $\beta$ grains in the HAZ of Ti-6Al-4V fusion welds[13]. Sundaresan et al. reported that the FZ microstructure of Ti-6Al-4V alloy consists of coarse prior $\beta$ grains and acicular $\alpha$ and $\alpha'$ phases [12]. According to Balasubramanian et al. (2008a), the formation of such microstructures is due to the prevailing thermal effect that occurs during the weld metal solidification and cooling [14]. Consequently, a loss of mechanical properties (namely the ductility) was often recorded in Ti-6Al-4V TIG welds due to their coarse grained microstructure. [15].

This paper investigates the weldability of Titanium-G5 alloy with different process parameters. It focuses on microstructure of the welded joint at different zone of the samples.

2. Experiment

Titanium alloy G5 which is also known as Ti-6Al-4V of thickness 2 mm is investigated in this experiment. The EDS (Electron Dispersive Spectroscopy) analysis was done on a sample prior to welding, which is shown in Figure 1 and table 1. In addition to oxygen there are some impurities like C and Fe also present in small quantity.

![Figure 1: EDS Analysis of Sample](image)

| Element | Al | C  | Fe | O  | V  | Ti  |
|---------|----|----|----|----|----|-----|
| Weight %| 5.9| 0.10| 0.20| 0.2| 3.4| Bal. |

In this experiment two Titanium G-5 sheets of dimension 100mm×50mm×2 mm are joined by modified TIG welding shielded by Argon. In the modified TIG welding process a PUG Cutter is properly calibrated to provide a speed controller in linear direction as shown in Figure 2. Several beds on trial experiments were conducted to check the experimental set-up. On the basis of several bed on
trial experiments three current and two speeds was chosen as process parameters. Six such samples are welded by varying current and speed as shown in Table 2. This arrangement provided a uniform speed and fixed angle during welding. It also provides constant arc length. The welding was done along 50 mm dimension of the metal sheet. The edge of each sheet was prepared by rubbing it through emery paper to remove dust and oxide layer at the edges.

![Modified TIG welding setup](image)

**Figure 2**: Modified TIG welding setup

| Sample No. | Speed (mm/sec) | Current (A) |
|------------|----------------|-------------|
| S1         | 2.5            | 60          |
| S2         | 2.5            | 70          |
| S3         | 2.5            | 80          |
| S4         | 3.5            | 60          |
| S5         | 3.5            | 70          |
| S6         | 3.5            | 80          |

**Table 2**: Process parameter for Experiment

From each welded plate a sample of 25mm×10mm×2mm has been cut out for microstructure analysis. The samples were polished with different grits of polishing paper gradually from 800 grit size to 1800 grit size. After proper polishing the samples were etched with Krols reagent which contain 85 % H₂O + 10% HNO₃ + 5% HF [15]. Microstructures of the welded samples were studied in FESEM (Field Emission Scanning Electron Microscope) Supra 55 with air locked chamber. Each sample was analyzed at fusion zone (FZ), Heat affected zone (HAZ) and base metal (BM) for studying the changes in the three zones.

The hardness across the weld cross section was measured using a Vickers micro-hardness testing machine (Economet VH-1 MD) with an indentation force of 500g and dwell time of 10 sec. From weld centered line towards base metal ten indentations were made at an interval of 1 mm.

**3. Results and discussion**

The result obtained from microstructural studies have been analyzed based on the literature review. Microstructures of Fusion zone, HAZ and base metal were investigated in FESEM. Figure 3 shows different phases of a base metal i.e. the area where heat of welding arc has least effect. It shows two
phases the gray color part is α phase while the black colored part is β phase [15]. In base-metal region α phase is predominant.

Microstructure at fusion zone of TIG joint contains the coarse grain and acicular α structures of grain boundary. In this zone the β phase is higher comparison to other zones. Increase in β phase increases the hardness. This is because it is harder than other phases. Microstructure of HAZ consists of the coarse distorted serrate and acicular α structures of grain boundary, coarse α + β structure.

![Microstructure images obtained by FESEM of (a) Fusion zone; (b) Heat Affected Zone (HAZ); (c) Base metal](image)

**Figure 4:** Microstructure images obtained by FESEM of (a) Fusion zone; (b) Heat Affected Zone (HAZ); (c) Base metal

From Figure 4 it can be clearly seen that as we move from base metal to fusion zone the microstructure grain become more and more coarse. The reason for such changes may be that α + β titanium alloy shows extremely low tensile ductilities in fusion zone on account of a large prior-β grain size and an acicular, at least partially martensitic matrix microstructure [15]. A similar type of micrograph is obtained for base metal in all the samples but the fusion zone and HAZ shows some variation with different current and speed as shown in Figure 5. As we increase the current fusion zone become coarser and melting and solidification can be clearly visible in micrograph of fusion zone in Figure 5. It is also observe that as we increase the current that is from sample1 (S1) to sample3 (S3) and sample4 (S4) to sample6 (S6) the microstructure become more coarse and more β Phase as shown in Figure 5.
Figure 5: Microstructure of fusion zone at a current of (a) 80 Amp; (b) 70 Amp; (c) 60 Amp

The Micro-hardness graph of the samples as shown in Figure 6 clearly reveals the trend in the hardness in different zones of all the samples. The micro-hardness of the welded samples is found to increase at fusion zone and Heat Affected zone. From the base metal zone to fusion zone there is large difference in the value of hardness. The variation in micro-hardness in the sample may be due to high Thermal Cycle. The heat input to the welded surface increases the hardness of fusion zone and its surrounding area i.e. heat affected zone. The maximum value of hardness was found in sample with highest current and lowest speed of the experimented i.e. sample 3. While the minimum value of hardness of fusion zone is found in sample with low current and high speed i.e. sample 4.
Figure 6: Micro-hardness profiles across weld centre line: (a) S1& S4; (b) S2& S5 and (c) S3& S6

From the microhardness graph in figure 6 it can also be observed that the microhardness is also affected by speed of welding. At fusion zone the hardness value at lower speed is more while at HAZ and base metal it varies. At high current and low speed the heat input which may be the probable cause for such variation in hardness.

4. Conclusion
A modified welding arrangement was implemented for TIG welding of titanium G5 alloy. This arrangement provided a uniform speed and fixed angle during welding. Current and speed are very important parameters in TIG welding. Based on the results of this investigation, the following conclusions are drawn:

- Microstructure of sample shows distinct variation at different zone of welding i.e. at Fusion Zone, HAZ and Base metal.
- As we move from base metal to fusion zone microstructure become coarser.
- Increasing the current also affect the microstructure. At higher value of current microstructure become coarser and distorted.
- In fusion zone \( \beta \) phase predominates which results in higher value of hardness.
• In all the samples the maximum hardness value is obtained at fusion zone.
• On increasing the current, the hardness value seems to increases and area of fusion zone also s increases
• There is slight variation of hardness with speed mainly at HAZ and Fusion Zone.

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