THE EFFECT OF PROCESS PARAMETERS ON TIG WELDING OF THIN TI-6AL-4V SHEETS

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Abstract- This study presents the details of investigations pertaining to welding of titanium grade 5 alloys by using TIG welding method. Thin sheets of 1.6 and 2 mm thickness respectively are selected for this study owing to several applications demanding this dimension. Welding current and welding speed are the chosen process parameters. With the help of suitable welding fixtures the shielding gas is supplied for the samples under welding trails. Butt joints with full penetration are achieved paving the way for understanding the effect of selected parameters on grade 5 alloy. Mechanical testing for tensile property evaluations and hardness measurements are performed on welded samples. Owing to the high heat input from the TIG welding process tensile strength recorded is considerably less as compared to its parent metal. Micro hardness is measured along the fusion zone, heat affected zone and base metal. Images are captured by optical micro scope to visualize the effect of heat input to their microstructure.

Keywords- Shielding Gas, Ti-6Al-4V, Thin sheets, TIG Welding

I. INTRODUCTION

Titanium is one of the super alloys which are suitable for wide range of applications. Several Literatures reported the application of titanium and its alloys. Titanium is widely used in the aerospace's applications. They have high strength to weight ratio, corrosion resistances and exhibited good thermal properties. This material suffers from the drawback of absorbing the harmful gases making it show cause embrittlement. Various welding methods are employed for titanium grade 5 alloys for achieving a perfect and defect free weldment. It is also established that with suitable arrangements it is possible to weld reactive material by GTAW.

The flow rate of shielding gas and their effects are investigated from the previous reports published in literatures. A strong correlation exists between no passes and shielding gas flow level while some colorizations produced on backside of the weld though well covered by shielding gas. It is essential to address this issue by designing effective fixture for shielding gas placement and supply. Research indicates that there is a reduction in strength due to the microstructure changes due to heat input. However, impact properties indicated reasonable improvement in TIG welded samples. Literatures are indicating maximum works being carried in thicker part of these materials which is extending for thin sheets in this study.

II. MATERIALS AND METHODS

Industrial titanium alloy sheets having the thickness of 1.6 and 2 mm respectively are chosen for this study. The base material properties are listed in the Table 1.

Table 1 Chemical composition and thermal & mechanical properties of Ti-6Al-4V sheets

Alloying elements (weight %)					
Al	V	Fe	O	H	Ti
6	4	0.30	0.25	0.015	90

Melting Point	1650°C
Thermal Conductivity	6.7 W/m-k
Density	4430 kg/m^3
Young's Modulus	114 GPa
Poisson's ratio	0.33

Ti-6Al-4V has the alloying elements like aluminium and vanadium which increases the strength. Thin titanium sheets are cut down by the wire cut EDM for conducting the bead on plate trials. Plates are brushed and cleaned with acetone before bead on plate trials are conducted. Fig. 1 shows the automated TIG weld experimental setup.

Figure 1 Automated TIG welding setup

TIG welding machine of Fronius, Austria make is employed for this experimental study. This equipment possesses an operational range of 3 A to 400 A with water cooled torch. Throughout the study an arc length of 3 mm and tungsten electrode diameter of 2.4 mm is adopted for this study. Welding current and travel speed are varied for carrying out the TIG welding trials. Many literatures have negligible information reporting about these parameters that play a major role in deciding the depth of penetration with minimum heat affected zone and quality of the weld.

III. RESULTS AND DISCUSSIONS

Nine trials are conducted by varying the TIG welding input process parameters. Their details are presented in Table 2 while emphasizing that titanium belongs to reactive materials group. It must be ensured that the processing temperature is exceeding the limit above 450°C. For welding titanium a customized gas arrangement is produced.

Table 2 Bead on plate trials welding parameters

Arc current range (A)	130-90
Travel speed (mm/min)	250-450
Shielding gas	Argon (99.99%)
Primary shielding gas flow level (l/min)	15-25
Secondary shielding gas flow level (l/min)	5-10
Shielding gas flow, level at Torch head (l/min)	15-25

Bead on plate trials are conducted on 2 mm thick Ti-6Al-4V sheets to study the effect of process parameters on weld bead geometry. The welded specimens are shown in Fig. 2. Each trial is conducted in a separate plate. It is observed from the Fig. 2 that all the welds are bright silvery metallic luster indicates that the weld is clean and good techniques are followed. After that the specimens are slashed at middle portion by using wire cut EDM. Later this piece is mounted and polished. To observe the micro structural changes and for further analysis of micro and macro structures, etching process is done. Solution of 2% HF and 3% HNO3 in 95% distilled water is used for this study. The selection of welding parameters is based on the results attained from the bead-on plate welding trials (not reported here). Bead on plate trials resulted in a full penetration, butt joint configuration produced on both the sheets (1.6 and 2 mm). Testing specimens are prepared according to the ASTM standards. Tensile tests are conducted on 50 kN Tensile testing machine of Tinius Olsen make. The strain rate of 1 mm/min is recorded. Further, Vickers Micro hardness measurements are measured along the weld bead with the load of 500 g for a dwell time of 10 seconds.

Figure 2 Bead on plate trials on Ti-6Al-4V sheets

Data's are collected from the previous works carried by the other researches in various welding methods for titanium materials. It is in fact known that the shielding gas must cover the welded portion from molten level to the temperature limit of 450°C. At the weld centre portion it must cover a distance of minimum of 5mm. According to that a new fixture is produced. There is a strong correlation existing for the flow level of shielding medium and contact time period. The essential shielding arrangement is shown in Fig. 3.

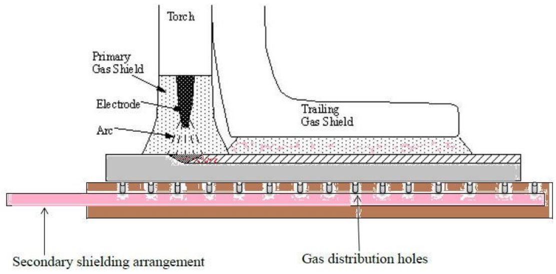
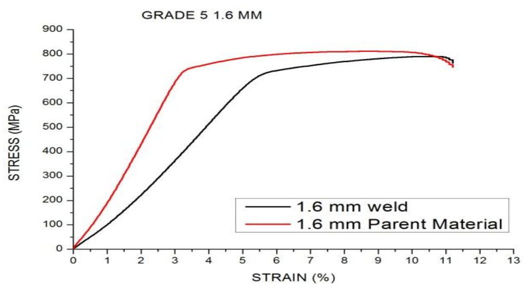


Figure 3. Typical shielding arrangement for titanium welding

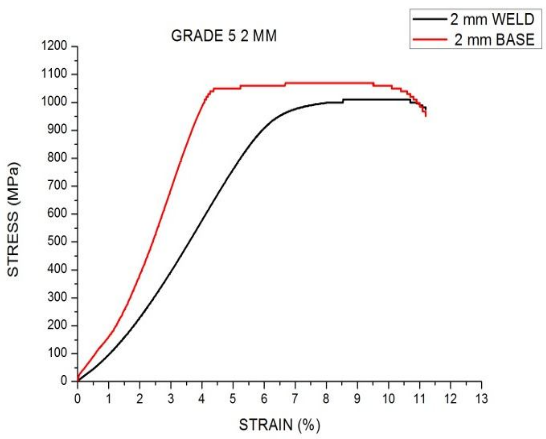
A. Mechanical & Metallurgical Examination

During welding, a tiny portion of base metal is melted and cooled rapidly. Due to complex heating and cooling cycles, internal stresses are produced in the welded portion. Besides, an important observation is the strength reduction when shielding is not in perfect level due to the presence of oxygen, hydrogen and nitrogen. Since microstructure of the titanium is sensitive to heat input. Literature indicates that generally GTAW has maximum heat input as compared with other welding process. Optical micro scope images indicate that size of the micro structure is bigger and coarse.

B. Tensile Test



(a)



(b)

Figure 4 Stress vs. Stain Plots (a) 1.6 mm and (b) 2.0 mm

Fig. 4 indicating the stress strain cure for both the sheets (1.6 and 2.0 mm). For 1.6 mm base metal thickness shows a maximum strength of 812 MPa and the joint exhibit a reduction of 2.7% and indicated up to 790 MPa. For both thickness joint failed at HAZ which is called as weakest zone of the weld. For 2 mm thickness joints reached up to 1010 MPa and got a reduction of 5.6%. As discussed previously, reduction is due to heat input which is dependent on process, micro structure and level of contamination. The mechanical properties of weld joint and parent metal are presented in Table 4.

Table 4 Plate thickness and failure location

Sl. No	Thickness (mm)	Type	Failure location
1	1.6	Base metal	---
2		Joint	HAZ
3	2.0	Base metal	---
4		Joint	HAZ

C. Hardness Measurements

Hardness values are measurements in longitudinal direction of weld and the measured values are presented in the Fig. 5. Hardness for 2 mm thickness base metal value is 6.3% less than that of the fusion zone value. For 1.6 mm thickness sheet metal value is 4% less than the fusion zone value. While moving along the fusion zone to HAZ, the micro hardness values increased and reached a limit of 357 HVN for 2 mm sheet. It is apparently seen from the figure 5, hardness values are having some fluctuation because of variation in grain size.

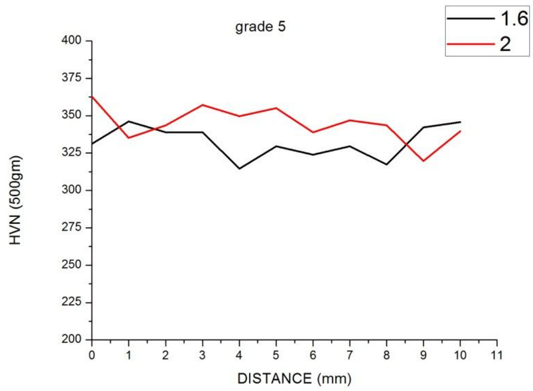


Figure 5 Hardness variation along the longitudinal direction

D. Micro structural Examination

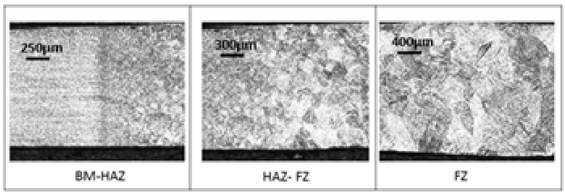


Figure 6 Optical micro graphs of base metal- HAZ, HAZ-fusion zone and Fusion zone

It is expected that micro structure undergoes phase deformation due to high heat input. Normally microstructure of titanium and its alloys are heat sensitive. Their properties are altered by the alloying elements and impurities.

In real, the mode of transformation depends on alloy chemistry and cooling rate. Here the presence of alpha and beta elements played a major role to control the growth of microstructure. Cooling rate governs the growth rate of micro structure. TIG welding while working normally gives lamellar or bi-modular structure (refer Fig. 6). They show enhanced strength. Faster cooling leads to fine grain size. Slip energy required for this structure is more compared to the coarse structure as they exhibit more strength. In parent metal, equiaxed α grains are observed. Fusion zone indicates the presence of widmanstätten α+β.

CONCLUSIONS

Based on the research study, the following conclusions are drawn:

- Mechanical characterization of Ti-6Al-4V under selected parameters (welding current and welding speed) is studied. Based on the bead on plate trials, butt joint configurations are produced. Subsequently, it is evaluated for its mechanical properties.
- Tensile results indicated the failure of specimens at HAZ. This indicates that 1.6

and 2mm thickness welded sheets exhibits fusion zones to withstand a load of 790 MPa and 1010 MPa, respectively.

- Maximum of 362.9 HVN and 339.6 HVN are recorded for 2mm fusion zone and base metal. For 1.6 mm thickness, 331HVN in fusion zone and 345HVN at base metal are recorded.
- An optical microscope image indicates the presence of widmanstätten α+β produced by higher heat input. This appears to indirectly control the mechanical properties of joint configuration. Optical microscope images showed that sizes of the micro structure of welded samples are increasing linearly towards base metal to fusion zone.

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