Experimental Investigation of Tensile Properties of Ti-6Al-4V alloy at Elevated Temperature

S. Dineshkumar, Shrinidhy Sriram, R Surendran, V.Dhinakaran

Abstract*: In this research work, Tungsten Inert Gas welded titanium sheet of 1.5 mm thickness is considered as candidate material for investigation. Weld joint is prepared using 80 A welding current and 200 mm/min travel speed. Tensile properties are evaluated at room temperature, 250 °C, 450 °C and 650 °C. It is evident that the ultimate strength and yield strength decreases with increase in temperature and also the percentage elongation increases with increase in temperature. At temperatures above 650°C, the ultimate tensile strength (UTS) had decreased to about 66% than the ultimate tensile strength (UTS) at room temperature.

I. INTRODUCTION

Titanium is a distinctive material; stronger than steel but half its weight and twice that of aluminium, with excellent corrosion resistance. Titanium alloys exhibit extensive properties with outstanding formability, eminent elevated temperature properties, high strength-to-density ratio and toughness, and superior corrosion resistance [1]. Another significant advantage of titanium alloys is their excellent capability to be joined using a diversity of different welding processes. The significant properties that are exhibited by titanium and titanium alloys have applications in aerospace, chemical plant, power generation, oil and gas extraction, medical, sports, and other industries like biomedical, and marine industries for precise joining which are being successful [2].

Lee et al. [3] proposed a paper on evaluating the tensile properties of SM570- TMCP steel weldment at high temperatures by performing tensile test at elevated temperatures varying from 20 to 800 °C with an interval of 100 °C. They also studied the residual stresses characteristics in welded joints by 3-D thermal elastic- plastic FE analysis with a reference to the high temperatures properties from the experiment that has been performed. It has been observed that there was a gradual decrease in yield strength and ultimate tensile strength of the SM570- TMCP steel at 100 °C and then increase with raise in temperature to 400 °C which was found due to the dynamic strain aging, and then decreased gradually for all conditions.

Woo Gon Kim et al. [4] presented a research by which the specimens for tensile test were machined into a rectangular cross section with 1.5mm thickness and the tensile test were conducted at a range of temperature varying from room temperature to 950°C. The results from the experiments on the base metal, weld joint and weld metal of Alloy 617 weldment shows 0.2% of yield stress (YS), ultimate tensile strength (UTS), and tensile failure elongation. The weld metal of the base metal is comparatively higher than that of yield strength of base metal. But it was observed that there were nearly similar values of the yield strength and also UTS of the BM, WJ, and WM over the temperature 800°C. Dhinakaran et al. developed an analytical model to predict the temperature distribution during the welding of titanium sheets. A heat source model namely Dhinakaran’s model was also used to predict weld bead geometry [5].

Wang et al. [6] published a paper regarding the study on tensile properties of Laser beam welded Ti-6Al-4V alloy plates by conducting tensile tests at different temperatures varying from room temperature to 450 °C. The tensile tests were conducted by fixing 25.4 mm as the gage length with varying evaluated temperature with a range from room temperature, 150°C, 300°C, and 450 °C. During the laser beam weld, helium gas is used as the shielding gas in order to avoid contamination of fusion zone under the influence of oxygen, nitrogen and carbon. The Microstructure of the weldment determines the strength which depends on the choosing of variable welding parameters. Increase in temperature causes decrease in strength and increase in ductility hence the ductility and the tensile strength are to be sensitive to temperature. A comparison study was taken and the understanding the inter relationship between the tensile strength, yield strength and elongation at different temperatures for both the parent metal and the summarization of the weldment has been done [7].

Feng et al. [8] had published his work on studying the mechanical properties and its microstructures of laser butt-welded plate of Inconel 718 super alloy by performing tensile tests at various temperatures from 950 °C to 980 °C. The tension test is performed in the transverse direction in temperature range over 950 °C to 980 °C and strain rate of 3.1× 10-4 s-1 has exhibited 458.56% at 950 °C of elongation of laser butt-welded plate which is the largest. It is also observed that there is a unique deformation on the base metal. In longitudinal direction tension, it exhibited the drastic reduction in elongation but with an increase in flow stress.

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It has been accounted that the largest elongation was at 965 °C with 178.96% elongation and strain rate of 3.1× 10-4 s-1. It is noticed from the conducted experiments that the base material is lower than the flow stress of the welding seam.

Izosaki et al. [9] have done an investigation on the tensile properties of JIS Type SUS 316 stainless steel and the results has been studied from the corresponding experiments. The tensile tests were conducted at room temperature and higher temperature at 400°C and 550 °C at strain rates of 10-3 s-1 and 10-2 s-1. The test motive was to give an clarity on the strain rate effects followed by the mechanical properties like yield strength (YS) 0.2%, ultimate tensile strength (UTS) and elongation by conducting test at elevated temperature on JIS Type SUS 316 stainless steel. By conducting the static and dynamic tests, it is being found that 0.2% yield strength and (UTS) Ultimate tensile strength of the (WM) weld metal specimen is higher than the (BS) base metal specimen. But it is to be observed that the static UTS are higher than the dynamic UTS when tested at high temperature. At room temperature, both the static and dynamic tests that were conducted shows that the deformation resistance of weld joint and weld metal specimen is greater and almost equal to the base metal specimen. As the result it is being understood that the characteristics of the weld joint specimen deformation is highly dependable on that of the weld metal specimen.

It has been observed there is a higher stiffness on the weld when compared to mild steel with a higher range of temperature at which the testing was conducted. It has also been noted that the butt welded mild steel plates were better in elasticity than the S420M steel when they were conducted at 100°C. At 300°C, the material showed reverse trend from the resulting graph. It is being noticed that below 150°C the proportional limit of the weld is lower at the steady state test than the corresponding transient state test [10]. Zacharia et al. [11] conducted elevated temperature tensile test on Al-Li-Cu-Mg Alloy in order to find its mechanical properties. Generally, a very low strength and ductility was exhibited by the Alloy 2091 in the as-cast condition at elevated temperature. As the material that has coarse dendritic structure which is being the cause for the relative poor strength and ductility of the material. The tensile strength of wrought Alloy 2091 is said to be in agreement frequently with the strength of Alloy 2024 when the hot tensile tests are taken throughout the temperature. Hence the Alloy 2091 was developed in order to replace the Alloy 2024 in field of aerospace applications. Above the temperature 454°C, the YTS (yield strength) and the UTS (ultimate tensile strength) which are to be relation with temperature that has peaks, where the low strain rate strength has been exceeded to the high strain rate strength [10].

An extensive literature review has been conducted on TIG welding of Ti-6Al-4V alloy. It is observed that not much more work has been carried out to know the material behaviour at elevated temperature. Hence, an initiative is taken through this research work is study the behaviour of the welded specimen at elevated temperature.

II. EXPERIMENTAL WORK

Specimens of two Ti-6Al-4V plates of dimensions 150 X 100 X1.5 mm were prepared from their raw sheets respectively. First specific dimension is marked on the sheet with marker and then cutting action was performed using the wire cut EDM. Having good corrosion resistance, Ti–6Al–4V α-β alloy is lightweight with a capability to withstand higher extreme temperature.

Table 2 shows the results of the Ti–6Al–4V alloy chemical composition analysis. The welding parameters were set and regulated with the digital signal processor which is with the equipment. It also helps in attaining different welding conditions with rapid feedback and adjustment.

Table 2: Chemical composition of Ti6Al4V

Alloy	C	O	N	H	Fe	Al	V	Ti
Ti6Al4V	0.01	0.19	0.05	0.0016	0.16	6.51	4.08	Balance

In this research work a setup of autogenous welding has been used to perform welding with a fixed velocity without the application of filler material. A movable setup is used to hold TIG torch. A constant distance has been maintained between work piece and torch tip through-out the welding process. The movable setup has been used such that the speed of the setup is controllable and modifiable. The setup can also be varied according to the welding speed and amount of heat required. Figure 2 shows experimental setup for present work.

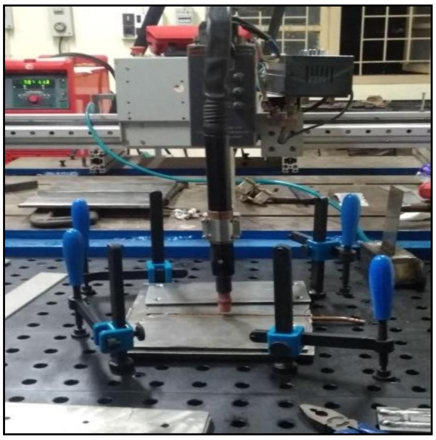

Figure 2: Experimental setup of TIG welding

Figure 3 shows the weld morphology on top side work piece during bead on plate trial and table 3 shows the welding parameters. Metallic bright silver color has been denoted from the weld appearance which determines that the weld pool is properly protected from the atmosphere and adequate shielding is provided that can be noted from the figure 3. Argon gas with 99.9% purity is used to provide the plasma and the arc shielding.

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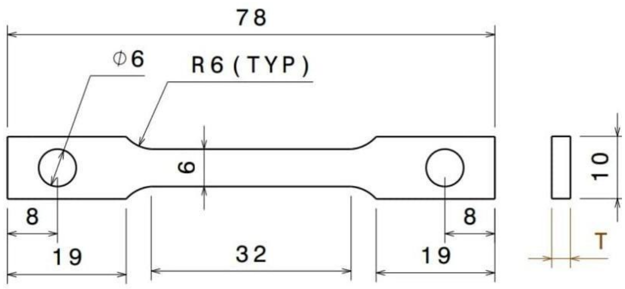
Table 3: Welding input process parameters and set up conditions

Electrode type	2% throated tungsten electrode
Diameter of electrode	1mm
Gas / Flow rate	12L/min
Shielding gas	Argon
Torch position	Vertical
Operation type	Automatic
Current	80A
Voltage	10.8 V
Travel speed	200mm/min
Arc length	8mm
Trailing shielding gas flow rate	20L/min

Figure 3 Weld appearances in Ti–6Al–4V sheet.

III. EFFECT OF TENSILE PROPERTIES

The dimensions of the tensile test specimen of TIG welded Ti-6Al-4V plates were cut by wire cut EDM in accordance with ASTM E8 standards as shown in figure 4. There were holes at both ends of each specimen (pinned specimen) to enable fixing to the loading shafts located at the top and bottom ends of the UTM and elevated temperature UTM furnace. These pinned specimens were designed so that they did not affect the specimen fracture.



(a)

(b)

Figure 4: tensile test specimen a & b- ASTM E8 standards (in mm)

Tensile tests were conducted at room temperature, 250 º C , 450 º C and 650 º C respectively. The set up available is shown in the Figure 5.

Figure 5(a): tensile test at room temperature

Figure 5(b): tensile test at elevated temperature of 250°C, 450°C and 650°C

The tensile test of TIG welded Ti-6Al-4V specimen has been performed at room temperature and its mechanical properties were found. From the figure 6, the ultimate tensile strength of the specimen was found to be 840MPa and the fracture was observed at the base material.

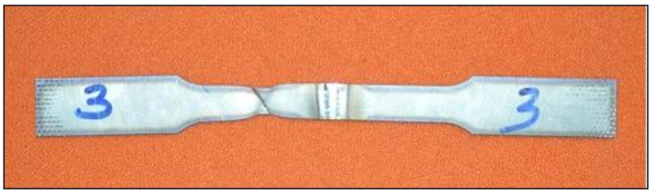


Figure 6: Tensile testing specimen at room temperature

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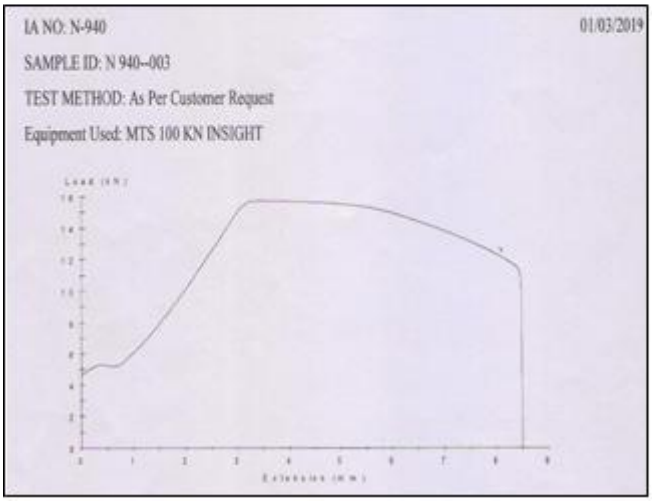

Figure 7: Load (kN) Vs. displacement (mm)

Figure 8: tensile fractured specimens

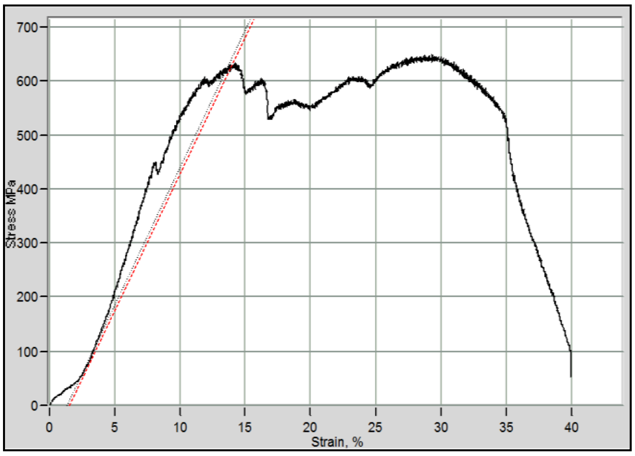

Figure 9 plot of stress Vs strain at 250°C

It is observed from the figure 9 that on increase in the temperature from 25°C to 250°C, both ultimate tensile strength (UTS) and yield strength (YS) decreases while there was a gradual increase in reduction area and elongation. From which it has been concluded that the increase in temperature results both UTS and YS to decrease yet the plastic behavior is improved that was associated with the merging of the fibrous zone with the radiation area at the tensile fracture surfaces. The ultimate tensile strength of the specimen was found to be 648.8 MPa and the fracture was observed at the base material.

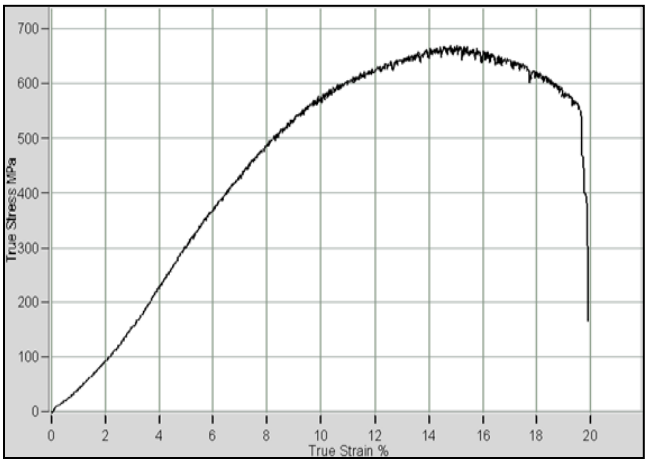

Figure 10 plot of stress Vs strain at 450°C

From the figure 10, it is observed that the mechanical property of the base metal testing has been decreasing as the temperature ranging above 450 °C. The mechanical properties of the welded joints had decreased with an increase in temperatures above 450 °C. It is also noticed that ductility of the welded joint had a smaller decrease at 450 °C. The ultimate tensile strength of the specimen was found to be 577.7 MPa and the fracture was observed at the base material.

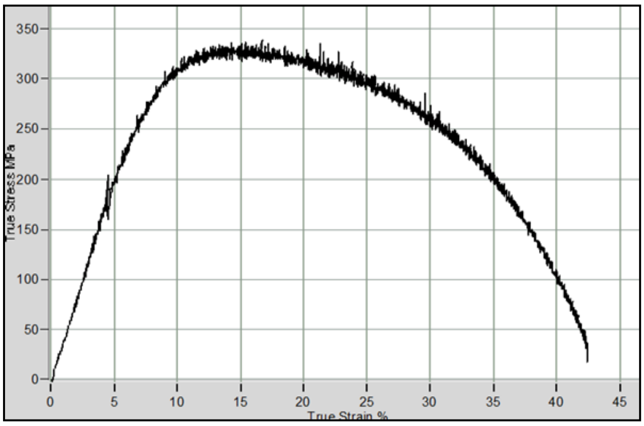

Figure 11 plot of stress Vs strain at 650°C

It was observed from the above figure 18(b); the fracture is localized in the base metal of the specimen. At 600°C and higher, it has been observed that as there is a decrease in tensile strength at the joint and increase in plastic deformation. The ultimate tensile strength of the specimen was found to be 293 MPa and the fracture was observed at the base material.

IV. CONCLUSION

TIG welding experiments are conducted on Ti-6Al-4V alloy using Fronius Magic wave welding equipment. Mechanical testing was conducted at elevated temperature as well as at room temperature. The following conclusions are drawn:

1. It is observed that the ultimate tensile strength of the welded specimen is 840 MPa at room temperature and the failure is found to be at the base material. This yields that the weld strength is on bar with the base material.

2. There is no crack is observed from the bend test and the weld integrity is found to be good.
3. It is evident that the ultimate strength and yield strength decreases with increase in temperature and also the percentage elongation increases with increase in temperature. At temperatures above 650°C, the ultimate tensile strength (UTS)had decreased to about 66% than the ultimate tensile trength (UTS) at room temperature.

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