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Study of Mechanical Properties on Thick Titanium Alloy (Ti - 6Al- 4V) Multi-Passes Weld

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***Abstract*—The aim of this study “Experimental study of Mechanical Properties on Thick Titanium Alloy (Ti – 6al – 4v) Multi-passes Weld”, is to assess the effect of heat input by GTAW process of mechanical properties on thick titanium alloy. Titanium alloy (Ti-6Al-4V) is alpha-beta alloys type when properly treated, have an excellent combination of strength and ductility. They are stronger than the alpha or the beta alloys. Furthermore, a heavy thickness application of titanium is being increasingly utilize. GMAW is recommending joining titanium and titanium alloys. It is less than costly, required skills and experience, and applications are widely especially compare with other welding processes. 200cm Ti-6Al-4V alloy pleats were prepared, and divided to four pieces (500 mm long, 200 mm widths and 15 mm thickness) each two pieces multi passes welded by GTAW process. Optimum selection of parameters such as Welding speed (mm/s), Welding voltage (V), Welding current (A) adapted as inputs and Ultimate tensile (MPa) Impact Strength (J), Hardness (HRC), as outputs. All weldment pass through requirement tests. For that, after welding process, the welding plate's specimen prepared for tensile test, impact tests, and hardness test. Thirty specimens fabricated for each test. The analysing of the mechanical properties as tensile strength, impact and hardness, of titanium weldment find slightly lower than in the base metal.**

Keywords—Mechanical Properties, Tensile test, Impact test, Hardness test, Titanium Alloy, GTAW.

I. INTRODUCTION

In a lot of the engineering applications, titanium takes over heavier, less serviceable or less cost-effective materials. Designs created with the properties provided by titanium often produce dependable, economic and more durable systems and components[1]. Ugur Esme et al,[2] were carried out investigated the multi-response optimization of tungsten inert gas welding (TIG) welding process for an optimal parametric combination to yield favorable bead geometry of welded joints using the Grey relational analysis and Taguchi method. Sixteen experimental runs based on an orthogonal array of Taguchi method were performed to derive objective functions to be optimized within experimental domain. The objective functions have been selected in relation to parameters of TIG welding bead geometry; bead width, bead height, penetration, area of penetration as well as width of heat affected zone and tensile load. S. Krishnanunni et al, [3] found that the effect of welding condition on hardness of pure titanium material. Butt welding of thin pure Ti sheets is prepared by TIG welding using argon gas as the shielding gas. Amount of shielding gas and number of passes are taken as the variables in welding conditions. It was found that the maximum value of hardness is obtained corresponding to shielding gas flow rate of 7 l/min and 4 numbers of welding passes. Raghuvir Singh et al, [4]were carried out investigated the effect of TIG welding parameters like welding speed, current and flux on depth of penetration and width in welding of 304L stainless steel has been studied. From the study it was observed that flux used has the most significant effect on depth of penetration followed by welding current. Optimization was done to maximize penetration and having less bead width. GTAW welding will be an important joining method for titanium and its alloys with their increasing applications in aircraft, aerospace, marine, automotive industries, electronics, military, and other industries. Some important GTAW processing parameters and their advantage and effects on weld quality are explained. The microstructure and metallurgical defects faced in GTAW welding of titanium and its alloys, such as porosity, cracking, HAZ, and penetration are good. Mechanical properties of welds such as tensile, hardness, fatigue strength, Impact and other properties are excellent. Given titanium’s lightness, strength, and resistance to corrosion and high temperatures, its most common use is in alloys with other metals for constructing aircraft, jet engines, and missiles. Its alloys also make excellent armor plates for tanks and warships. It is the primary metal used for constructing the stealth aircraft that are difficult to detect by radar[5]. The completed molds are then embedded on a casting table for centrifugal casting. Cast components of up to 2750 kg have already been successfully produced. Even larger structures are likely, but can also be manufactured by welding together two or more castings[6]. In addition to, forging is one of process using to produce titanium productions for large ingots. By Forging process it can produces up to 600 mm or 4500 kg [6].

II. EXPERIMENTAL PROCEDURE

Titanium alloy (Ti-6Al 4V) plate (Grade 5) with chemical composition presented in Table 1 was used as workpiece material as shown in Figure 3. The dimension of each specimen was 500 mm long × 200 mm width with thickness of 15 mm. The needs to achieve higher productivity and stringent safety requirement have put growing emphasis on the achievement best weldment with lowest defects. The basis for success weldment starts with perfect selection of welding parameters. Optimum parametric setting of heat input corresponding to each factor need long experience and dependent on optimum condition suggested as 1, 70, 11 and 61.7172 (i.e. Filler diameter= 1 mm, welding current = 70 A, welding voltage = 1l V and travel speed= 61.7172 mm/s). Table 2 shows welding other parameters that involves in the process.

TABLE 1. CHEMICAL COMPOSITION

Elements / *Material*	%N Max	%C Max	%H Max	%Fe Max
Ti-6Al-4V	0.00	0.04	0.012	0.2
%O Max	**%Al**	**%V**	**%Ti**	
0.10	5.8	4.1	Balance	

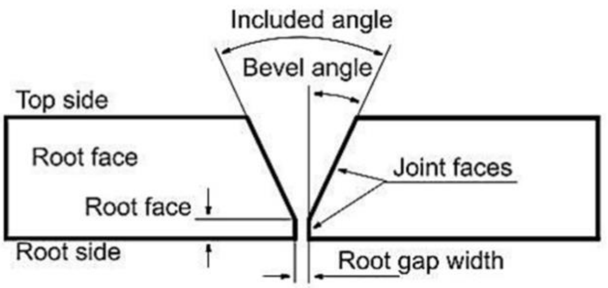

Fig. 1. *joint with edges preparation*

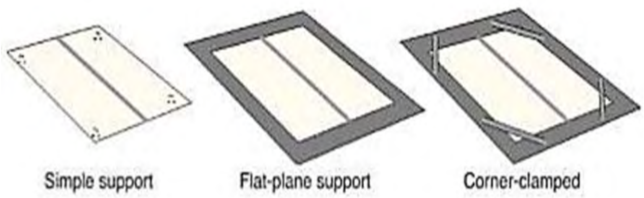

Fig. 2. *supporting for butt welding*

Table 2. WELDING PARAMETERS

Joint Type	Type of welding current	Type of shield gas	Gas flew (L/Min)
Butt	DCEN	Argon	8-2
Electrode's data		**Filler's data**	
Classification	**Alloying element**	**Classification**	**Filler metal type**
EWCe-2	Cerium	AWS A5.16	ER Ti-5

III. TENSILE TESTS

The tension test is the most common method for determining the mechanical properties of materials, such as strength, ductility, toughness, elastic modulus, and strain- hardening capability[7]. The tensile test makes it possible to determine the standard characteristics of materials, often required in specifications. Which are proof strength, tensile strength, elongation after fracture. Secondly, it makes it possible to deduce the true stress-strain relation. Despite its simplicity, the tensile test requires certain precautions, both in achievement, and its use[8]. The tensile samples manufacturing processes was completed by milling machine taking into consideration the use of cooling liquid during the cutting processes. The manufacturing processes are clarified in Figure 3 below:

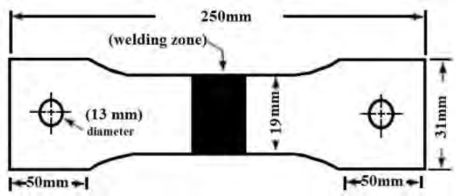

Fig. 3. *Tensile sample*

A. *Analysing of Tensile Data*

Tensile tests were carried out in 4000 KN. The electro-mechanical controlled Universal Testing Machine. The specimen was loaded at the rate of 15 mm/min, and the average of maximum loads during the test was above 244 KN. The tensile test results show that the average ultimate tensile strength values of GTAW joints are all above 880 MPa, while the ultimate tensile strength of base metal was 896 MPa. This indicates that there is a 1% reduction due to the GTAW process. Figure 4 shows the main effect plots, it was found that welding parameters had considerable significant for the tensile strength whereas travel speed had a linear effect. Welding current and welding voltage has the same effect in both lower to higher values on tensile strength.

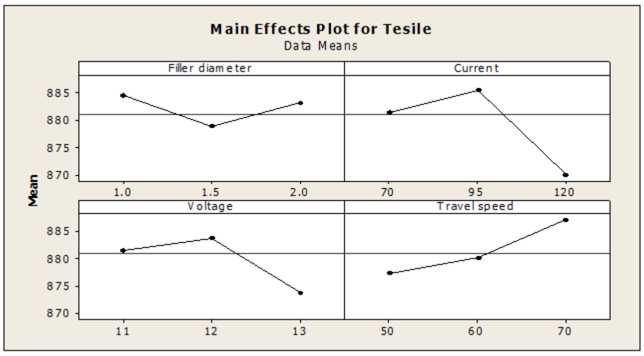

Fig. 4. *Main effect plots for welding parameters via tensile strength*

Figure 5 and Figure 6 shows the contour plots of tensile strength via welding voltage welding current and travel speed. Consequently, the maximum value of tensile strength is achieved with the welding voltage, as well as to be medial as discussed in the previous figure and the voltage needs to be medial synchronous with higher travel speed which is indicated in the top of the figure and observed from the graph.

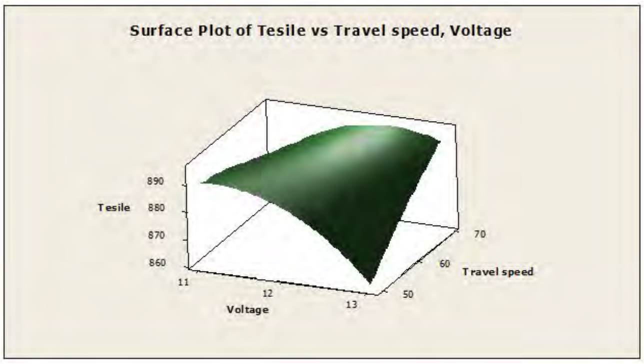

Fig. 5. *Contour plot of tensile strength via welding voltage, travel speed*

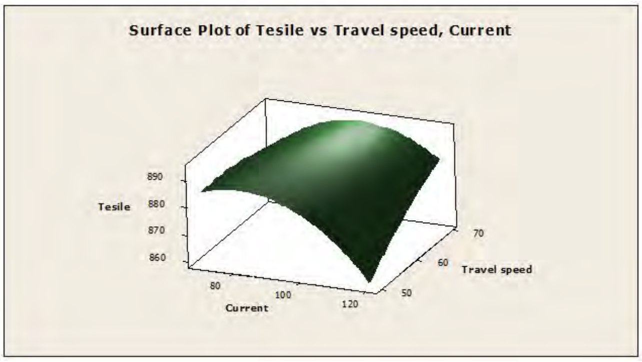

Fig. 6. *Contour plot of tensile strength via welding current, travel speed*

Figure 7 shows the contour plot of tensile strength via welding voltage and welding current. The higher of tensile strength is achieved with the welding current as well as welding voltage values to go between11-13V, as discussed in the previous figure and the current and voltage needs to be minimum which is indicated in the top left corner of the figure.

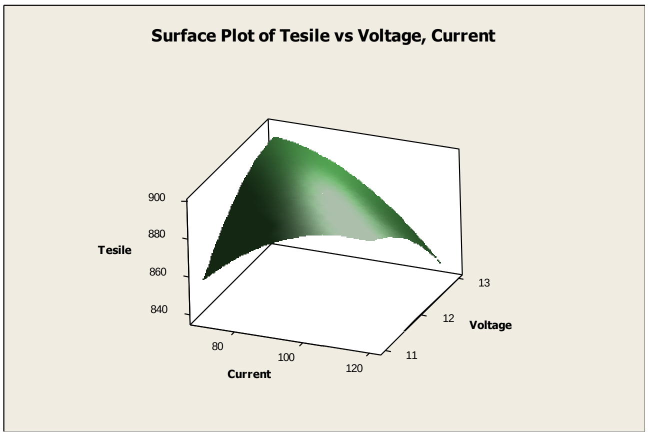

Fig. 7. *Contour plot of tensile strength via welding current, welding voltage.*

Figure 8 shows the contour plot of tensile strength via filler diameter, travel speed. The maximum value of tensile strength is achieved with the travel speed being at highest values for all filler diameters.

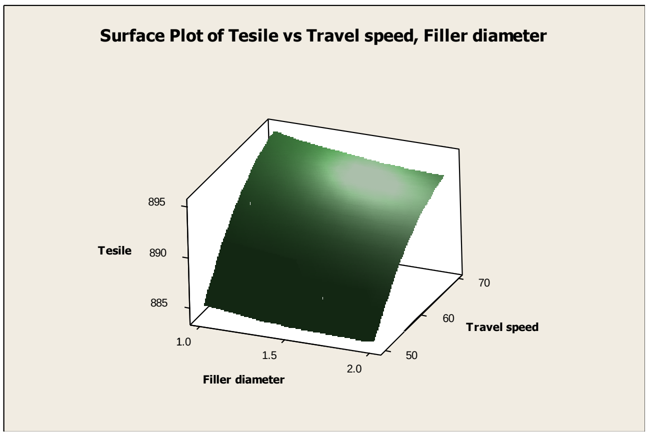

Fig. 8. *Contour plot of tensile strength via filler diameter, travel speed*

Figure 9 and Figure 10 shows the contour plots of tensile strength via, filler diameter, welding voltage, welding current. The maximum value of tensile strength is achieved with the welding voltage being lower as discussed in the previous figure, and the voltage and current need to be at lowest with larger filler diameter which is indicated in the lower right corner of the figure from.

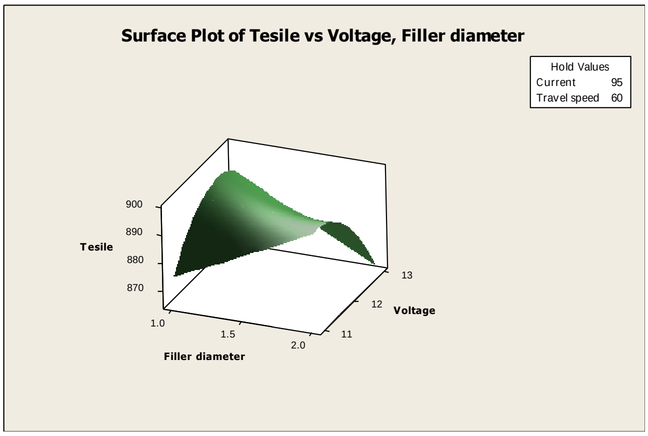

Fig. 9. *Contour plot of tensile strength via filler diameter, welding voltage*

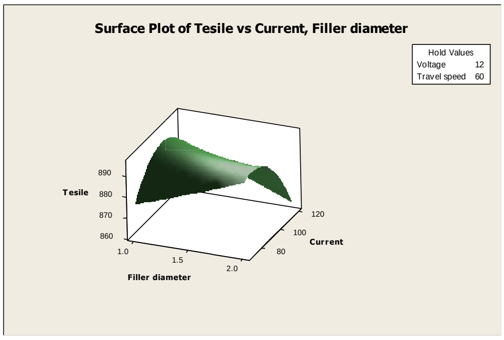

Fig. 10. *Contour plot of tensile strength via filler diameter, welding current*

B. Impact Tests

Knowing the mechanical characteristics deduced from tensile tests may be insufficient since fractures can take place below the yield strength in conditions where the material is brittle. A common factor of these conditions is stress concentration linked to a defect, which can vary according to temperature, strain rate and dimensions of loaded parts. One of the most traditional mean to characterize steel brittleness is the impact test[8]. As a tensile test specimen, the impact samples manufacturing processes by milling machine take into consideration the use of cooling liquid during the cutting processes. Manufacturing processes have been clarified in Figure 11.

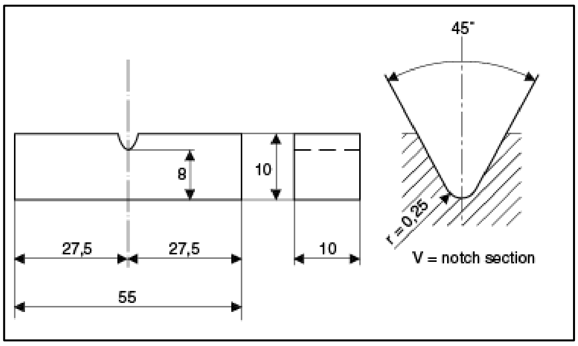

Fig. 11. *Charpy V-notch Impact test specimen*

C. Analysing of Impact Data

Figure 12 shows the main effect plots, it is found that welding parameters are considerably significant on impact. Welding current and welding voltage have the opposite effect, as well as for filler diameter and travel speed.

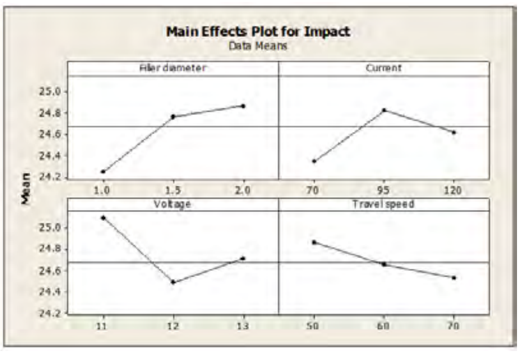

Fig. 12. *Contour plot of impact via welding parameters*

Figure 13 shows the contour plot of impact force via welding voltage, travel speed The maximum value of impact is achieved with the welding voltage being maximal, as discussed in the previous figure, and the voltage needs being maximum and at the high range of travel speed which is indicated in the two regions upper left corner and lower right corner of the figure.

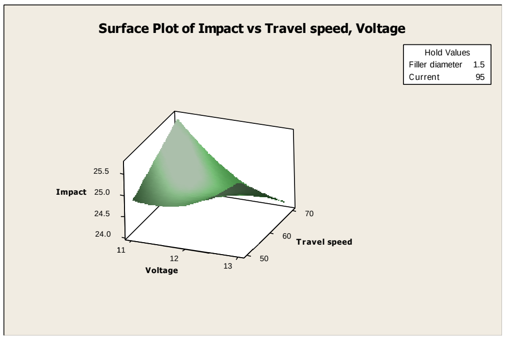

Fig. 13. *Contour plot of impact via travel speed, welding voltage*

Figure 14 shows the contour plot of impact via welding current, travel speed. The maximum value of impact force is achieved with the welding current being maximum and travel speed being minimum, which is indicated in the lower right corner of the figure.

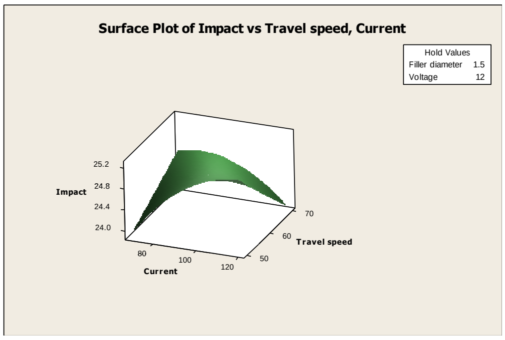

Fig. 14. *Contour plot of impact via welding current, travel speed*

Figure 15 shows the contour plot of impact force via welding current, welding voltage. The maximum value of impact force is achieved with the welding voltage being minimal and higher current, as is indicated in the lower right corner of the figure.

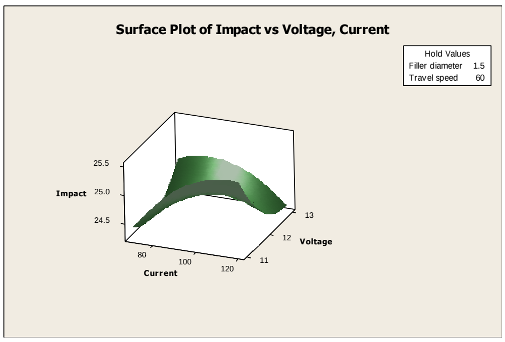

Fig. 15. *Contour plot of impact via welding current, welding voltage*

Figure 16 shows the Contour plot of impact force via welding current, filler diameter. The maximum value of impact force is achieved with the welding current at minimal through midtrial, which is indicated in the lower left corner of the figure.

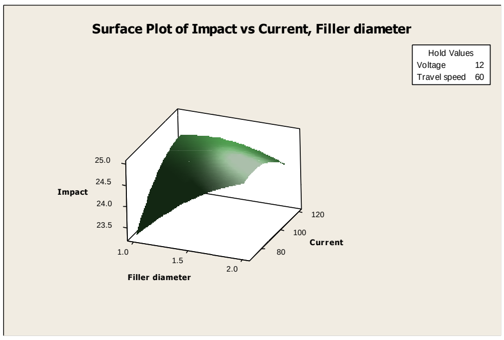

Fig. 16. *Contour plot of impact force via welding current, filler diameter*

Figure 17 shows the contour plot of impact force via welding current and welding voltage filler diameter respectively. The maximum value of impact force is achieved with the welding voltage at minimal for larger filler diameter, which is indicated in the lower right corner of the figure.

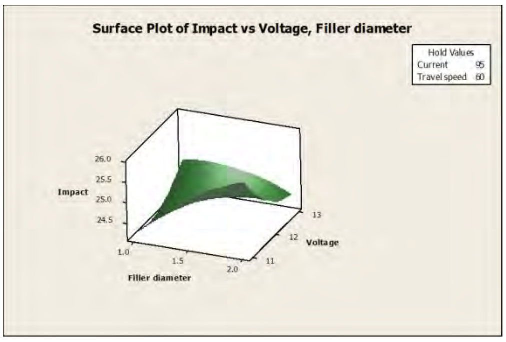

Fig. 17. *Contour plot of impact force via welding voltage, filler diameter*

Figure 18 shows the contour plot of impact force via filler diameter, travel speed. The maximum value of impact force is achieved with the filler diameter at maximum with higher travel speed, which is indicated in the lower left corner of the figure.

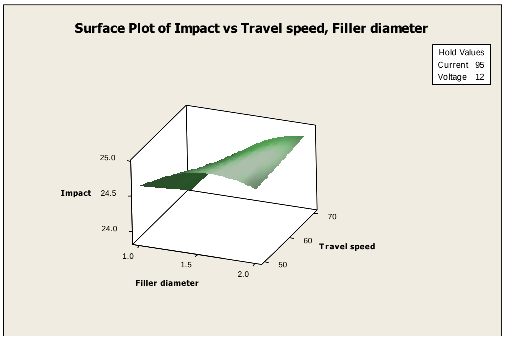

Fig. 18. *Contour plot of impact force via travel speed, filler diameter*

D. Effect of Multi Weld Joint on Hardness

Due to the tiny indentation of hardness test, the samples" surface roughness will affect the test results directly. Therefore, the samples" hardness should be tested passing by through polishing processes. Rockwell Hardness tester (Figure 19) is used for determines hardness at the joints' different area and loaded with 1471 N for 10s during testing. The hardness of the Ti-6Al-4V weldment is shown in Figure 20. It can be seen that hardness distribution from Ti-6Al-4V base metal to weld seam presents downward trend. The hardness in seam is higher than that in the Ti-6Al-4V base metal apparently. The hardness of seam welded by GTAW is lower than in the HAZ.

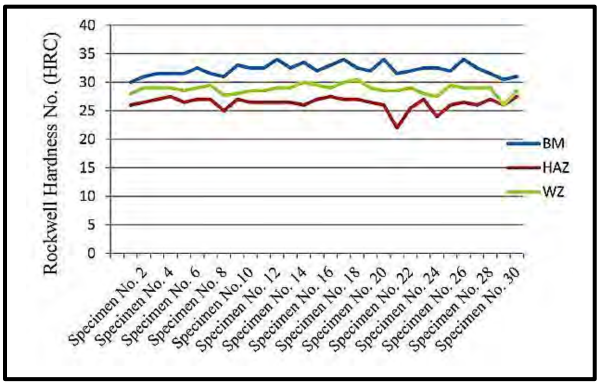

Fig. 19. *Rockwell Hardness No. (HRC) for the BM, WZ, and HAZ in Ti-6Al-4V weldment*

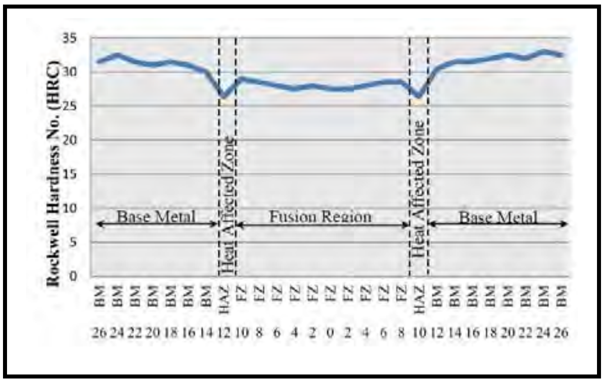

Fig. 20. *Relationship between Hardness No. and the (BM, HAZ, FZ) regions in Ti-6Al-4V weldment*

The width of HAZ ranged between 3.5 to 4.5 mm, while the length of the fusion zone from the upper surface of the weld region between 17.5 to 20 mm. Figure 20 show that the value of hardness has decreased in the HAZ, and FZ. The average values of the hardness in the base metal were 32 HRC, and 29 HRC in HAZ, while average hardness values descended to 28 HRC in the fusion zone, which means that the hardness decreased about 10% from the core values which is acceptable[9].

E. Conclusion

Clear side effect of welding on the titanium Ti-6Al-4V alloy is a heat input during the welding process. This effect changed in different faces with unsuitable welding parameters. The optimal welding parameter makes the welding process successful, and reduces the negative impacts associated with them when welding titanium, which expands its uses. From the study, the following points can be concluded:

1. The gas tungsten arc (GTAW) is the preferred welding process of titanium alloys, Ti-6Al-4V, owing to its comparatively easier applicability, and better economy especially for heavy thicknesses. Direct current electrode negative (DCEN) polarity is suitable for thick titanium plate. DCEN polarity obtains a full penetration with strong joints. Success to single side welding and full penetration joint for 15mm thick titanium joint produce makes welding titanium weldments with large thicknesses possible when taking into account the change in the design of weldment. The effect of heat input by four welding pass on 15mm titanium Ti-6Al-4V alloy plates had a small effect on the microstructure, and mechanical properties.
2. Welding parameters are considerably significant on tensile strength whereas travel speed has linear effect. Welding current and welding voltage has the same effect in both its lower though higher values on tensile strength. On the other hand, Welding current and welding voltage has the opposite effect, as well as for filler diameter and travel speed on impact.
3. The average values of the hardness in the base metal 32 HRC, and 29 HRC in HAZ, while average hardness values descended to 28 HRC in the fusion zone, which means that the hardness decreased about 10% from the core values and that acceptable.

D. Reference

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