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Experimental Investigation of Various Welding Parameters on TIG Welding of Aluminium Alloy-2014

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Abstract

Aluminium alloys are the king in aircraft construction materials for aircraft industry since 1930. In the aerospace industry, 2014-Aluminum alloy after 2024-Aluminum alloy is the second most popular of the 2000-series. It is commonly forged and extruded. TIG welding can be a potential tool which is superior to other joining techniques, resulting in weight reduction with high strength. In order to find out the weakest locations of the joints and determine the optimum TIG welding parameters, this present work aims to demonstrate its TIG weldability and the emphasis is placed on the relations of the tensile properties and hardness to the welding parameters. To improve welding quality of Aluminium alloy (Al-2014) is welded with TIG welding system by changing different welding parameters. Effect of welding current and gas flow rate (Argon) on the tensile strength and hardness of the weld joint has been investigated. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality. Micro-hardness value of the welded zone has been measured at the cross section to understand the change in mechanical property of the welded zone. From the experimentation.

Keywords: TIG Welding Machine, Aluminum Alloy-2014, ER-1100, Hardness, Tensile Strength

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I. INTRODUCTION

On TIG welding of Aluminum alloys a lot of work has been done that is revealed by the literature survey. In literature for TIG welding of Aluminum alloys, the research work has been found that is based on past work and drawn the following conclusion:

- For TIG welding, the important process parameters are welding voltage, work piece material, Welding speed, shielding gas, electrode diameter and electrode gap and welding current.
- To perform precise and uniform welding of aluminum alloys, the gas flow rate, welding speed and welding current play a vital role in determining the mechanical properties of Aluminum alloys.
- The parameter selection and range depends on the type of material, the strength requirement and the specification of the welding machine that are to be used.
- With selection of welding material and welding technique, the welding strength and welding profile is greatly influenced.
- In TIG welding of Aluminum for better strength and cleanliness, the AC power source is mostly preferred.
- At different zones of weldment, the Microstructure investigation provides a comparative outcome between base material and TIG to differentiate the effect of temperature distribution.

II. OBJECTIVES OF RESEARCH

- To Evaluate Process Parameters of TIG Welding for Aluminum alloy-2014-T4.
- To analyze impact of Process Parameters- Gas flow rate, Welding Current, filler material and voltage on Tensile strength and Hardness of weld joint.
- To find out Optimum gas flow rate and welding Current combination on the mechanical properties of AA2014 weldments.

III. EXPERIMENTAL WORK

A. Material Selection

After going through literature survey it is found that less amount of research work is conducted on Aluminum Alloy-2014. After going through market survey, 2xxx Aluminum alloy is found to be widely used in aircraft industries because Copper content in AA Alloy-2014 is 2-10% which increases strength and hardness by reducing ductility which is best fit for aerospace applications.

B. Experimentation

Commercial Aluminum (Al-2014) plate of thickness 3 mm was selected as work piece material for the present experiment. Al-2014 plate cut into 150 mm x 85 mm with the help of shearing machine and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished with emery paper to remove any kind of external material or dust. After sample preparation, Aluminum plates fixed in the working table with flexible clamp side by side and welding done so that a butt joint can be formed.

C. Testing

Aluminum Alloy 2014 is a copper based alloy with very high strength together with excellent machining characteristics. AA2014 is commonly used in many aerospace structural applications due to its high strength. Other applications include military vehicles, bridges, weapons manufacture and structural applications. For the present work, butt welding of AA2014 plate (3 mm thickness) done at different current setting and flow rate of argon gas keeping voltage constant. Filler material is ER-1100.

- Commercial Aluminum (Al-2014) plate of thickness 3 mm was selected as work piece material for the present experiment.
- AA2014 plate was cut into dimension of 150 mm x 85 mm x 3mm with the help of shearing machine and grinding done at the edge for the formation of v groove at an angle of 45 degree.
- After that surfaces are polished with 200 grit emery paper to remove any kind of external material or dust.
- After sample preparation, Aluminum plates are fixed in the working table with flexible clamp side by side and welding done so that a butt joint can be formed.
- Zirconiated tungsten electrodes of diameter 3.4 mm was taken as electrode for this experiment.
- A number of trial experiments have been performed on the aluminum alloy to get best parameters for study

IV. TIG WELDING PARAMETERS USED

A. Tensile Strength Test

Ultimate tensile strength (UTS) often shortened to tensile strength (TS) or ultimate strength and is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is defined as a stress, which is measured as force per unit area. Maximum tensile strength and toughness was calculated from the stress strains graph plotted during tensile test.In the SI system, the unit is the Pascal (Pa) Newton per square meter (N/m^2).In tensile testing specimen are prepared as shown in fig according to ASTM standard B 557 and its testing is done on UTM.[1]

Table - 4.7
TIG welding parameters used for final Experimentation

SAMPLE NO.	*NUMBERING ON PLATES*	*CURRENT (AMPERES)*	*GAS FLOW RATE (LITRES/MINUTE)*	*VOLTAGE (V)*
1	*1-2*	*150*	*5*	*250*
2	*3-4*	*150*	*7*	*250*
3	*5-6*	*150*	*9*	*250*
4	*7-8*	*175*	*5*	*250*
5	*9-10*	*175*	*7*	*250*
6	*11-12*	*175*	*9*	*250*
7	*13-14*	*200*	*5*	*250*
8	*15-16*	*200*	*7*	*250*
9	*17-18*	*200*	*9*	*250*

B. Metallurgical Test

When describing the structure of a material, we make a clear distinction between its crystal structure and its microstructure. The term crystal structure is used to describe the average positions of atoms within the unit cell, and is completely specified by lattice type and the fractional coordinates of the atoms. In other words, the crystal structure describes the appearance of the material on an atomic length scale. The term microstructure is used to describe the appearance of the material on the nm-cm length scale.

C. Vickers Hardness Test

The Vickers hardness done on welded specimen by indenting them with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces and subjected to a load of 1 to 100 kgf . After experimentation data tabulated as per the under given vicker hardness equation Micro-hardness measurement was done on weld pool and on heat affected zone (HAZ) for each sample. Before micro-hardness measurement cross section of the welded specimen mounted and polished with 220, 600 and 1200 grit size polishing paper sequentially. Micro-hardness was measured with Vickers micro-hardness tester.

V. RESULTS AND DISCUSSION

A. *Effect of Gas Flow Rate & Current Intensity*

Fig 5.1 and Fig 5.2 shows that tensile strength and toughness of welded joint increased by increasing the current rate and the maximum value is reached at the highest current value. It shows the maximum tensile strength of 171.4 MPa and toughness 6650 Kj/m^3 is achieved at 9 liters/min at highest current value of 200 Ampere. From the above results it is revealed that with increase of current intensity the tensile strength and toughness of welded joint increases.

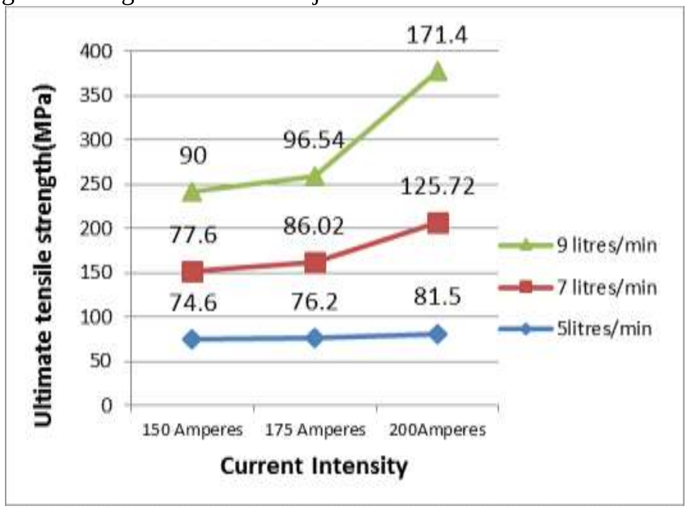

Fig. 5.1: Effect of Current on Tensile Strength of AA2014 Weldment

The size and the distribution of $CuAl_2$ precipitates play a major role in deciding the tensile strength and the hardness of the welds of AA2014. More evenly distributed $CuAl_2$ precipitates contribute in the high strength of AA2014. During GTAW welding, these precipitates are dissolving due to high heat generation and weld metal left devoid of any precipitates which makes the weld zone weaker than the base metal [1].

After going through the literature survey it is found that pulsed current welding improves the welding strength of the welded metal joint as compared to continuous welding. The refinement of microstructure due the pulsed current welding results in an uniform distribution of the fine precipitates more effectively enhancing the amount of precipitates in the matrix .Refinement of the grains directly depends on the heat input , as current increases the heat increases, resulting in the refining of the grains by uniform distribution at the weld zone. Therefore, refining of the grains by increasing the heat input results in the higher tensile strength and toughness of the welded joint [2].

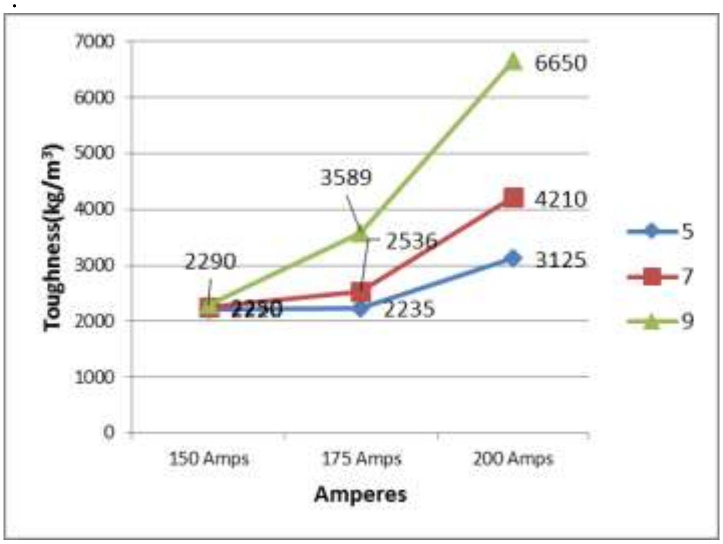

Fig. 5.2: Effect of Current on Toughness of AA2014 Weldment

In general, the UTS of welded joints increased with an increase of the heat input because too low a heat input led to the presence of partial penetration and pores. During the TIG welding of AA2014, too low a heat input easily results in the presence of welding defects, which seriously decreases the tensile strength of the welded joint see Fig 5.1. At high current and with increase in gas flow rate there is more homogeneity in microstructure which is the reason for high toughness. With an increase of the current intensity heat input increases, resulting in the proper fusion of the filler material with the base metal resulting in the increase of the ultimate tensile strength of the welded joints [3].

B. *Effect of Gas Flow Rate on Tensile Strength and Toughness*

As observed from the fig 5.3 and fig 5.4 at the constant current tensile strength and the toughness of the welded joint increases with the increase in gas flow rate and the maximum value is achieved at 9 liters/min. The effects of heat input on the tensile strength of the FZ plays the vital factor. As the gas flow rate increases penetration effect increases due to more effective shielding. As shielding effect increases there is an increase in heat input resulting in the reduction of oxidation effect in welding. Therefore at low gas flow rates due to poor shielding effect results in the entrapping of impurities from atmosphere resulting in defects like pores which can be seen in sample 1 and 2.Therefore low heat input leads to brittle material resulting in low UTS. As the gas flow rate increases leads to less atmospheric oxidation and better joint with high UTS.[3]

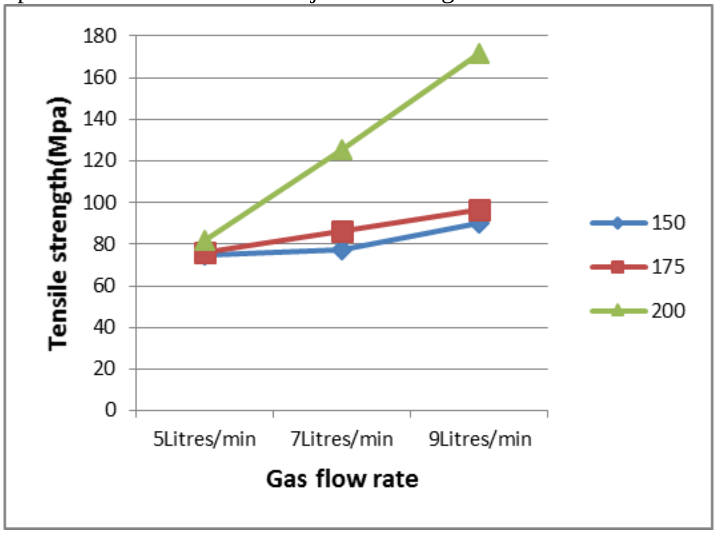

Fig. 5.3: Effect of Gas Flow Rate on Tensile Strength of AA2014 Weldment

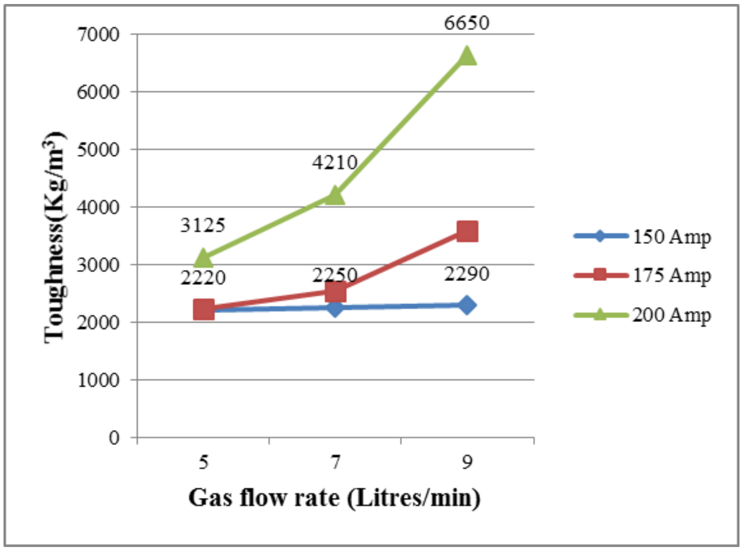

Fig. 5.4: Effect of Gas flow rate on Toughness of AA2014 Weldment

C. *Microstructure Analysis of Welded Section*

Microstructure of base metal and at the cross section of the weld was taken by using an optical microscope after proper polishing. Microstructures of base metal (Aluminum-2014 alloy) and welded metal are shown in figure 5.5. Microstructure of base metal contains the brighter part which is pure Aluminum and darker part is inter-metallic compounds mainly of $CuAl_2$ which was expected in case of Al-2014.

From these microstructures it can be clearly observed that proper fusion between weld pool and parent material has taken place during welding and there is clear distinction of fusion zone and parent material. Base metal has random oriented grains where as re-crystallized grains in rolling direction whereas weld metal of GTAW joint shows coarse and elongated grains normal to the welding direction can be seen in welded metal microstructure.

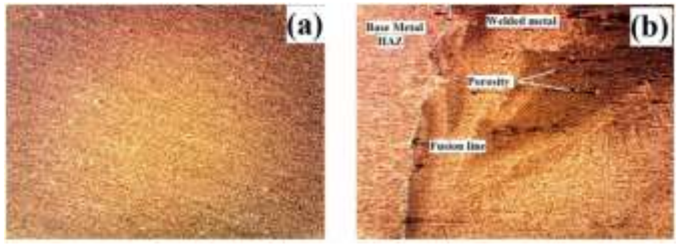

Fig. 5.5: Micro Structure of Al-2014 Alloy (a) Base Metal and (b) Welded Metal

The GTAW joint exhibit widely spaced and less dense dislocations. The evenly distributed fine precipitate is one of the reasons for higher strength of AA2014. In GTAW joint the precipitates are completely dissolved in the matrix and very few are visible. Microstructures of all the welded samples are shown in fig 5.6. As it can be seen that there is a clear distinction of fusion zone and base metal at lower gas flow rates (5 liters/min) at 150 and 175 ampere current. At high current and with increase in gas flow rate there is more homogeneity in microstructure which can be reason for high toughness. Moreover, it is evident that at 150 ampere current especially in sample 1 and sample 2, a partial penetration and pores were observed in the welded seam. At low heat input, during the welding process, the shielding gas usually protects the surface of heat input at the molten pool, while the back of the sample failed to be protected.

Hence, air may intrude into the molten pool easily through the gap between two plates and result in the formation of pores in the welded seam. Due to high porosity sample 1, 2 have failed shown low strength. Specimens welded at 200 amperes i.e. sample 7, sample 8 sample 9 has most homogeneous microstructure as compared to other samples. It shows proper fusion of filler metal with base metal which is reason for higher toughness and tensile strength of these samples. GTAW results in precipitates free zone (PFZ) due the solution treatment of weld zone by sufficient heat input caused by thermal cycle during welding since the PFZ is soft strain concentration will be extremely high even though the macroscopic strain is very low and this produces voids which then grow and coalescence along PFZ leaving the coarse dimpled structure. Hence, the matrix of the weld zone comprising precipitate free zone results in lowest hardness [4].

Pulsed welds have shown fine grain structure due to thermal disturbances and decrease in heat input. In general, hardness in the fusion zone is lowest due to the as cast nature of the microstructure, which is characterized by the coarse dendrite grains, inter dendrite segregate phases, and the lack of strengthening phase. Hardness is higher compared to the continuous welds and this could be due to refinement of grain structure and low segregation of phases [5].Multi criteria Decision Taking techniques are developed to determine the optimal solution [6,7,8].

D. Microhardness Test of Specimens

The Vickers hardness test was done on welded specimen by indenting them with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf.

E. Effect of Current on Hardness

From the graph it is found that as the current increases at constant gas flow rate VH value decreases. Fig.5.4.1 shows that maximum value of hardness is achieved at lowest current of 150 Ampere and the lowest value of hardness is achieved at highest current of 200 Ampere at gas flow rates 5, 7 and 9 Liters/min respectively.

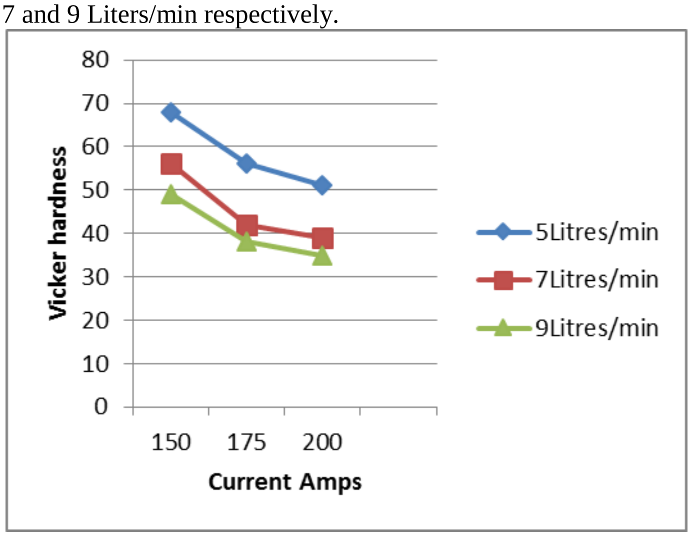

Fig. 5.6: Effect of Current Intensity on Micro Hardness at FZ

With increase of current value in TIG welding, heat generation at the fusion zone increases. Due to the fast cooling rates experienced near the weld area produces the super saturated solid solution, whereas during subsequent cooling and natural ageing very fine precipitates are formed near the weld area. At low current values heat generation is less due to which rapid cooling at the fusion zone boundary takes place with the generation of coarse grains small in size. With the increase of current value heat generation increases resulting in the formation of more coarse grains and grain size increases and becomes equixed. According to the Hall–Petch equation, the smaller the grain size is, the higher is the micro hardness. Therefore at low current values micro hardness increases whereas at high current value decreases. [6]

F. *Effect of Gas Flow Rate on Hardness Value of Aa2014 Weldment at Fusion Zone*

From the graph it is found that as the gas flow rate increases at constant current VH value decreases. Fig. 5.8 shows that maximum value of hardness is achieved at lowest gas flow rate of 5 Litre/min and the lowest value of hardness is achieved at highest gas flow rate of 9 Litre/min.

As observed from the Fig 5.8 at 150 Ampere current hardness is decreasing with increasing gas flow rates and same trend is observed for the other current values. So from the trend of the graph it can be concluded that with the increasing gas flow rate the hardness of the weld pool decreases. The effects of the gas flow rate and heat input on the micro hardness of the FZ plays the vital factor. At low gas flow rate poor shielding effect takes place resulting in lower heat input at the FZ. Due to low heat input cooling rates are high at the FZ resulting in the formation of less coarse grains small in size. According to the Hall–Petch equation, the smaller the grain size is, the higher is the micro hardness. Therefore as the gas flow rate increases at a constant current value, size of the grains increases due to more effective shielding effect and less oxidation resulting in low hardness values [7].

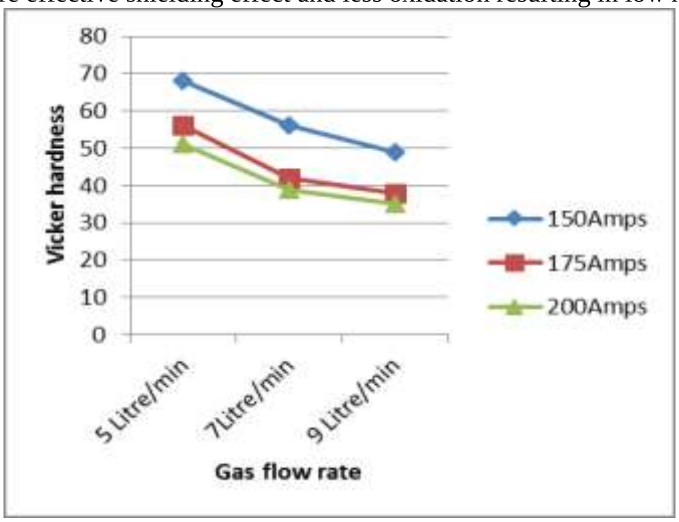

Fig. 5.7: Effect of Gas Flow Rate on Micro Hardness at FZ

VI. CONCLUSION

From the experiment of TIG welding of Aluminum alloy AA2014 plate following conclusion can be made.

1) Welding strength or tensile strength of the weld joints of AA2014 depends on the welding parameters: welding current, gas flow rate and filler material.
2) Optimized parameters for highest tensile strength of 171.4 Mpa & toughness of 6650 KJ/m3 of the AA-2014 are obtained at highest current intensity of 200 Ampere, gas flow rate of 9 Litre/min with filler material ER-1100.
3) Optimized parameter for highest hardness value of 68 VH is obtained at lowest current intensity of 150 Ampere, gas flow rate of 5 Litre/min with filler material ER-1100.
4) Tensile strength of the specimen increases with increase in current intensity as a result of which highest tensile strength of 125.72 MPa is achieved at highest current intensity of 200 Ampere.
5) Toughness is directly proportional to increase in current intensity which increases heat input as a result of which highest toughness of 4210 KJ/m^3 is obtained at highest current intensity of 200 Ampere.
6) Tensile strength and Toughness is directly proportional to gas flow rate as a result of which highest tensile strength is achieved at highest gas flow rate.
7) Welding defects like Porosity can drastically affect the properties of welded specimens of Al-2014 alloy which decreases the tensile strength.
8) With the increase in current and gas flow rate, hardness of the weld joint decreases as lowest value of 35 VH is obtained at highest current of 200 Ampere and gas flow rate of 9litres/min.

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