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VARIOUS EFFECTS OF WELDING PARAMETERS ON TIG WELDING OF 2024-T3 CLAD ALUMINUM ALLOY PLATE

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ABSTRACT

To improve welding quality of Aluminum alloy (Al) plate an automated TIG welding system has been developed, by which welding speed can be control during welding process. Welding of Al plate has been performed in two phases. During 1st phase of welding, single side welding performed over Al plate and during 2nd phase both side welding performed for Al plate by changing different welding parameters. Effect of welding speed and welding current on the tensile strength of the weld joint has been investigated for both type of weld joint. 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.

Keywords*: Automated TIG Welding System, Micro hardness Test, Tensile Test*

INTRODUCTION

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weld ability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position.

1.1 Different *type of welding processes*

Based on the heat source used welding processes can be categorized as follows:

Arc Welding: In arc welding process an electric power supply is used to produce an arc between electrode and the work-piece material to joint, so that work-piece metals melt at the interface and welding could be done. Power supply for arc welding process could be AC or DC type. The electrode used for arc welding could be consumable or non-consumable. For non-consumable electrode an external filler material could be used.

Gas Welding: In gas welding process a focused high temperature flame produced by combustion of gas or gas mixture is used to melt the work pieces to be joined. An external filler material is used for proper welding. Most common type gas welding process is Oxy-acetylene gas welding where acetylene and oxygen react and producing some heat.

Resistance Welding: In resistance welding heat is generated due to passing of high amount current (1000–100,000 A) through the resistance caused by the contact between two metal surfaces. Most common types resistance welding is *Spot-welding*, where a pointed electrode is used. Continuous type spot resistance welding can be used for *seam-welding* where a wheel-shaped electrode is used.

High Energy Beam Welding: In this type of welding a focused energy beam with high intensity such as Laser beam or electron beam is used to melt the work pieces and join them together. These types of welding mainly used for precision welding or welding of advanced material or sometimes welding of dissimilar materials, which is not possible by conventional welding process.

Solid-State Welding: Solid-state welding processes do not involve melting of the work piece materials to be joined. Common types of solid-state welding are ultrasonic welding, explosion welding, electromagnetic pulse welding, friction welding, friction-stir-welding etc.

OBJECTIVE OF THE WORK

It is found that welding of Aluminium is a big challenge by conventional arc welding process. Again repeatability of welding depends on its control on welding speed and other processing parameters.

In this work to perform welding of 3 mm Aluminium plate, an automated TIG welding setup was made. Welding of the Aluminium plate was done by changing the welding current and welding speed to get a high strength joint. To get better strength welding of the Aluminium plate also done from both side. Effect of welding speed and applied current on the tensile strength of weld joint, micro hardness of the weld pool and macrostructure of the joint was analysed.

LITERATURE REVIEW

Ahmed Khalid Hussain et. al [7] investigated the effect of welding speed on tensile strength of the welded joint by TIG welding process of AA6351 Aluminium alloy of 4 mm thickness. The strength of the welded joint was tested by a universal tensile testing machine. Welding was done on specimens of single v butt joint with welding speed of 1800 -7200 mm/min. From the experimental results it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed.

Indira Rani et. al [6] investigated the mechanical properties of the weldments of AA6351 during the GTAW /TIG welding with non-pulsed and pulsed current at different frequencies. Welding was performed with current 70-74 A, arc travel speed 700-760 mm/min, and pulse frequency 3 and 7 Hz. From the experimental results it was concluded that the tensile strength and YS of the weldments is closer to base metal. Failure location of weldments occurred at HAZ and from this we said that weldments have better weld joint strength.

Karunakaran et. al [10] performed TIG welding of AISI 304L stainless steel and compare the weld bead profiles for constant current and pulsed current setting. Effect of welding current on tensile strength, hardness profiles, microstructure and residual stress distribution of welding zone of steel samples were reported. For the experimentation welding current of 100-180 A, welding speed 118.44 mm/min, pulse frequency 6 Hz have been considered. Lower magnitude of residual stress was found in pulsed current compared to constant current welding. Tensile and hardness properties of the joints enhanced due to formation of finer grains and breaking of dendrites for the use of pulsed current.

Narang et. al [9] performed TIG welding of structural steel plates of different thickness with welding current in the range of 55 -95 A, and welding speed of 15-45 mm/sec. To predict the weldment macrostructure zones, weld bead reinforcement, penetration and shape profile characteristics along with the shape of the heat affected zone (HAZ), fuzzy logic based simulation of TIG welding process has been done.

Raveendra et. al [11] done experiment to see the effect of pulsed current on the characteristics of weldments by GTAW. To weld 3 mm thick 304 stainless steel welding current 80-83 A and arc travel speed 700-1230 mm/min. More hardness found in the HAZ zone of all the weldments may be due to grain refinement. Higher tensile strength found in the non-pulsed current weldments. It was observed that UTS and YS value of non-pulsed current were more than the parent metal and pulsed current weldments.

Sakthivel et.al [12] studied creep rupture behaviour of 3 mm thick 316L austenitic stainless steel weld joints fabricated by single pass activated TIG and multi-pass conventional TIG welding processes. Welding was done by using current in the range of 160-280 A, and welding speed of 80-120 mm/min. Experimental result shows that weld joints possessed lower creep rupture life than the base metal. It was also found that, single pass activated TIG welding process increases the creep rupture life of the steel weld joint over the multi-pass TIG weld joints.

Sanjeev kumar et. al [5] attempted to explore the possibility for welding of higher thickness plates by TIG welding. Aluminium Plates (3-5mm thickness) were welded by Pulsed Tungsten Inert Gas Welding process with welding current in the range 48-112 A and gas flow rate 7 -15 l/min. Shear strength of weld metal (73MPa) was found less than parent metal (85 MPa). From the analysis of photomicrograph of welded specimen it has been found that, weld deposits are form co-axial dendrite micro-structure towards the fusion line and tensile fracture occur near to fusion line of weld deposit.

Tseng et. al [8] investigated the effect of activated TIG process on weld morphology, angular distortion, delta ferrite content and hardness of 316 L stainless steel by using different flux like TiO_2, MnO_2, MoO3, SiO2 and Al_2O_3. To join 6 mm thick plate author uses welding current 200 Amp, welding speed 150 mm/min and gas flow rate 10 l/min. From the experimental results it was found that the use of SiO_2 flux improve the joint penetration, but Al_2O_3 flux deteriorate the weld depth and bead width compared with conventional TIG process.

EXPERIMENTAL WORK AND METHODOLOGY

Development of an automated TIG welding system

For proper welding and control on welding parameters mainly on welding speed an automated welding setup has been developed in-house. The automated welding setup with its main components is shown in fig. 1.

Experimental set-up for TIG welding

The welding setup consists mainly following parts

a) Speed control unit (movable tractor) – Here, speed control unit is a movable tractor which run with a predefined speed required for welding. TIG welding torch is fixed with it using a clamp in a particular angle so that during welding a stable and continuous arc form. Welding speed can be change using a regulator. Distance between the torch tip and work piece and angle of torch tip can also be control using the adjustable knob.

b) Rail track –Movable tractor is run in a particular speed over this rail track in a straight line.

c) TIG Welding torch- Torch is fixed with the movable tractor unit. A tungsten electrode is fixed in the torch and Ar gas is flow through this.

d) TIG welding machine– This is the main part of TIG welding setup by which controlled amount of current and voltage is supplied during welding. A Rectifier (made by FRONIUS) with current range 10-180 A and voltage up to 230 V, depending on the current setting has been used.

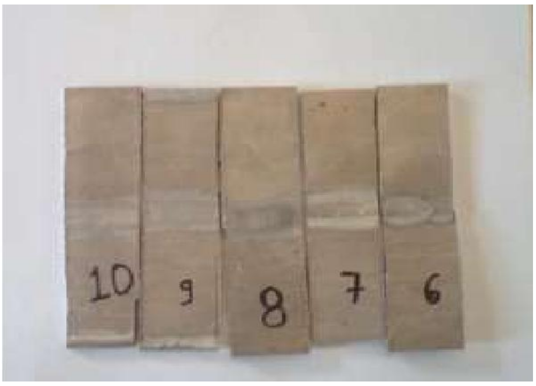
e) Gas cylinder- For TIG welding Ar gas is supplied to the welding torch with a particular flow rate so that an inert atmosphere formed and stable arc created for welding. Gas flow is control by regulator and valve.

f) Work holding table- a surface plate (made of grey cast iron) is used for holding the work piece so that during welding gap between the tungsten electrode and work piece is maintained. Proper clamping has been used to hold the work piece.

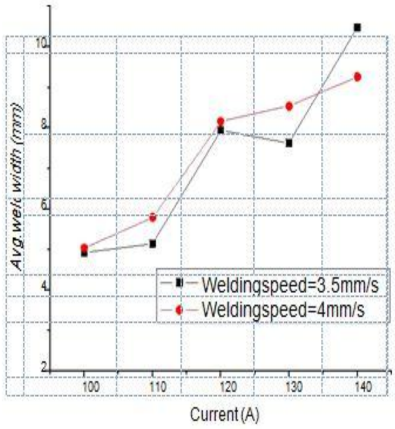
g) The torch was maintained at an angle approximate 90° to the work piece.

RESULT AND DISCUSSION

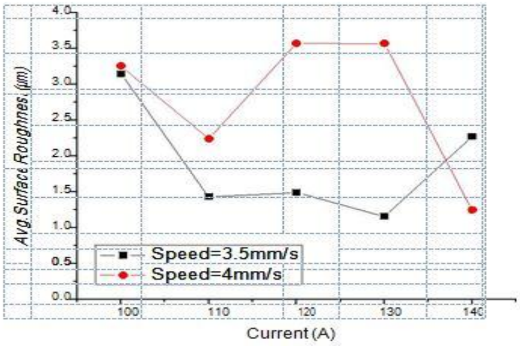
Welding width for all the samples were measured and calculated average welding width as shown in table 4. Average value of welding width then plotted against the applied welding current for different welding speed as shown in Figure below. From the plot it is clearly seen that welding width increases almost linearly with increase of welding current.



welded specimen performed with (a) welding speed 3.5 mm/s and welding current 100, 110, 120, 130 and 140 A for sample no 1, 2,3,4,5 respectively (b) welding speed 4 mm/s and welding current 100, 110, 120, 130 and 140 A for sample no 6,7,8,9,10 respectively



The above graph shows the welding width of the samples with different welding speed and welding current condition



Optical microscopy images of the weld zone at the cross section:

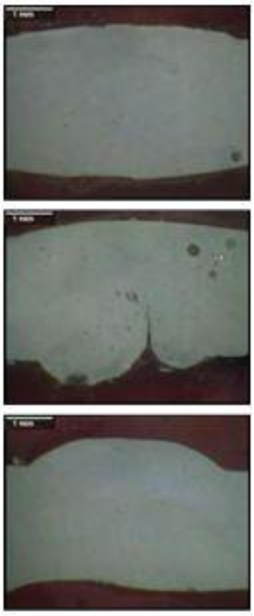
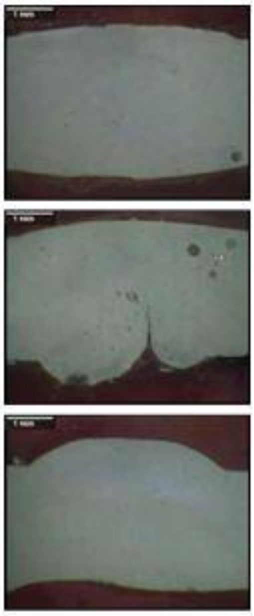
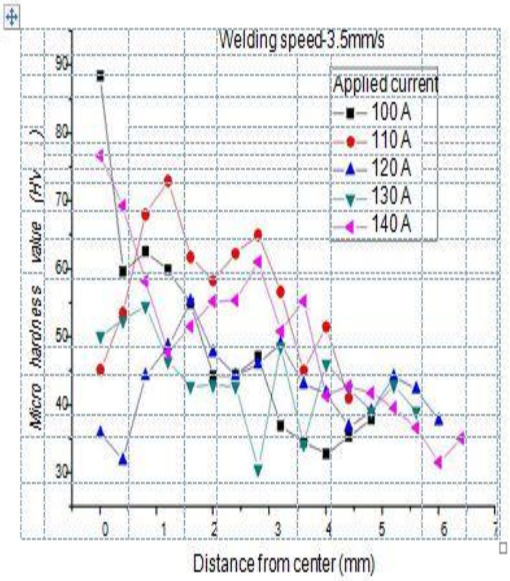


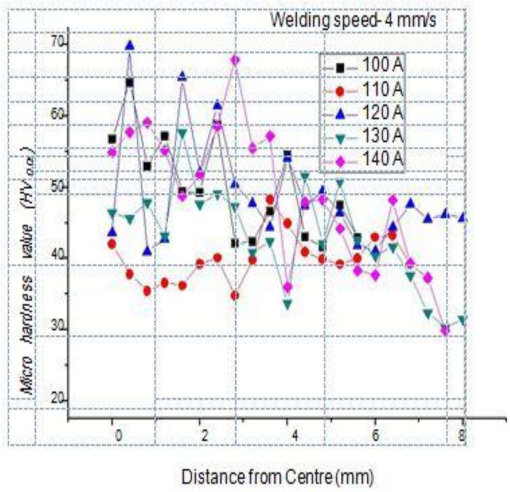
Figure: Optical microscopy photograph at the cross section of the welding done with different current setting and welding speed



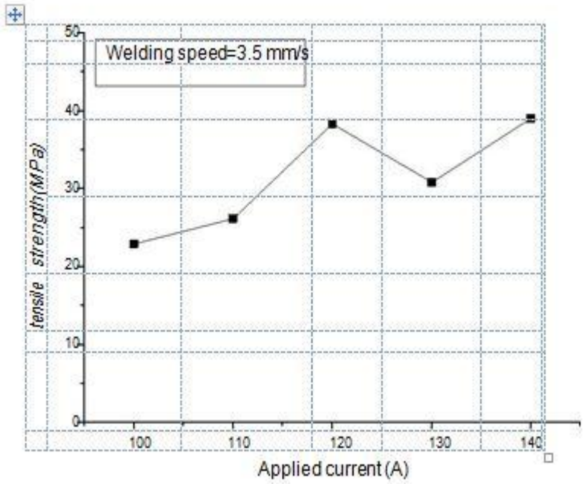
Micro-hardness test: Micro-hardness value of the welded zone was measured for all the welded specimens at the cross section to understand the change in mechanical property of the welded zone. Graphs below shows the micro-hardness value at the welded zone taken from the center of the welding zone towards the base material for different samples performed with different welding speed and welding current. From the graph it is found that for almost all the sample micro hardness value increases in the welding zone than the base material and these values are in the range of 40 to 80 HV in the welded zone. After a certain distance these value reduces to the hardness of the base material for the sample processed with welding speed 3.5 mm/s and different current setting as shown in Fig. 8. However for the welding done with welding speed 4 mm/s and different current setting micro-hardness value reaches to the micro-hardness value of base material after 5 to 6 mm.



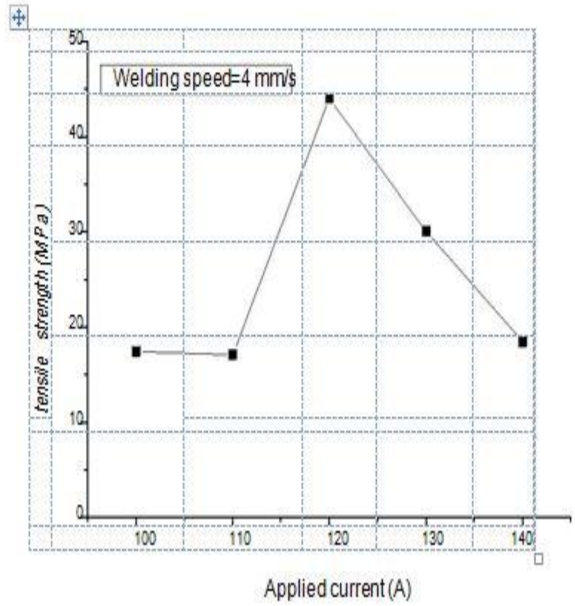
The above graph shows the Micro-hardness value from the Centre of the weld zone towards the base material for welding done with welding speed 3.5 mm/s and different welding current.



The above graph shows the Micro-hardness value from the Centre of the weld zone towards the base material for welding done with welding speed 4 mm/s and different welding current.



The above graph shows the Tensile strength of the welded joint against applied current for welding speed of 3mm/s.



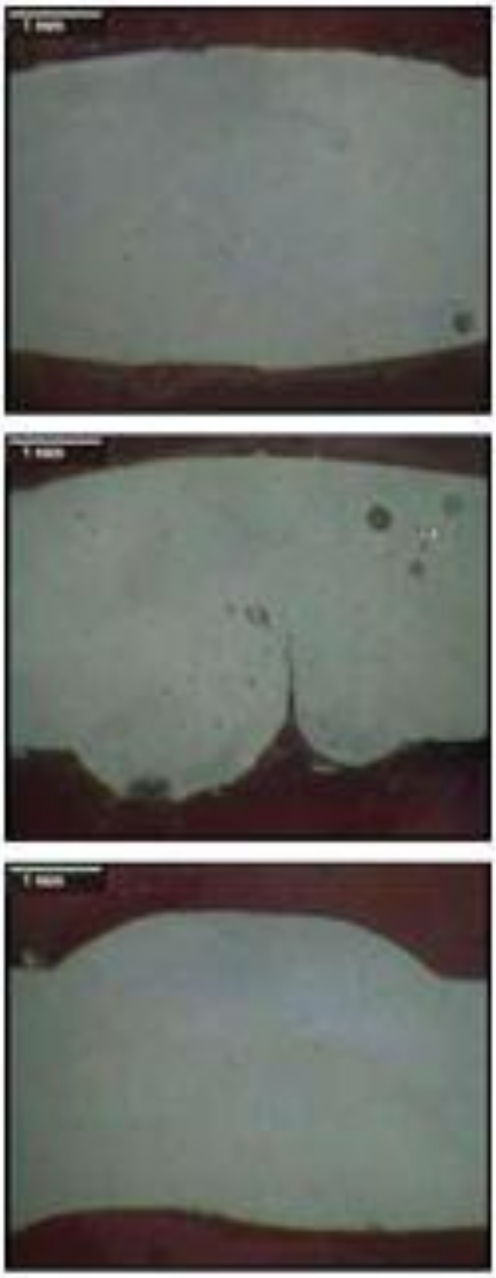
The above graph shows the Tensile strength of the welded joint against applied current for welding speed of 4 mm/s.

Optical image at the cross section for both sided weld joints

Optical image at the cross section of the weld was taken by using an optical microscope after proper polishing. Optical photo graph at the cross section of the welded samples are shown in figure below.

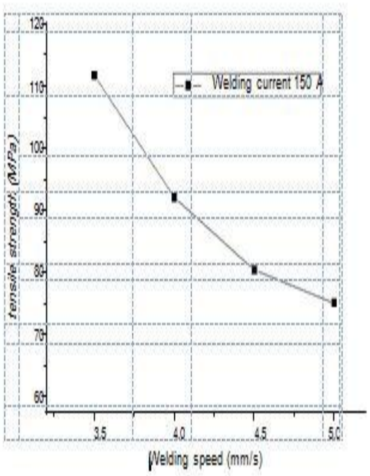
From these images it is observed that when welding performed at both sides joining take place throughout the thickness of the Aluminium plate.

Figure: Optical microscopy image of the welded zone at the cross section of both sided TIG welded Aluminium samples with current setting of 150 A and welding speed(a) 3.5 mm/s (b)
4 mm/s (c) 4.5 mm/s (d) 5 mm/s

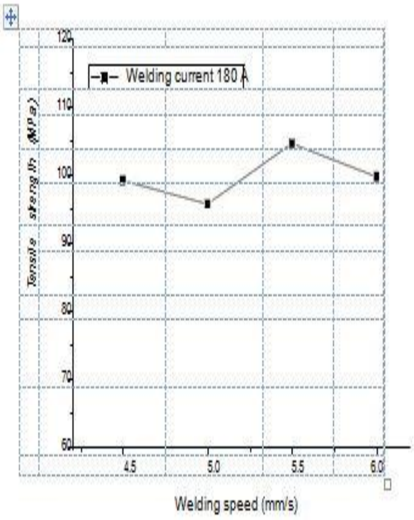


Optical microscopy image of the welded zone at the cross section of both sided TIG welded Aluminium samples with current setting of 180 A and welding speed(a)4.5 mm/s (b)
5 mm/s (c) 5.5 mm/s (d) 6 mm/s

Figure: Tensile test specimen



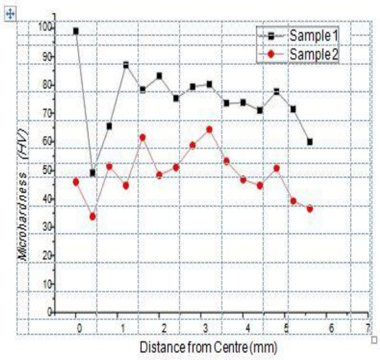
The above figure shows the Tensile strength of the welded joint against different welding speed for applied current of 150 A.



The above figure shows the Tensile strength of the welded joint against different welding speed for applied current of 180 A.

Micro hardness value for both side welding:

The figure below shows the micro hardness profile from the Centre of the weld zone towards the base material for welding done with welding speed (3.5 mm/s and 4mm/s) and welding current(150 A) when welding done from the both side. From the figure it is found that hardness value almost decreasing with the distance from the Centre.



The above figure shows the Micro-hardness value from the Centre of the weld zone towards the base material for welding done with welding speed (3.5 mm/s and 4mm/s) and welding current (150 A).

FINITE ELEMENT ANALYSIS

In this project finite element analysis was accomplished using the ANSYS software. The primary unknowns in this structural analysis are displacements and other magnitudes, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

Static analysis: Static analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A static analysis can be either linear or non-linear. In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed for varying slowly with respect to time. The kinds of loading that can be applied in static analysis is included,

1. Externally applied forces, moments

and pressures

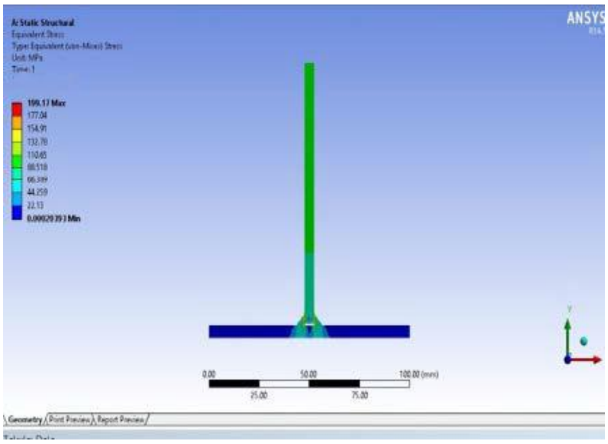
2. Steady state inertial forces such as spinning & gravity
3. Imposed non-zero displacements

If the stress values obtained in this analysis crosses the allowable values it will result in the structure failure in the static condition itself. To avoid such a failure, this analysis is unavoidable.

Equivalent (von-misses) stress

Von misses stress is widely used by designers to check if their design will be withstand a given load condition. Von misses stress is considered to be a safe haven for design engineers, if the maximum value of von misses stress consumed in the material is more than strength of the material. Its work good for most kinds, specifically when the material is ductile in nature.

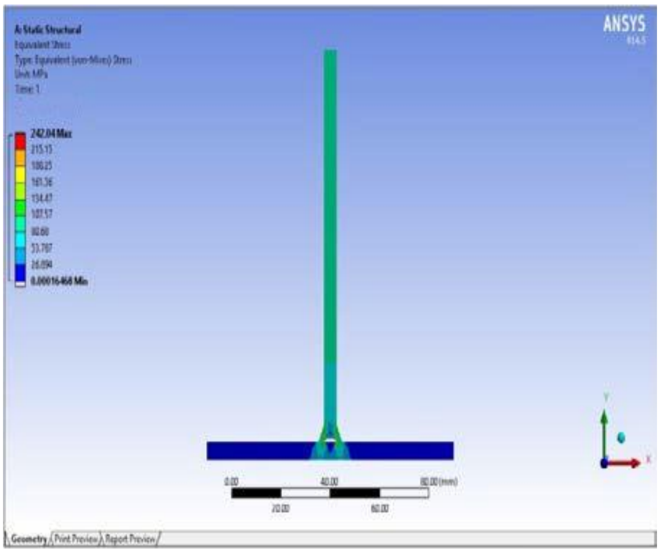
For 25KN load, $\theta = 45^{\circ}$ and 0.3 mm gap



Equivalent von-misses stress for 45º degree and 0.3mm gap

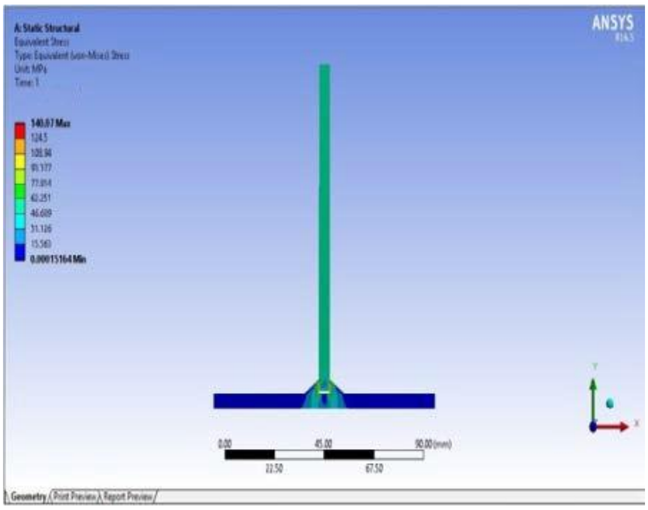
The above Figure represents the equivalent von misses stress value is 199.17 Mpa for 45º and 1mm gap between the parent materials.

For 25KN load, $\theta = 60^{\circ}$ and 0.3mm gap



Equivalent von-misses stress for 60º Degree and 0.3mm gap

For 25KN load, $\theta = 30^{\circ}$ and 0.3mm gap



Equivalent von-misses stress for 30º and 0.3mm gap

ANALYSIS RESULT

FE analysis is also carried out by considering the chamfer on vertical plate. The Maximum von-misses stresses present in T-joint weldment at the throat thickness with gap variation are carried out and the variation of Maximum breaking stress with respect to gap and angle is also shown in

Table. Where 30°, 45° & 60° chamfer is provided on the vertical plate by varying the gap of 0.3, 0.6 and 0.9mm.

Gap between parent plats(mm)	Breaking stress for 25KN(Mpa)		
	30°	45°	60°
0.3	140.07	197.17	242.04
0.6	142.89	197.91	247.02
0.9	149.12	205.09	252.73

Analysis results for Von misses stress with different angle and gap

The above table shows the breaking stress for gap between parent plates. The maximum breaking stress 252.73Mpa for 60° angle with 0.9mm gap welded section. From the analytical and numerical results the equivalent von misses stress 80% approximately equal. The FE analysis of T-joint weld for the same geometry revealed the maximum Von-misses stress of 252.73Mpa it's approximately equal to numerical maximum breaking stress of 224.6Mpa.

1) The finite element of equivalent von misses stress are carried out and the FE analysis of T-welded joint for the same geometry revealed the maximum Von-misses stress of 252.73Mpa.

2) From the finite element analysis maximum breaking stress is 252.73Mpa (0.9mm gap and 60°) and minimum breaking stress is 140Mpa (0.3mm gap and 30°).

3) The maximum breaking Von-misses stress is 242Mpa.

CONCLUSION

From the experiment of TIG welding of Aluminium plate following conclusion can be made

- With the automated welding system uniform welding of Aluminium plate can be possible.
- Welding strength or tensile strength of the weld joint depends on the welding parameters like welding speed and welding current.
- With the increase in current, tensile strength of the weld joint increases.
- Hardness value of the weld zone change with the distance from weld centre due to change of microstructure.
- At lower welding speeds strength is more due to more intensity of current.
- For both side welding tensile strength is found almost equivalent to the strength of base material.
- For both sided welding performed with high current (180 A), welding speed have no specific effect on tensile strength of the weld joint.

FUTURE SCOPE

In present work welding is performed without any filler material. A filler rod/wire feeding system can be included in the system so that by using filler rod/wire thicker plate can be welded. Welding setup can also be use for welding of some other materials.

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