Experimental and Finite Element Analysis of Single-V Groove Butt Weld on Weld Pool Geometry of Aluminium Alloy Plate under Different Joint Parameters

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Abstract— Gas Tungsten Arc Welding Process (GTAW) is widely used in fabrication of Aluminium and Aluminium Alloy material when precision is considered as a prime importance. Deformations in the object undergoing welding are one of the foremost problems encountered in the welding industry. Thus it is often required to study the factors which affect the deformations produced during welding to avoid errors in the geometry. Present investigation highlights Experimental and Finite Element Analysis of a Single-V Groove Butt Weld on Weld Pool Geometry of Aluminium Alloy Plate under Different Joint Parameters.Finite Element Method (FEM) has been employed to do the transient thermal and structural analysis of the assembly. The Finite Element Analysis has been done on ANSYS 14.5 Workbench. Number of factors is liable to produce effects in the job during the welding operation. Aim of this paper is the effect of welding parameters like as welding current, shielding gas flow rate and welding speed with mechanical Properties like tensile strength and hardness. After that finite element analysis for temperature distribution and distribution of the stresses in the welded Aluminium alloy plate. The results show that the larger the Welding current and smaller welding speed will lead to the maximum residual tensile stress. Therefore a residual stress will arise from the restraint position. The ultimate residual stress of weldment is determined by material yield strength at different temperature. The higher yield strength at different temperature has higher material residual stress. Because of its higher thermal conductivity, aluminium alloy test specimens have small temperature differential.

Key words: Aluminium Alloy Plate, Single-V Groove, Welding Parameter, Welding Joint, Mechanical Properties, FEA, ANSYS

I. INTRODUCTION

Aluminium alloys has been found wide application in industry as it has many virtues, such as light weight, easy machining, nontoxic, excellent ductility, good corrosion resistance and high strength ratio. However, physical and mechanical properties of aluminium alloy has been blamed for some defects in its welding, such as hot cracking, deformation, porosity and decrease in the strength of heat affected zone. Among them, deformation, besides the influence of material properties such as high coefficient of thermal expansion and thermal conductivity is also closely related to welding processes. As for the appearance of hot cracking, apart from the influence of material alloy content, it is also connected to contraction stress resulting from heating and cooling in welding [1,2]. However, due to rapid local heating, the distribution of internal temperature in the weldment is uneven. With their larger thermal conductivity and lower high - temperature strength often lead to greater stress and deformation of the welded components, which can result in a series of issues such as low intensity, instability of the joint in size and small ductile deformation, thus their further development and applications. With the development of technology, understanding of stress and deformation has not been dependent solely on the physical measurements. It can be also predicted using finite element methods quickly and accurately. At present, the vast majorities of research on the welding numerical simulations are reported to be aiming at MIG welding, but less at the TIG, Particularly at gas tungsten arc welding. In this paper, the GTAW process of aluminium alloy plates was numerically analysis by using finite element method, and stress after welding was predicted. Finally, the mechanical properties of welded materials are measured in terms of tensile strength and Brinell hardness using experimentally. After that temperature distribution and distribution of the stresses in the welded aluminium alloy plate during the welding operation are investigate by finite element method.

Tungsten Inert Gas (TIG) welding is a welding process used for high quality welding of a variety of materials with the coalescence of heat generated by an electric arc established between a non- consumable tungsten electrode and the metal. The process of melting the work piece and filler rod to form a weld results in the formation of fumes and gases. Argon used as shielding gases for better welding because they do not chemically react. The inert gas

– Shield the welding area from air, preventing oxidation
– Transfer the heat from electrode to metal
– Helps to start and maintain a stable arc due to low ionization potential

Fig. 1: (a) TIG welding machine

Fig.1. (b) Argon gas cylinder

The finite element method cuts the structure into small number of elements and interconnecting the elements through nodes. By assembling all the element matrices, it will give the total displacement of the structure. In transient thermal analysis, temperature field (T) of welded plate is a function of time (t). Thermal conduction will take place on the metal. Therefore three dimensional transient heat transfer equation is

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left[k_x \frac{\partial T}{\partial x}\right] + \frac{\partial}{\partial x}\left[k_y \frac{\partial T}{\partial y}\right] + \frac{\partial}{\partial x}\left[k_z \frac{\partial T}{\partial z}\right] + Q$$

Here Q_{int} is the internal heat source, ρ, C_p, k are density, specific heat and thermal conductivity of material respectively. During the welding, the heat will be lost due to radiation and convection. The convection and radiation heat losses are determined by the following equations

$$q_{rad} = \varepsilon\sigma(T^4 - T_0^{\ 4})$$

$$q_c = h(T - T_0)$$

Here, T_0 is atmospheric temperature is considered as initial temperature, T is surface temperature of plate, h is Convective heat transfer coefficient, σ is the Stefan-Boltzmann constant, ε emissivity. Convection boundary condition applied all surfaces of metal plate except bottom surface of the plate. If system is in equilibrium with surroundings then it should have surrounding temperature. In welding, the applied heat through the welding torch is lost by conduction, convection and radiation. Conductivity is the ability to conduct the heat. In welding, the temperature is higher in weld region, so the metal conducts the heat from higher region to lower region to bring the metal equilibrium. Conduction is mainly depends on thermal conductivity of a metal. Convection is heat transferred by moving fluid. The plate is static position and the moving fluid is atmospheric air. The atmospheric air is taking the heat from metal to bring the metal equilibrium to surrounding temperature.

Total heat loss = convection + radiation

$$q_{tot} = q_{rad} + q_c$$

$$q_{tot} = \varepsilon\sigma(T^4 - T_0^{\ 4}) + h(T - T_0)$$

Butt-welding is the process of joining two pieces of material together along a single edge in a single plane. This process can be used on many types of materials, though metal and thermoplastics are the most common. When two sheets of aluminium are laid side-by-side and joined together along a single joint, this is an example of butt-welding.

Past researches on aluminium alloy welding mainly gave priority to the changes in properties of hot cracking and heat affected zones and investigated residual stress, which was an important factor leading to hot cracking. By taking heat treatable aluminium alloy Al-5083 as objects of study, after a single V- groove welding on aluminium alloys at Vee preparation angles, this study investigated the correlation between weldment residual stress and welding processes and material mechanical properties. This research adopted as to measure the mechanical Properties like tensile strength and hardness. After that finite element analysis for temperature distribution and distribution of the stresses in the welded Aluminium alloy plate. We also hoped that results of this research could be used by our counterparts for reference.

II. Design of Experiment Approach

This research mainly investigated the residual stress and temperature distribution of weldment at single-V groove angles in restrained conditions. Therefore, guided by the principle of maintaining a complete weld bead, we kept certain heat input in welding (welding current, welding speed and gas flow rate were variable) but adjusted filler metal feed according to the angles of a single-V groove.

A. Base Metals

The base metals used in this experiment were aluminium alloy Al5083.The dimensions of base metal were 200mm X50mm X5mm (Length X Width X Thickness). The nominal chemical composition of this alloy is presented in table.1.

Fig. 2: Base Metal

Materials	Mg	Mn	Si	Fe	Zn	Cr	Ti	Cu
Al5083	4.45	0.7	0.4	0.4	0.25	0.15	0.14	0.1

Table 1: Chemical Composition of 5083 Al – Alloy (wt. %)

Physical and Mechanical properties of 5083 Al-Alloy are shown in Table.2 below:

Density	Tensile Strength	Brinell Hardness	Yield Strength	Modulus of Elasticity
2.65	315	75	228	72

Table 2: Physical and Mechanical Properties of 5083 Al-Alloy

The filler wires used to transfer the extra material to fill the gap between the joints of same composition of base metal. There are different types of filler wires (5183, 5356, 5554, 5556 and 5654) available in the market on the basis of base metal compositions of 5083 Al-Alloy. In this study, the filler metal of 5183 graded is used for welding the specimens because of its good.

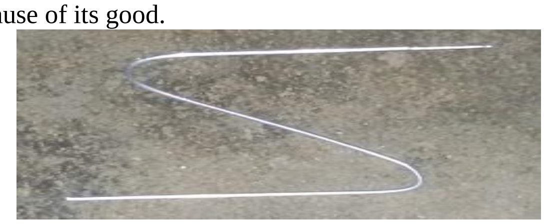

Fig. 3: Filler Wire

The chemical compositions of 5183 filler wire are shown in table 3:

Materials	Mg	Mn	Si	Fe	Zn	Cr	Ti	Cu
Al5183	4.55	058	0.1	0.27	0.06	0.11	0.11	0.01

Table 3: Chemical Composition of 5183 Filler Wire (Wt. %)

The physical and mechanical properties of 5183 filler wire are shown in table 4:

Density(g/cc)	Melting Range	Corrosion Resistance	Hardness
2.65	1060-1175	Excellent	105

Table 4: Physical and Mechanical Properties of 5183 Filler Wire

III. WELDED SPECIMEN

Two Al5083 aluminium alloy plates with a thickness of 5mm, and 200mm X 50mm (Length X Width) were prepared for TIG welding. Make V-groove angle in each specimens at 60^o of butt weld shown in fig.4.

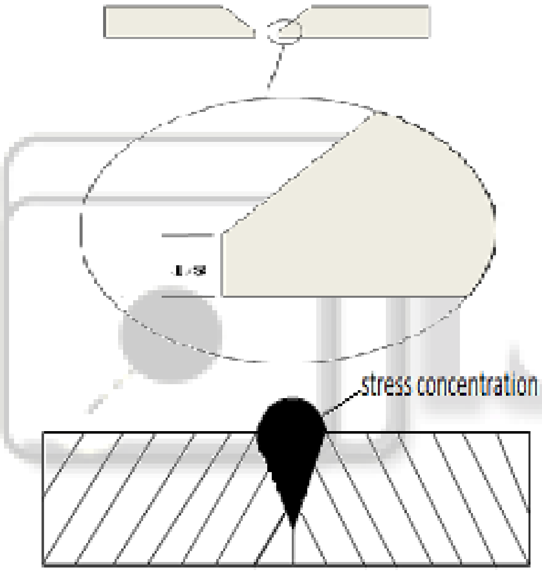

Fig. 4: Single V-Butt weld

IV. FINITE ELEMENT MODEL

In this work, an aluminium alloy plate has been modelled as a work piece. The basic transient thermal analysis and static structural analysis performed using ANSYS 14.5 to determine the temperature distribution, heat flux in the plate and distribution of the stresses (von-mises stress), which has a dimension of 400mmX50mmX5mm.

A. Meshed Model

The work pieces have been modelled using CATIAV5R20.The coordinate system along x, y and z direction and temperature, at each node. The element is applicable to 3-D transient thermal analysis and static structural analysis performed using ANSYS 14.5.

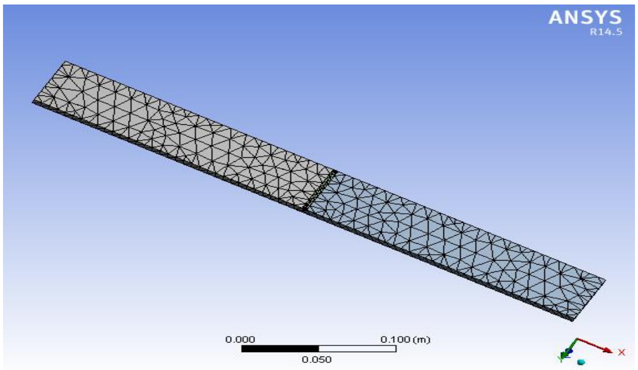

Fig. 5: Meshed Model

B. Boundary Conditions

The initial temperature of Al5083 Aluminium plate is 30^{0}C.The initial condition of the plate can be created by defining the predefined field in the load module. Convection is heat transferred by moving fluid. The plate is static position and the moving fluid is atmospheric air. The atmospheric air is taking the heat from metal to bring the metal equilibrium to surrounding temperature. In this analysis combined convection and radiation film co-efficient was used as convection film co-efficient. Heat convection coefficients, h = 15 W/m^2-k as used surface film co-efficient on the outer surface of the work piece and the bottom surface of lower work piece with the ambient temperature of 30^{0}C.

C. Load Conditions

Heat input is one of the most important process parameters in controlling weld response. It can be referred to as an electrical energy supplied by the welding arc to the weldment.

In practice, however, heat input can approximately be characterized as the product of the arc power supplied to the electrode and voltage. Where, I is welding current; *V* is welding arc voltage; v is the arc welding speed, and Q is the heat input. In this work, the effect of heat input on welding responses was evaluated using three values (heat input in Watt), characterized as in the Table. V illustrates the values used for the analyses. This evaluation was carried out by considering the rest of parameter; Arc voltage was kept constant at low value and restraint was kept constant at high value.

Sr. No.	Distance(mm)	Temp. by Expt.(^{0}C)	Temp. by FEM(^{0}C)	Percentage Difference
1	10	213.35	204.49	8.86
2	20	192.55	185.11	7.44
3	30	171.89	165.72	6.17

Table 5: Comparison of Temperature Distribution by experiment and FEM

Welding current(I)	Arc Voltage(V)	Welding speed(v)	Heat input(Q)	Heat flux(q)
110	25	5.04	595	3.91e6
115	25	4.85	625	4.47e6
125	25	4.65	855	5.02e6

Table 6: Heat flux calculation for FEA

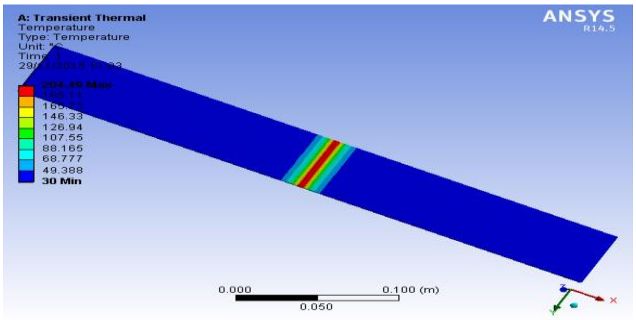

Fig. 6: Temperature distribution in welding plate by FEM

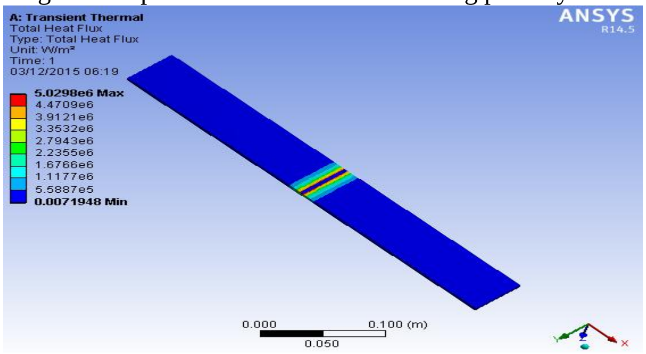

Fig. 7: Heat Flux in welding plate by FEM

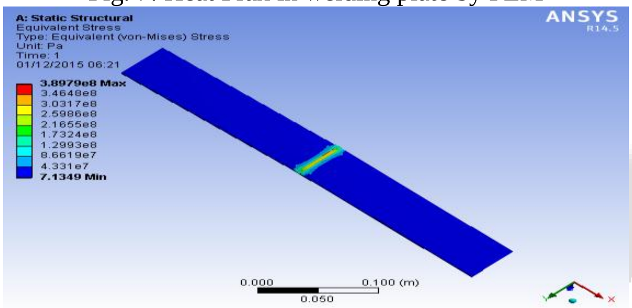

Fig. 8: Stress distribution in welding plate by FEM

V. RESULT & DISCUSSION

A. *Tensile Testing Results*

The effect of welding input parameters on tensile strength of the weld joint is discussed as below:

1) *Effect of Welding Current on Tensile Strength of Weld Joint*

This phase reveals the effect of welding current of different levels such as 110 amps, 115 amps and 125 amps on mechanical properties of weld joint such as tensile strength. Fig. shows the effect of welding current on tensile strength of weld joint. As welding current increases at constant gas flow rate, the tensile strength increases till optimum value of 125 amps current that shows the maximum tensile strength of 130 MPa of weld joint.

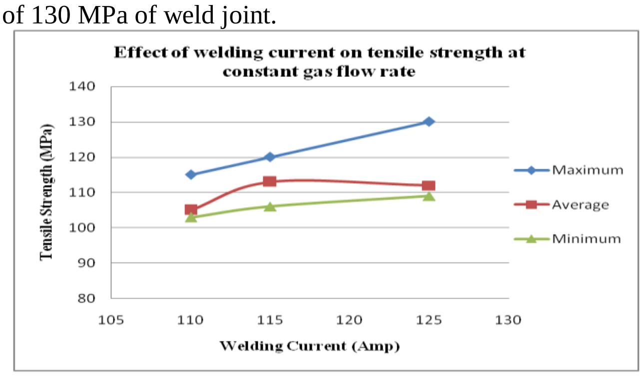

Fig. 9: Welding current vs. Tensile strength

2) *Effect of Gas Flow Rate on Tensile Strength of Weld Joint*

In this, the effect of shielding gas flow rate of 8 Lt/min, 9 Lt/min and 10 Lt/min of three different levels on mechanical properties as a tensile strength of weld joint is describes. Fig. shows the effect of gas flow rate on tensile strength of weld joint at constant current. The tensile strength increases by the variation of shielding gas in increasing order till an optimum value of 9 Lt/min that shows the maximum tensile strength of 130 MPa of weld joint.

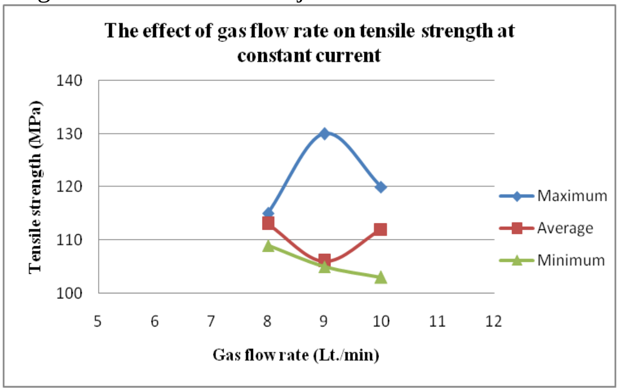

Fig. 10: Gas flow rate vs. Tensile strength

3) *Effect of Welding Speed on Tensile Strength of Weld Joint*

This phase reveals the effect of the different values of welding speed on mechanical properties of weld joint such as tensile strength. The effect of welding speed on tensile strength of weld joint is shown below in Fig. The tensile strength increases by increasing the welding speed at constant current till optimum value of 4.85 mm/sec. at current of 125 amps that shows the maximum tensile strength of 130 MPa of weld joint. After that tensile strength starts to decrease by further increment of welding speed

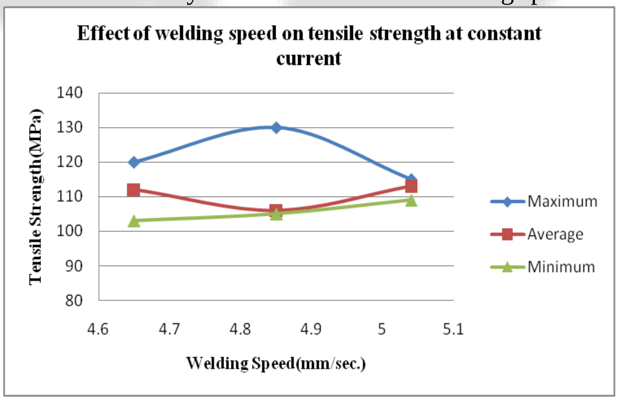

Fig. 11: Welding speed vs. Tensile strength

4) *Hardness Testing*

We are found out by considering the UTS as the reference for the hardness results. The hardness testing is conducted and the hardness of the various portion such as base metal, weld metal and heat affected zone (HAZ) are found out for Specimen A, Specimen E, Specimen I. From the results obtained it is found that Specimen A is better with hardness 52 HB for base metal, 57 HB for heat affected zone, 30 HB for weld meal.

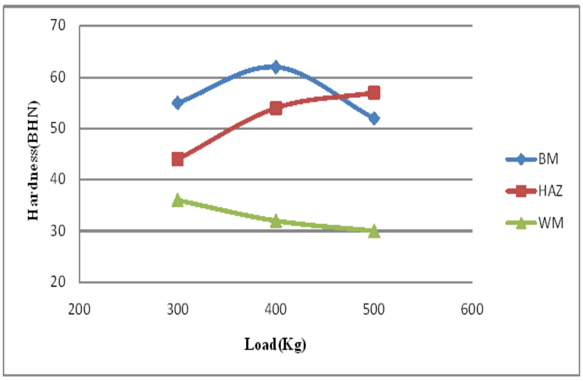

Fig. 12: Hardness vs. Load

5) *Finite Element Analysis*

The results of the thermal analysis and structural analysis conducted on specimens are shown below as in graph. By using FEM methodology at different welding parameters the residual stresses generated in the butt weld plate is calculated. When the current of the weld plate is increase the residual stresses are increases. When the welding speed is increase the residual stresses are decreases.

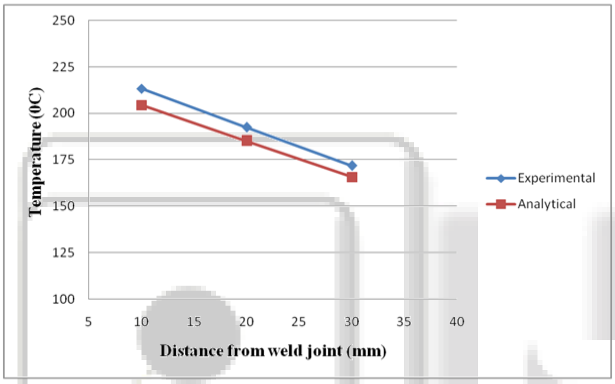

Fig. 13: Comparison of Temperature Distribution by experiment and FEM

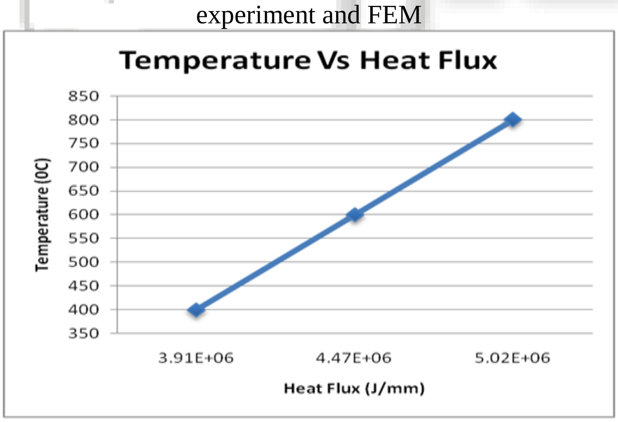

Fig. 14: Temperature vs. Heat flux

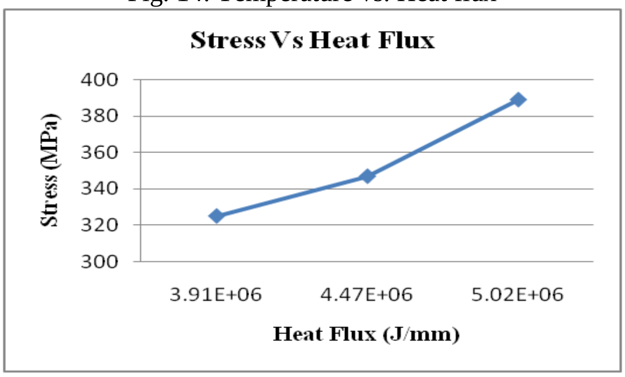

Fig. 15: Stress vs. Heat flux

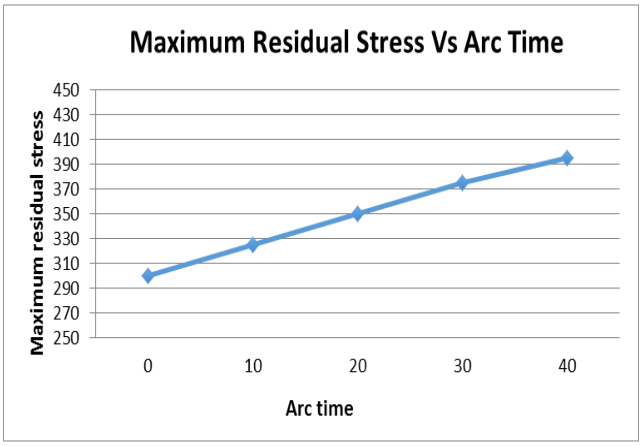

Fig. 16: Maximum residual stress vs. Arc time

The welding parameters combination of weld specimen for minimum residual stress (325MPa) is current 110amp, voltage 25volt, welding speed 5.04 mm/sec.

The welding parameters combination of weld specimen for maximum residual stress (389MPa) is current 125amp, voltage 25volt, welding speed 4.65 mm/sec. Obtained.

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VI. CONCLUSION

All the experimental trials are analysed under precautionary measures in order to keep the error factors low and optimize the reliability of results to produce the efficient weld joint with 5083 Al-alloy specimens. The following conclusions are drawn from the analysis of collected data of input and output parameters:-

– Maximum tensile strength of 130 MPa is obtained at welding current of 125 amps, gas flow rate of 9 Lt/min and welding speed of 4.85 mm/sec.
– The tensile strength of weld joint in 5083 Al-alloy plate increases by increasing welding speed up to an optimum value of 4.85 mm/sec. for current of 125 amps and after that tensile strength decreases by further increasing welding speed.
– The optimum range of input parameters are evaluated as 125 amps of welding current, 9 Lt/min of gas flow rate and 4.85 mm/sec. of welding speed by which efficient weld joint is produced with good tensile strength of weld joint.

In this work, a three dimensional finite element model has been developed for Butt Welding Process, in which a heat generation, temperature distribution and residual stress were taken into consideration. This is cost saving process because experimental processes are costly. From the simulation results we also conclude that heat input, welding speed has significant impacts on the weld response which are as follows based on the present work, the following conclusions can be made.

- A finite element computational investigation of a single V-groove butt weld of an Al-Fe-Mg alloy Al5083 is carried out.
- Methodology has been developed for a single V-groove butt weld for the plate made up of Aluminium Al5083 with dimensions 200mm x 50mm x 5 mm.
- As the speed of welding increases the stresses induced in the plate decreases because as welding speed increase for welding time decreases and thus it is noted that the faster the welding speed is made, the less heat is absorbed by the base metal and thus stresses induced decreases.
- Welding parameters such as welding current and welding speed has been varied from 110amp to 125amp; 4.65mm/sec. to 5.04mm/sec. to estimate the residual stress using finite element analysis.

VII. SCOPE OF FUTURE WORK

The future scope of the study is discussed in steps such as shown below

- In order to study the mechanical properties like tensile strength and hardness, stress and temperature distributions during welding, a number of other factors can also be studied upon.
- In the present study, welding current, gas flow rate and welding speed are taken into account as input parameters. The other welding parameters such as arc voltage, groove angle, heat input can be investigated on same as well as different alloys of aluminium.
- Further, weld heat treatment can be applied on same or different materials to achieve better results.

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