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Thermal Analysis on Butt Welded Aluminium Alloy AA7075 Plate Using FEM

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Abstract : Thermo-mechanical finite element analysis has been performed to assess the residual stress in the butt weld joints of aluminium Alloy AA7075 plates by utilizing the commercial software package ABAQUS. This paper presents an efficient FE technique using equivalent load to precisely predict welding deformations and residual stresses in butt joints. The radial heat flux distribution is considered on the top surface of the weldment. Convective and radiative heat losses are taken into account through boundary conditions for the outward heat flux. Linear FE transient thermal analysis is performed using surface heat source model with Gaussian distribution to compute highest temperature in AA7075 plates. The objective of this project is to simulate the welding process by using the finite element method. After the model is built and verified, the main objective of this project is to study the effects of varying the welding process parameters on the thermo-mechanical responses. In addition to that, the aim of this research is also to find a relationship between welding parameters and the responses of single pass butt welding are evaluated through the finite element analysis. The study of this paper covers the effects of varying heat input, welding speed on the thermo-mechanical responses of the weldment after cooling down to room temperature.

Keywords: Residual stresses, Heat flux, FEM, Al Alloy, Ansys

I. INTRODUCTION

Modern welding technology started just before the end of the 19th century with the development of methods for generating high temperature in localized zones. Welding generally requires a heat source to produce a high temperature zone to melt the material, though it is possible to weld two metal pieces without much increase in temperature. There are different methods and standards adopted and there is still a continuous search for new and improved methods of welding. Welding can be described as the joining of two components by a coalescence of the surface in contact with each other. This coalescence can be achieved by melting the two parts together – fusion welding – or by bringing the two parts together under pressure, perhaps with the application of heat, to form a metallic bond across the interface. Welding that involves the melting and fusion of the parent metals only is known as autogenous welding, but many processes involve the addition of a filler metal which is introduced in the form of a wire or rod and melted into the joint. Together with the melted parent metal this forms the weld metal.

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 steel are laid side-by-side and joined together along a single joint, this is an example of butt-welding.

II. MATHEMATICAL MODEL

A. Heat Flow in Welding

The heat source efficiency η is defined as

$$\eta = \frac{Qt_{\text{weld}}}{Q_{\text{nominal}}t_{\text{weld}}} = \frac{Q}{Q_{\text{nominal}}}$$

Where, Q is the rate of heat transfer from the heat source to the work piece, Q_{nominal} the nominal power of the heat source, and t_{weld} the welding time. A portion of the power provided by the heat source is transferred to the work piece and the remaining portion is lost to the surroundings. Consequently, $\eta < 1$.

If the heat source efficiency η is known, the heat transfer rate to the work piece, Q, can be easily determined from the below equation

In arc welding with a constant voltage E and current I, the arc efficiency can be expressed as

$$\eta = \frac{Qt_{\text{weld}}}{EIt_{\text{weld}}} = \frac{Q}{EI}$$

It should be noted that in the welding community the term heat input often refers to Q_{nominal}, or EI in the case of arc welding, and the term heat input per unit length of weld often refers to the ratio Q_{nominal}/V, or EI/V, where V is the welding speed.

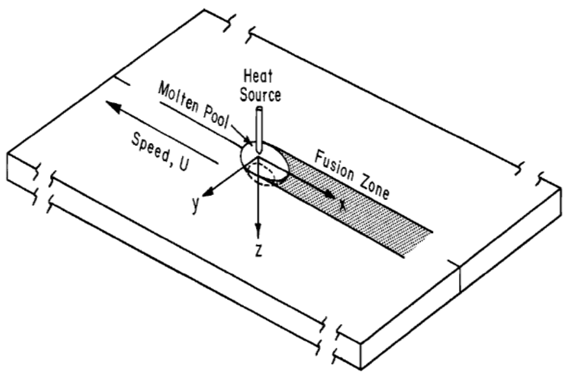

Fig.1 Coordinate system (*x*, *y*, *z*) moving with heat source

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, 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

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

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

In this analysis combined convection and radiation film co efficient was used as convection film co-efficient.

B.Heat Source Modeling

A heat source is in welding continuous travelling along the specified path on top surface of the work piece where fusion process should be take place. Distortion, residual stresses, and reduced strength of structures result directly from the thermal cycle caused by localized intense heat input. The first critical step in creating an efficient welding simulation strategy is to accurately compute the transient temperature fields. Accurate modeling of moving heat source is mandatory in order to capture exact temperature distributions and subsequently the weld induced imperfections. The heat source is modeled by the following equation.

$$q(r) = \left(\frac{3Q}{\pi r_b^{\ 2}}\right)\exp\left(\frac{-3r^2}{r_b^{\ 2}}\right)$$

Here, r_b is Surface heat flux radius. Q is the Net heat input (W), r is the radial distance from the centre of the heat source. q (r) is Heat flux (W/m^2).

III. FINITE ELEMENT MODEL

In this work, a thin aluminum alloy 2014 plate has been modeled as a work piece. The basic thermal analysis performed using ABAQUS to determine the temperature distribution and heat flux in the plate, which has a dimension of 300x300x6mm.

A. Meshed Model

The work pieces have been modeled using (C3D8T) an 8-node thermally coupled brick, tri-linear displacement and temperature. Total 11704 nodes and 5700 elements have been created in hard faced circular grid plate The element has eight nodes with a four degree of freedom such as displacement along x, y and z direction and temperature, at each node. It has a 3-D thermal conduction capability. The element is applicable to 3-D, steady-state or transient thermal analysis.\

B. Boundary Conditions

The initial temperature of AA7075 Aluminium plate is 30^{o}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 coefficient on the outer surface of the work piece and the bottom surface of lower work piece are, with the ambient temperature of 30^{0}C.

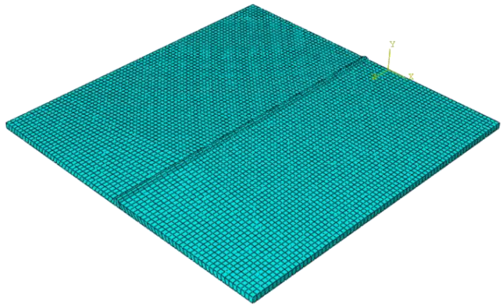

Fig.2 Meshed Model

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.

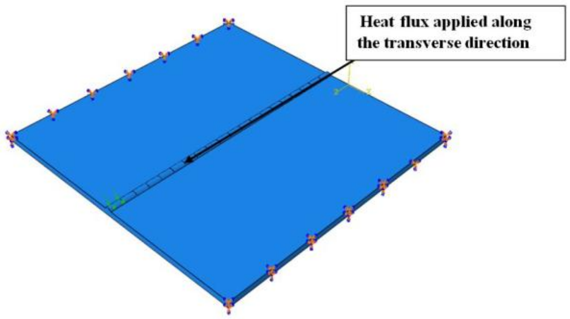

Fig.3 Heat flux applied at the model

In practice, however, heat input can approximately be characterized as the product of the arc power supplied to the electrode, efficiency 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 six values (heat input in Watt), characterized as in the. Table.1 illustrates the values used for the analyses. This evaluation was carried out by considering the rest of parameters; welding speed was kept constant at low value and restraint was kept constant at high value.

(I)	(V)	(η)	Heat input(Q)	Heat flux(q)
50	22	0.85	935	7.92e6
52	22	0.85	972	8.23e6
54	22	0.85	1009	8.55e6
56	22	0.85	1047	8.87e6
58	**22**	**0.85**	**1084**	**9.19e6**
60	22	0.85	1122	9.52e6

Table.1 Heat flux calculation for FEA

IV.RESULTS AND DISCUSSION

FE simulation results discussed in this chapter consists of thermal response of butt welding process. The geometry and the mesh used in the FE models were kept the same throughout this work. When the welding current is 58amp, voltage of 22volt and the efficiency of 85% with the heat input of 1084W and heat flux of 9.19e6 W/m^2.The temperature distribution and equivalent vonMises stress acting on the plate is found as 655^{o}C and 509MPa is shown in fig 4,5, 6 and 7.

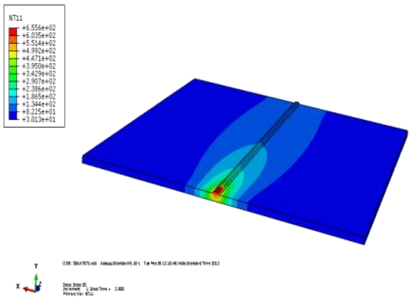

Fig.4 Temperature distribution along the direction of tool

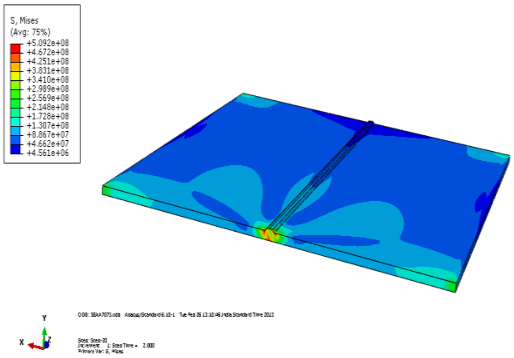

Fig.5 vonMises stress distribution

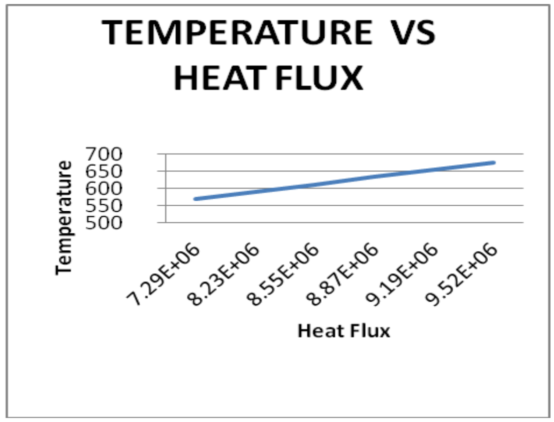

Fig.6 Temperature VS Heatflux

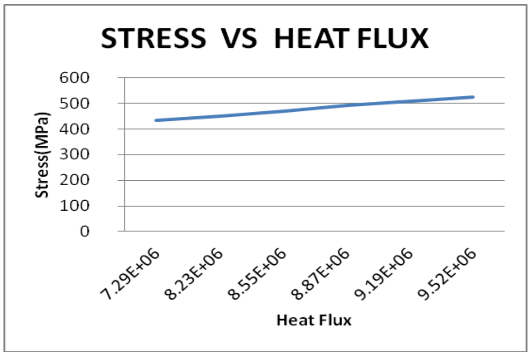

Fig.7 Stress VS Heatflux

From the above analysis it has been found that as the heat flux increases the stress acting on the plate increases. It has been found that when the given heat flux goes beyond the value of 9.19e6 the stress acting on the material goes beyond the yield stress.

A. Effects of Welding Speed

Total time taken for the entire welding process for different welding speed is given as follows:

(i) Time for completing welding at 3 mm/sec = length of plate/welding speed= 300/3=100sec

(ii)Time for completing welding at 3.5mm/sec = length of plate/welding speed= 300/3.5= 85sec

(ii) Time for completing welding at 4 mm/sec = length of plate/welding speed= 300/4=75sec

Welding speed represents the distance of the welding torch traveled along the weld line per unit of time. The heat input is inversely proportional to the welding speed. Therefore, when the welding speed is slower the heat input is larger, for a constant heat input rate. In this project work, low, medium, and high welding speeds are considered while considering the rest of parameters constant. Table 2 illustrates different values of thermal analysis result for corresponding welding speed used in the finite element analysis and Fig.8 shows the difference in temperature distribution for different welding speed of 3mm/sec, 3.5mm/sec and 4 mm/sec. Table 3 illustrates the residual stress and fig 9 shows the variation of residual stress with respect to welding speed.

Table.2 Temperature obtained during different welding speed condition

Welding Speed (mm/sec)	Temperature(°C)
3	915
3.5	841
4	741

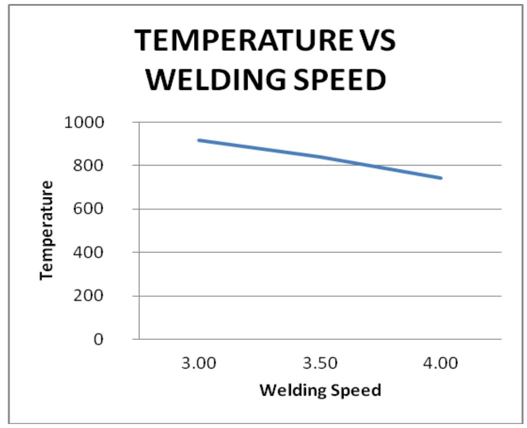

Fig.8 Temperature with respect to welding speed plot

Welding Speed (mm/sec)	Residual Stress(MPa)
3	524
3.5	485
4	471

Table .3 Residual stress obtained during different welding speed condition

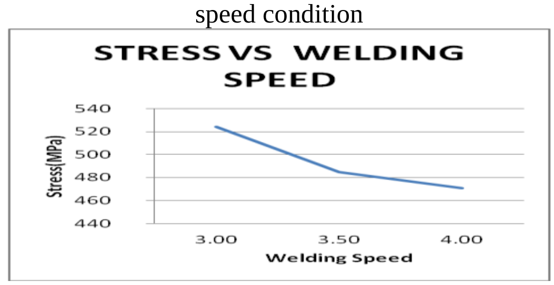

Fig.9 Residual stress with respect to welding speed plot

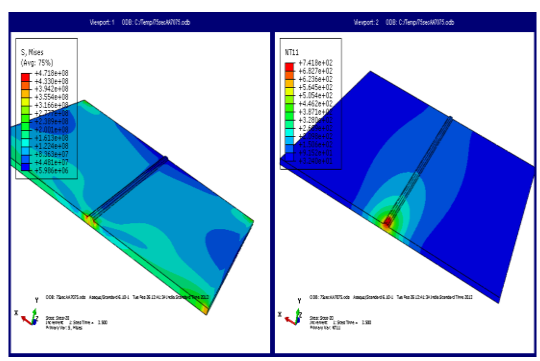

Fig .10 Temperature distributions and residual stress for the welding speed of 4mm/sec

V. CONCLUSION

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 and conclusions can be made,

- A finite element computational investigation of butt welding of an Al-Cu-Mg alloy AA7075 is carried out.
- Methodology has been developed for butt welding process for the plate made up of made up of Aluminum AA7075 with dimensions 300mm x300mm x6 mm.
- As the speed of welding increases the stresses induced in the plate decreases because as welding speed increase time for welding 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.
- One of the welding parameters such as welding current has been varied from 50amp to 60amp to estimate the residual stress using birth and death element technique of finite element analysis.
- One of the welding parameters such as welding speed has been varied with 3mm/sec, 3.5mm/sec and 4mm/sec, estimated residual stress using birth and death element technique of finite element analysis.

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