International Research Journal in Global Engineering and Sciences. (IRJGES)
ISSN : 2456-172X | Volume7, Issue1 (March 2022 - May 2022) | Pages 90-101

An Investigation of Mechanical Properties in Butt welding process of AA2014 aluminium alloy plates: A finite element approach

Vairamuthu J, Tamilarsan C, Ganeshmoorthyo V, Vengateshwaran T
Department of Mechanical Engineering
Sethu Institute of Technology Pulloor, Kariapatti, India

ABSTRACT

The residual stress in the butt weld joints of aluminium Alloy AA2014 plates has been evaluated by thermo-mechanical finite element analysis using the commercial software package ABAQUS. The effective FE method for accurately predicting welding deformations and residual stresses in butt joints is presented in this study, utilising equivalent load. On the top surface of the weldment, the radial heat flux distribution is taken into account. By setting boundary conditions for the outward heat flux, convective and radiative heat losses are considered. The greatest temperature in AA2014 plates is calculated via linear FE transient thermal analysis with a Gaussian distribution surface heat source model. The goal of this research is to use the finite element approach to simulate welding. Once the model is constructed and verified, this work's primary goal is to investigate how changing the welding process parameters affects the thermo-mechanical reactions. Furthermore, the goal of this study is to determine a correlation between the welding parameters and the finite element analysis responses of single pass butt welding. This work investigates how different heat input and welding speed affect the thermo-mechanical responses of the weldment once it has cooled to room temperature.

KEYWORDS:
Residual stresses, Gaussian distribution, Heat flux, FEM, Al Alloy

1. INTRODUCTION

The invention of techniques for locally producing high temperatures right before the end of the 1800s marked the beginning of modern welding technology. Although it is possible to fuse two metal pieces without considerable temperature increase, welding typically requires a heat source to create a high temperature zone that melts the material. There is still a constant search for new and better welding techniques, in addition to the adoption of various standards and procedures. The uniting of two components by the coalescence of their surfaces in contact with one another is known as welding.

The two components can be brought together under pressure, maybe with the use of heat, to create a metallic bond across the interface, or they might be melted together to create coalescence through fusion welding. Autogenous welding is the method of welding in which just the parent metals are melted and fused together; however, many procedures also include the insertion of a filler metal, which is melted into the joint after being delivered as a wire or rod. This forms the weld metal along with the melted parent metal.

The process of connecting two pieces of material together along one edge in one plane is called butt-welding. Metal and thermoplastics are the most popular materials for this procedure, although it may be used to many other kinds as well. Butt welding is the process of joining two sheets of steel together by laying them side by side along a single joint.

2. MATHEMATICAL MODEL

A. Heat Flow in Welding

The heat source efficiency η is defined as

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

Where, Q is the rate of heat transfer from the heat source to the workpiece, Qnominal the nominal power of the heat source, and tweld the welding time. A portion of the power provided by the heat source is transferred to the workpiece and the remaining portion is lost to the surroundings. Consequently, η< 1. If the heat source efficiency η is known, the heat transfer rate to the workpiece, Q, can be easily determined from the below equation

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

$$\eta = \frac{Q t_{weld}}{E I t_{weld}} = \frac{Q}{EI}$$

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

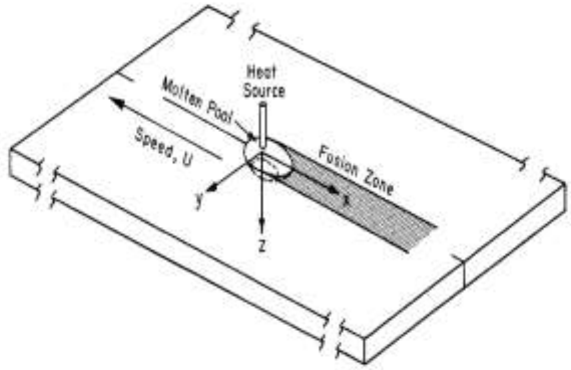

Figure 1 Coordinate system (x, y, z) moving with heat source

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 Qint 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, T0 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, ℰ 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, rb 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/m2).

3. FINITE ELEMENT MODEL

In this work, a thin aluminum alloy 2014 plate has been modeled as a workpiece. 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 modelled using (C3D8T) an 8-node thermally coupled brick, trilinear 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 AA2014 Aluminium plate is 30oC. 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/m2- k as used surface film coefficient on the outer surface of the workpiece and the bottom surface of lower work piece are, with the ambient temperature of 300C.

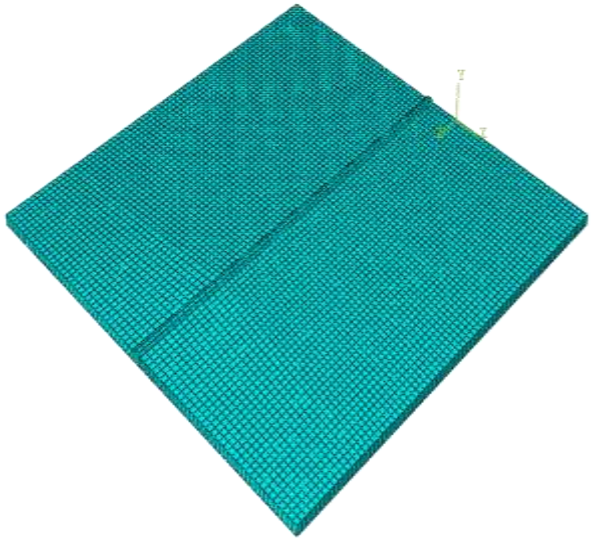

Figure 2 Meshed Model

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

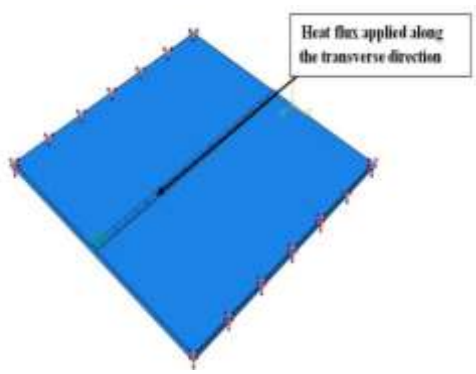

Figure 3 Heat flux applied at the model

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 that 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.

Table.1 Heat flux calculation for FEA

(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

4. 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.The temperature distribution and equivalent vonMises stress acting on the plate is found as 605oC and 426MPa is shown in fig.4

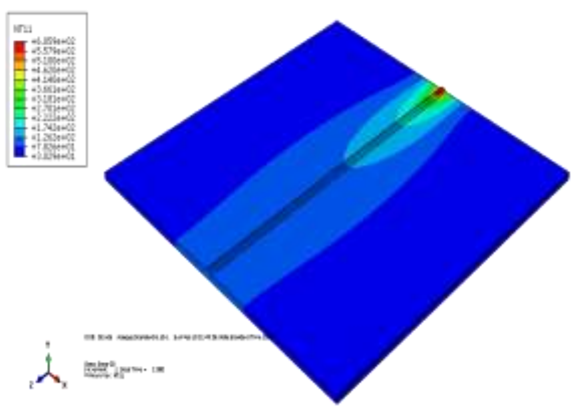

Figure 4 Temperature distribution along the direction of tool

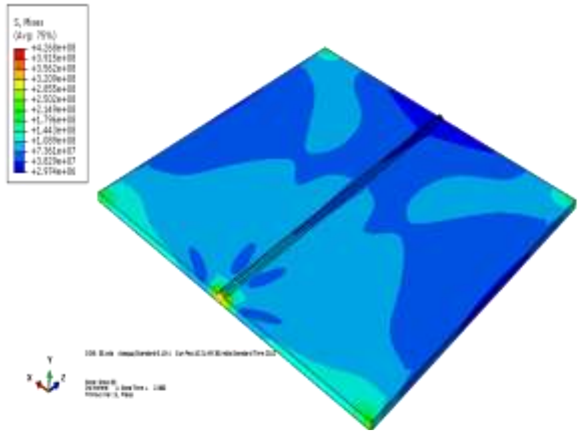

Figure 5 vonMises stress distribution

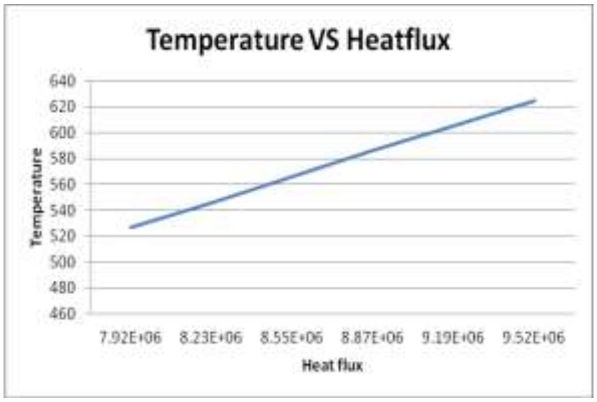

Fig. 6 Temperature VS Heatflux

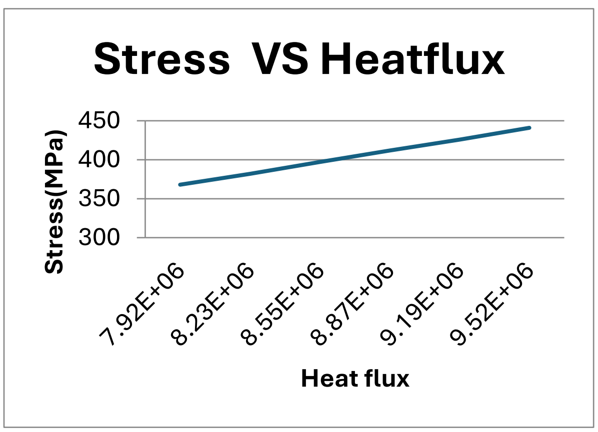

Figure 7 Stress VS Heatflux

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 vale 9.19e6 the stress acting on the material goes beyond the yield stress.

4.1. 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 Temperature obtained during different welding speed condition

Welding Speed (mm/sec)	Temperature (^{o}C)
3	835
3.5	769
4	681

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 surface temperature distribution for difference welding speed of
3mm/sec, 3.5mm/sec and 4 mm/sec.

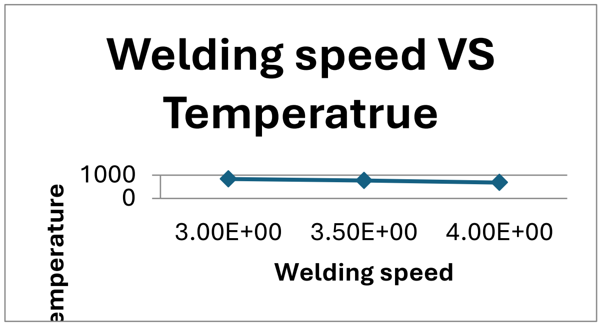

Figure 8 Temperature with respect to welding speed plot

Table. 3 Temperatures obtained during different welding speed condition

Welding Speed (mm/sec)	Residual Stress (MPa)
3	519
3.5	409
4	384

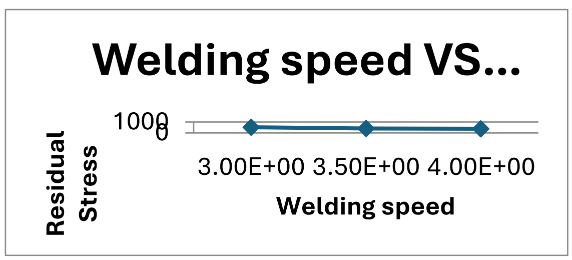

Figure 9 Residual stress with respect to welding speed plot

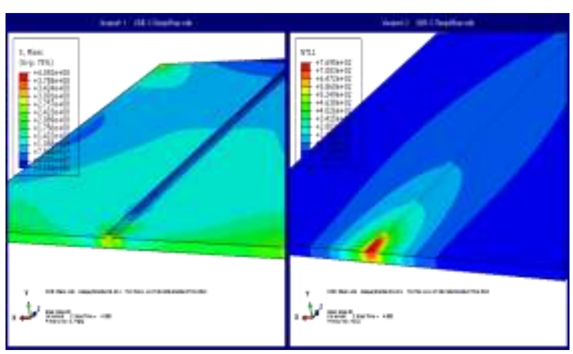

Figure 10 Temperature distributions and residual stress for the welding speed of 4mm/sec

5. CONCLUSION

This work constructed a three-dimensional finite element model for the butt welding process, accounting for residual stress, temperature distribution, and heat generation. Because experimental procedures are expensive, this method saves money.
The following conclusions can also be drawn from the simulation results: heat input and welding speed have a major influence on the weld reaction.

Conclusions can be drawn from the current work as follows:

- A finite element computational investigation of butt welding of an Al-Cu-Mg alloy AA 2014 is conducted.
- A methodology for the butt welding procedure of an aluminium plate with dimensions of 300 mm by 300 mm by 6 mm has been created.
- The strains generated in the plate diminish as the welding speed increases since the welding duration also lowers as the welding speed increases.
- It has been observed that as welding speed increases, the base metal absorbs less heat, resulting in a decrease in stresses.
- Through the use of the birth and death element approach of finite element analysis, one of the welding parameters, namely welding current, has been adjusted from 50 amp to 60 amp estimated residual stress.
- One of the welding factors, the welding speed, was adjusted to 3 mm/sec, 3.5 mm/sec, and 4 mm/sec. The residual stress was evaluated using the finite element analysis birth and death element technique.

REFERENCES

1. Harshal K. chavan et al "Finite element model to predict residual stresses in MIG welding" International journal of mechanical engineering and technology, volume 3, issue 3, - pp. 350-361 (2012).

2. Rong-Hua Yeh et al "Thermal analysis of welding on aluminum plates", Journal of Marine Science and Technology, Vol. 11, No. 4, pp. 213-220 (2003)

3. Brickstad B and Josefson B L, "A parametric study of residual stresses in multi-pass butt-*welded stainless steel pipes", International Journal of pressure Vessels and Piping, Vol. 75, pp: 11-25, (1998).*

4. Dragi Stamenkovi and Ivana Vasović, "Finite Element Analysis of Residual Stress in Butt Welding Two Similar Plates", Scientific Technical Review, Vol. 59, pp: 57-60, (2009).

5. Fricke S, Keim E and Schmidt J, "Numerical weld modeling – a method for calculating weld-induced residual stresses", Nuclear Engineering and Design, Vol.206, pp: 139-150, (2001).

6. Tso-Liang Teng, Chin-Ping Fung, Peng-Hsiang Chang, "Effect of weld geometry and residual stresses on fatigue in butt-welded joints", International Journal of Pressure Vessels and Piping, Vol. 79, pp: 467-482, (2002).

7. Vakili and Saeimi-s, "3D finite element analysis of the residual stresses in butt welded plates with modelling of the electrode movement", The Journal of Zheijiang University Science, Vol. 10, pp: 37-43, (2009).

8. Murugan. N and R. Narayanan, "Finite element Simulation of the residual stresses and their measurement by contour method", materials and design, Vol. 30, pp: 2067-2071, (2009).

9. Gerlich, A., Su, P., and North, T., "Peak Temperatures and Microstructures in Aluminum and Magnesium Alloy Friction Stir Spot Welds", Science and Technology of Welding and Joining, vol. 10, p.647-652, (2005).

10. Su, P., Gerlich, A., North, T., and Bendzsak, G., "Energy Utilization and Generation during Friction Stir Spot Welding", Science and Technology of Welding and Joining, p. 163-169, (2006).

11. Awang, M., Mucino, V., Feng, Z., and David, S., "Thermo-Mechanical Modeling of Friction Stir Spot Welding (FSSW)" Proceeding of the 2006 SAE World Congress, Michigan. (2006).

12. Kakarla, S., Muci-Kuchler, K., Arbegast, W., and Allen, C., "Three- Dimensional Finite Element Model of the Friction Stir Welding Process", Proceeding of Friction Stir Welding and Processing III, p. 213-220. (2005).

13. Cheng, Lifu & Chen, Xinyuan & Wei, Guoqian & Ye, Fan, "Initiation Behavior of Microscopic Short Cracks in Weld Toe of Structural Steel Q345B. Metals", 12. 618. 10.3390/met12040618, (2022).

14. Zheng, J., Ince, A., & Tang, L. "Modeling and simulation of weld residual stresses and ultrasonic impact treatment of welded joints", Procedia Engineering, 213, 36–47, (2018). https://doi.org/10.1016/j.proeng.2018.02.005

15. Tomerlin D, Kozak D, Ferlič L, Gubeljak N. Experimental and Numerical Analysis of Fracture Mechanics Behavior of Heterogeneous Zones in S690QL1 Grade High Strength Steel (HSS) Welded Joint. Materials. 16 (21):6929, (2023). doi: 10.3390/ma16216929.