International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Numerical Simulation of Arc Welding

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Abstract

Welding simulation is considered as one of the major drivers that will shape the future of the welding technology in the 21st century. Simulation can be used to predict the physical phenomena; joint geometry and microstructure during the welding process, and thus can partially replace the expensive, time-consuming and experience-based trial-and-errors in the development of new welding procedures. Welding is very common in industries like petrochemical, manufacturing, power plant and process industries. Weld joint life and structural integrity is depending on residual stresses and structure phase transformation. These residual stresses are responsible for the stress corrosion cracking, brittle fracture, reduced fatigue and creep strengths, poor scaling performance and reduced buckling strength. However, the temperature profile generated during the welding is having strong influence on both phase transformation of microstructure and residual stress. The objective of this work is to develop and evaluate a method for introducing a moving heat source into FE-model and investigate the temperature profile generated during the butt-welding in thin sheet. The effect of welding speed and heat input on temperature profile during the welding is evaluated. In the whole process of welding simulation there are couple of things that must be added or corrected. One of these things is that this model gives no feed-back or verification if the correct amount of energy is given into the model. This may vary due to mesh and geometry changes. This simplification of process of modeling welding will contribute to make simulations more commonly used by the industry.

Keywords: Fem, Filler Materials, Movingheat Source, Simulation, Specific Heat Of Materials, Stefanboltzman Constant.

1. Introduction

Electric arc welding process has been in use for steel fabrication since late nineteenth century. However, the commonly used arc welding processes, GTAW and GMAW were brought in commercial use in early 1940s. The metal deposition by arc welding process is a non-linear and complicated phenomenon mainly due to non-linear thermal and structural material properties. The process involves temperature gradients of thousands of degrees, over a distance of less than a centimeter, occurring on a time scale of seconds, involving multiple phases of solids, liquids, gas and plasma. The modeling of deposition process requires an integration of welding simulation and layer build-up by successive material addition. Present study covers the theoretical background of the finite element modeling of welding, Various physical, metallurgical and numerical aspects such as governing equation of thermo-mechanical analysis, finite element (FE) matrix formulation, coupling (thermal–metallurgical structural) between different fields, temperature dependent material properties, heat source modeling, addition of filler material. Finite

Element Method (FEM) is one of the most accepted and widely used tool for the solution of nonlinear partial differential equations which arises during the mathematical modeling of various processes. Originally developed for the analysis of aircraft structures FEM is now applicable in all fields of engineering and applied sciences like heat transfer, fluid dynamics, vibrations, magnetism etc. The origin of the process is the mathematical model from which everything originates. The mathematical model usually comprises of an ordinary or a partial differential equation.

2. Governing equation [1]

The governing equation for the temperature distribution in weldment or thermal analysis of welding is similar to the governing equation of 3-D heat conduction with suitable boundary condition.

$$k(T)\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+Q=c(T)\rho\frac{\partial T}{\partial t}$$

Where,
T=Temperature
c(T)=Specific heat of the material which varies with temperature.
k (T)=Thermal conductivity of material which varies with temperature.
ρ=Material density
Q = Heat input or rate of heat generated in the material
T = Time

3. Plate Dimension and Mesh Model

In the present work two plate of dimension 150 x 150 x 3 mm are butt-welded. So, symmetrical boundary condition is used symmetrical plane of plate for the simulation. The dimensions of geometry model considered are 150 x 150 x 3 mm. Figure-1 shows 2-D mesh model for the simulation. There are 11476 nodes used. Fine mesh is used for the weld bead and near region simulates HAZ Minimum mesh size in x direction is 1 mm, y direction is 0.5 mm.

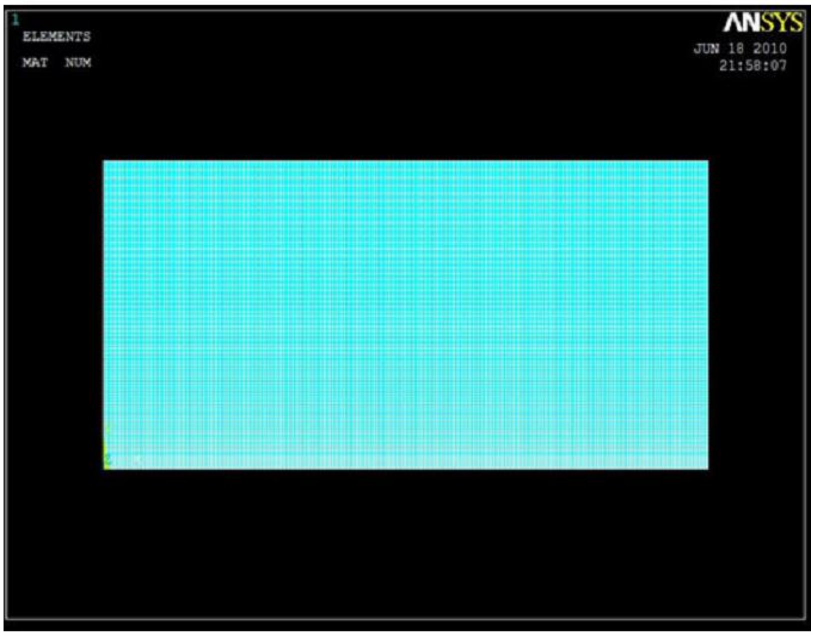


Figure-1 2D mesh model of plate

4. Boundary condition

Heat loss occurs from the material surface through both convection and radiation. Radiation losses are dominating for higher temperatures near the weld and convection losses are dominating for lower temperature away from the heat sources.

Convection

Convection is the mode of heat transfer between a solid and a fluid surrounding.

$Q=hA(T_w-T_\infty)$ (4.2)

Where,

T_w=solid surface temperature, K

T_∞= surround fluid temperature, K

h = convection film coefficient, w/m2 K

Radiation

The radiative surface boundary condition is governed by,

$Q = \sigma\lambda A\varepsilon\lambda\ (T^4-T_{ref}^4)$ (4.3)

Where,

T = Element surface temperature, K

Tref = Reference temperature in absolute units, K

σλ = Stefan Boltzmann constant, w/m2 K4

ελ= Emissivity of surface.

Equivalent heat transfer coefficient

The combine heat losses by convection and radiation is given by,

$Q = h_w(T_w-T_a)$

Equivalent heat transfer coefficient is defined as sum of convective heat transfer coefficient and radiative heat transfer coefficient.

$h_e = h_c+h_r$

Where, radiative heat transfer coefficient is given as,

$h_r = \sigma\varepsilon(T_w^4-T_a^4)/\ (T_w-T_a)$

5. Numerical aspect

General-purpose finite element code ANSYS is used in the present work. Various numerical intricacies in welding simulation and software options to handle them are to be focused. The complex welding phenomena is modeled as sequentially coupled transient non-linear thermal-stress analysis. Generally, non-linearities may be due to three reasons.

- non-linearity due to changing element status.
- Geometrical non-linearities
- Material non-linearities

The use of contact elements is very limited in the present work and only one such case with contact element pair on the mating surfaces of a butt joint assembly is analyzed Iterative incremental Newton-Raphson (NR) scheme was used to solve the system of equation. The use of this scheme is also essential in the software to adopt quiet elements technique for modeling of filler material. The opted “Full” NR scheme updates the stiffness matrix at every equilibrium iteration and thus shows more flexibility to incorporate non-linear behavior of material properties. Though frequent updating for stiffness matrix formulations and inversions but gives relatively fast convergence. The matrices obtained from finite element formulations are usually sparsely populated therefore the system of simultaneous equations are solved by using direct sparse matrix solver (elimination solver). Software (ANSYS) options to improve convergence such as “line search”, “adaptive descent” and “ramped or stepped load” are used. The line search option attempts to improve a NR solution $\{\Delta u_i\}$ by scaling the solution vector by a scalar value termed as a line search parameter at the start of each equilibrium iteration. The scalar multiplier is automatically determined by minimizing the energy of the energy of the system, which reduces to finding the zero of the nonlinear equation. Adaptive descent is a technique which switches to a “stiffer” matrix if convergence difficulties are encountered and switches back to the full tangent as the solution convergences, resulting in the desired rapid convergence rate. Further detail of these options can be found in ANSYS user manual.

A. Selection of Heat Source Model.

From the study of past research and discussion it was consider that the Tsai model for heat input [2] involved only one constant that is heat distribution coefficient, which is nothing but surface width of weld pool, which can easily be measured after experimentally. On other side, double ellipsoidal heat distributed model involved four constants, which is very difficult to measure. So, in this study, Gaussian distributed model is assumed for carbon steel material.

B. Addition of Filler Materials and Moving Heat Source.

Modeling of filler material and moving heat source has always been a hard-core issue in computational weld mechanics because of its effects on the final weld bead geometry and computational expense. In numerical simulation of welding, deposition of material and moving heat source is modeled by element movement or node, volume movement techniques.

$$t_e = \frac{(l_w)(v)}{n_n}$$

Where,

l_w= Length of weld

V = weld speed

n_n= No of node in X-direction

te = Time for activation of element or node

C. Implementation of Tsai heat input model.

In the welding process heat source is moving, so it is very difficult to model heat source. Addition of filler metal and moving heat source can be implemented by changing geometry as discussed in section IV-C For the calculated time sec node in the region of weld bead are activated and heat is input to te at node is given by following equation for heat source modeling.

q(r) = q (0)e-cr2

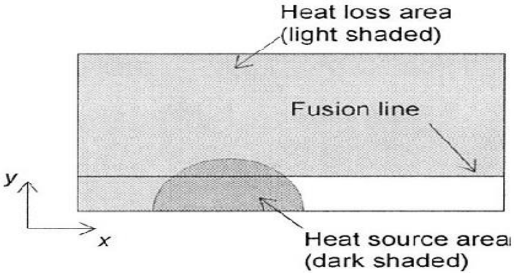


Figure-2 Zone of Heat input and Heat loss area

The moving heat load is applied as distributed heat flux to the top surface of the model, Figure-2. The region within which the heat is applied has a circular shape assuming the heat source is applied perpendicularly to the plate without any inclination. As shown in Figure-2 maximum heat input is given to the node which at center of heat source. Heat input to nodes comes under the radius of C i.e., heat distribution coefficient, will be decreased in Gaussian manner. Heat input is in term of heat flux which depend upon the surface area comes under the radius of C.

D. Implementation of heat input model in terms of addition of filler metal.

Implementation of heat input model in terms of addition of filler metal is similar to Tsai. Heat input model as discussed in section 3.5.3.4. But here the only those nodes are selected as heat input which fall in fusion line as shown in figure is given by following equation. Heat input is in term of heat density, which depends up on the control volume of nodes.

$$q_v = \frac{\rho_f \; q^{1-b}}{a}$$

E. Boundary and Initial Conditions.

The convection boundary conditions used for different surface are different. The heat transfer coefficient used for top and bottom surface is taken as 7.5 (w/m2-k) [1]. While, due to high velocity of shielding gas, heat transfer coefficient for surface subjected to heat input or under the nozzle is taken as 30 (w/m2-k) [3]. For the Radiation boundary condition emissivity for the surface is taken as 0.9 [3]. Initial Temperature of plate is taken as 200C. Symmetrical boundary condition is used on symmetrical plane of plate.

F. Input Data for Simulation.

Thermal analyses of welding for materials are done for three different heat inputs to carry out study of effect of heat input on temperature profile. Weld velocity for the analysis is being taken from the time taken for welding. Heat distribution coefficient is the constant using in Tsai heat input, which is taken after the measurement of weld bead in the experiment. Input data for carbon steel the thermal analysis of welding is performed using Finite Element Method and implemented n ANSYS-APDL. Temperature distribution during the welding was obtained by the numerical results. Temperature distribution during welding is obtained in carbon steel by using Tsai heat input model.

Input data for welding of carbon steel

Sr.No	Current (Amp)	Voltage (Volt)	Weld Efficiency	Weld Velocity (mm/sec)
1.	80	16	0.6	1,2,3
2.	100	16	0.6	1

6. Results and discussion

The contour plot of temperature at different time for carbon steel subjected to I = 80 amp and V = 16 volt are shown in Figure 6.1 to Figure 6.4 respectively. This figure shows the movement of welding torch with respect to time. It also shows the temperature distribution as welding torch moves away from weld start position. The result of parametric study shows maximum temperature of weld bead in carbon steel is around 1960 ^{0}C.

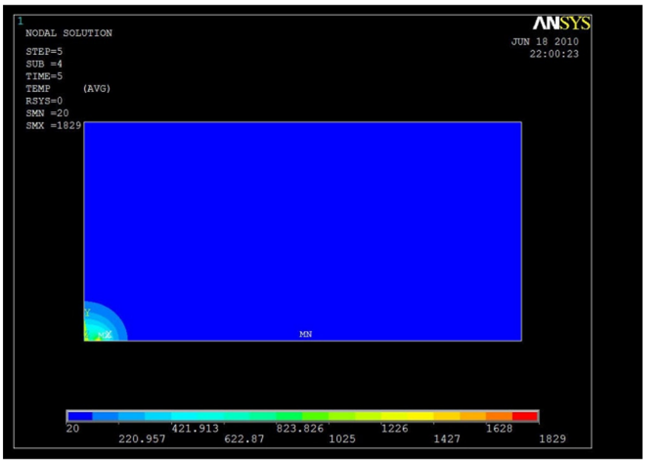


Figure-6.1 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=5 sec, at speed of 1 mm/sec.

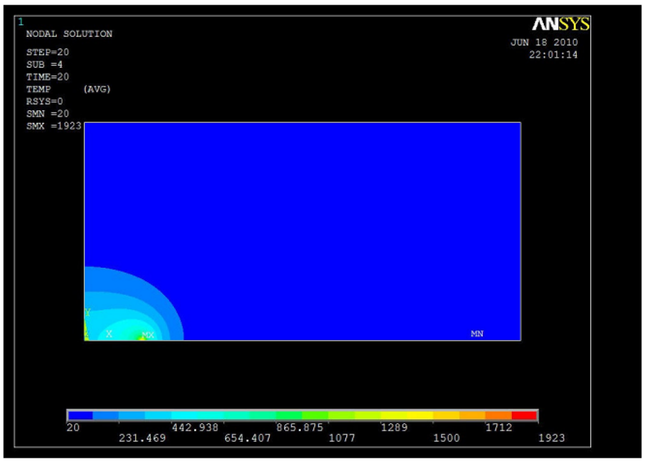


Figure-6.2 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=20 sec, at speed of 1 mm/sec.

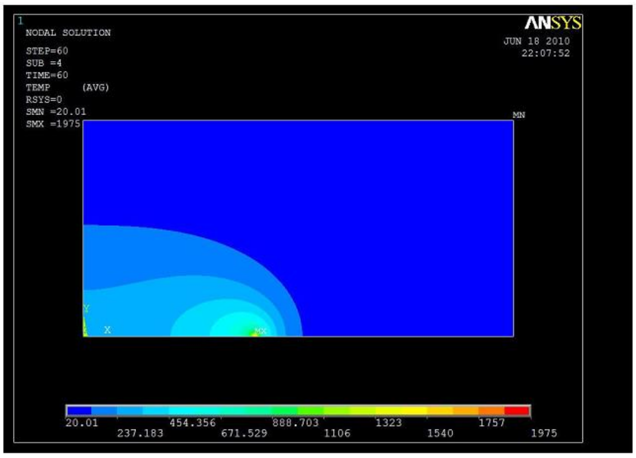


Figure-6.3 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=60 sec, at speed of 1 mm/sec.

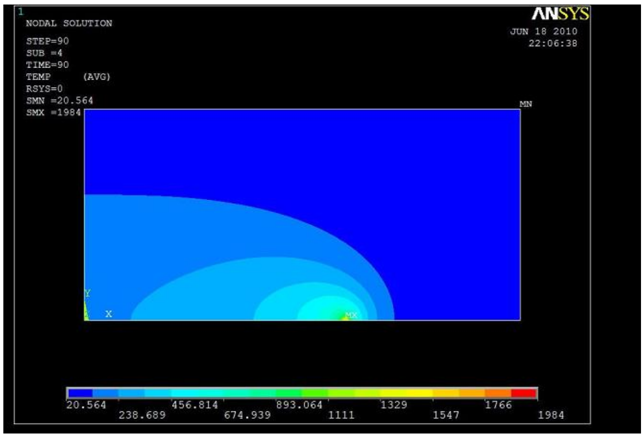


Figure 6.4 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=90 sec, at speed of 1 mm/sec.

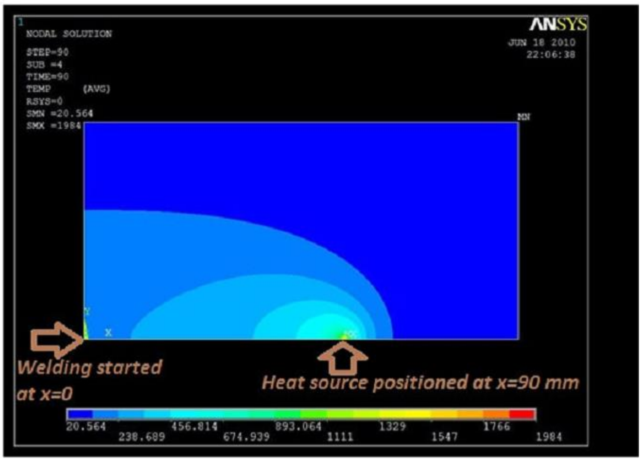


Figure 6.5 Temperature distribution of welded plate.

Figure 6.5 shows the temperature distribution of the welded plate when the welding torch passes the position at the coordinate of x = 90 mm in the welding direction. As can be seen from the Figure 5.5 the temperature around the torch reaches 1984 0C suggesting melted material in the fusion zone (FZ). High temperatures are present at immediate vicinities of the FZ, which defines the heat affect zone. The torch also preheats a very small area in front of the torch where the heat source is going to pass. The heat inputs generated by the moving heat source along the welding line are gradually transferred in all directions of the plate by conduction, convection and radiation. The temperature around the edge where the welding is started is decreased greatly to the range of 600–650 0CThe temperature variations of the plate with time due to a moving heat source and the rapid heat transfer during fusion. Heat input in the welding is transferred quickly in the width direction (y) to reach uniform distributions. It is also clear that the heat conduction plays an important role in heat flow and the surface convection and radiation have little effect on FZ and HAZ boundaries. Figure 6.5(a) shows temperature distributions at the top surface of the plate of the reference plane along the transverse direction (y) at different time steps. It shows that the temperature in the fusion zone is substantially higher when the welding torch just passes the plane but it decreases rapidly with time. Temperatures in the area outside of FZ and HAZ increase gradually with time when the heat in the FZ is transferred through conduction. Figure 6.5(b) shows the temperature distributions at the top surface along the longitudinal direction (x). It shows a sharp temperature drop close to FZ but temperatures further away from FZ increase at different rates which are proportional to their transverse distances (y) to the welding line.

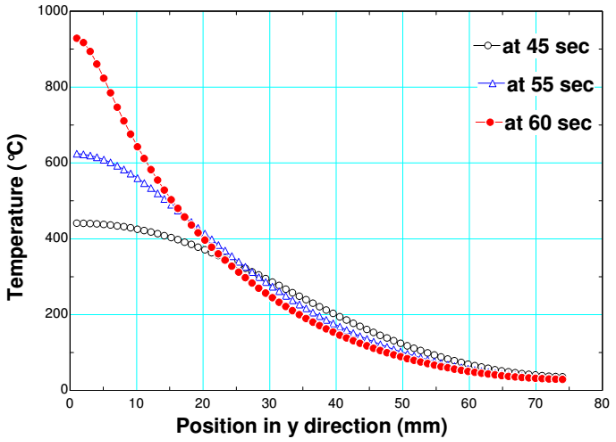


Figure 6.5(a) Temperature distributions of the top surface of the welded plate (a) along transverse direction at a speed of 1 mm/sec.

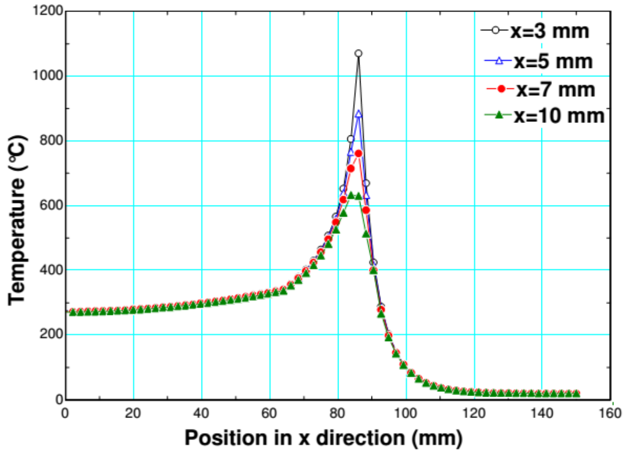
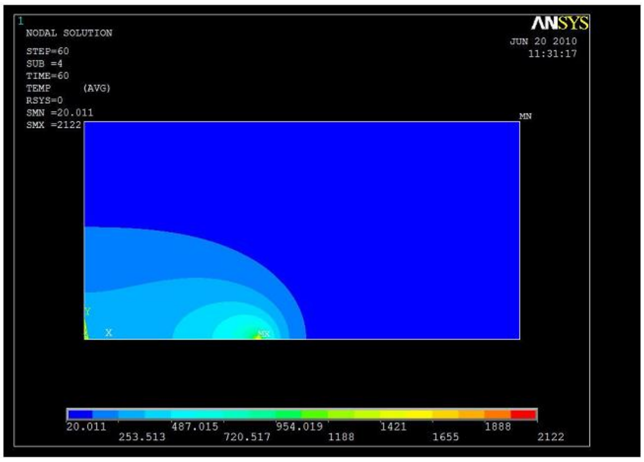


Figure 6.5(b) Temperature distributions of the top surface of the welded plate (b) along longitudinal direction at a speed of 1 mm/sec.

7. Comparison of counter plot for effect of energy input on temperature.



```
NODAL SOLUTION

STEP=60
SUB =4
TIME=60
TEMP      (AVG)
RSYS=0
SMN =20.011
SMX =2122
```

Figure 7.1 Temperature contour for carbon steel subjected to I = 100, V = 16 volt at 60 sec.

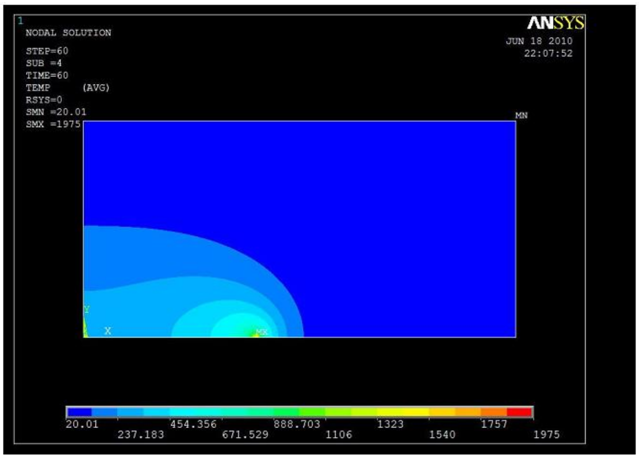


Figure 7.2 Temperature contour for carbon steel subjected to I = 80, V = 16 volt at 60 sec.

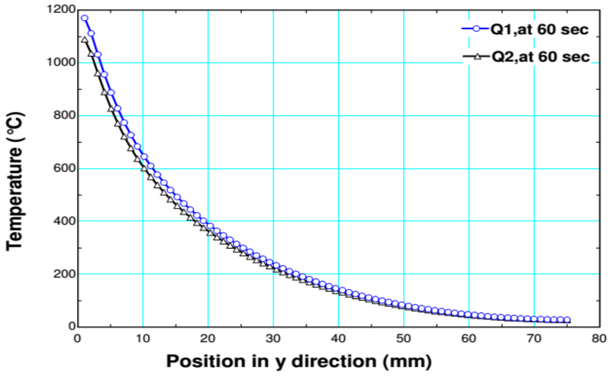
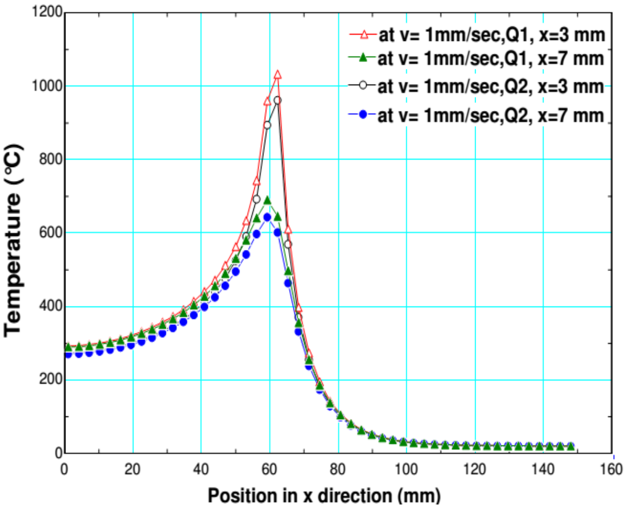


Figure 7.3(a) Effect of energy input on temperature (a) along transverse direction at a speed of 1 mm/sec.



Where, Q1 = 960 W, Q2 = 768 W

Figure 7.3(b) Effect of energy input on temperature (b) along longitudinal direction at a speed of 1 mm/sec.

The 2D model is used to evaluate the effect of welding process and heat source parameters on the temperature of the plate. When the energy input rate has been changed from the original value of 768 W, the temperature distributions at the top surface along the transverse and longitudinal directions are shown in Figure 7.3 (a, b). The change of energy input causes obvious temperature decreases in FZ and in the areas both close to and outside of HAZ with an approximate linear relationship between the temperature and energy input changes.

8. Comparison of counter plot of temperature for carbon steel at different speed.

Temperature distributions at the top surface are shown in Figure 8.4(a, b) for different heat source speeds in the transverse and longitudinal directions. The increase of the welding speed has resulted in temperature decreases in the plate as the heat source applies for a shorter period of time when it moves faster. However, the change of the speed has mainly influenced peak temperatures in FZ and it has a less effect on the temperatures in other areas.

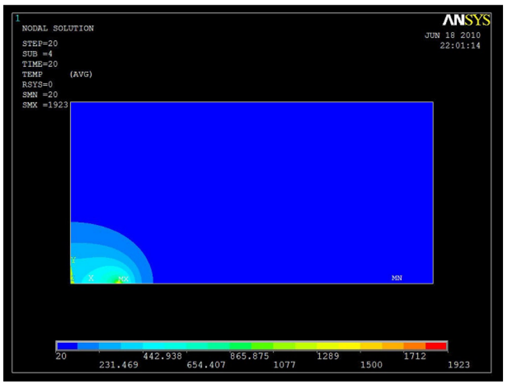


Figure 8.1 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=20 sec, at speed of 1 mm/sec.

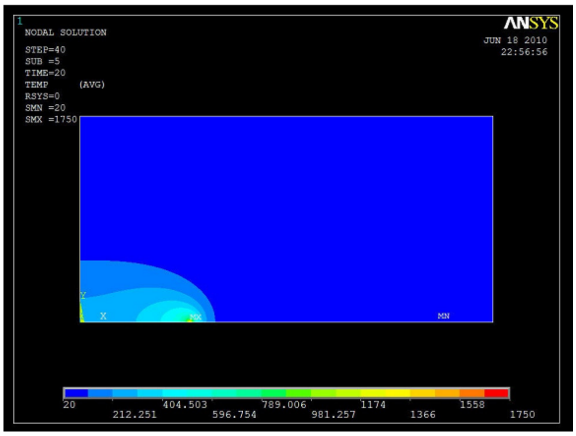


Figure 8.2 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=20 sec, at speed of 2 mm/sec.

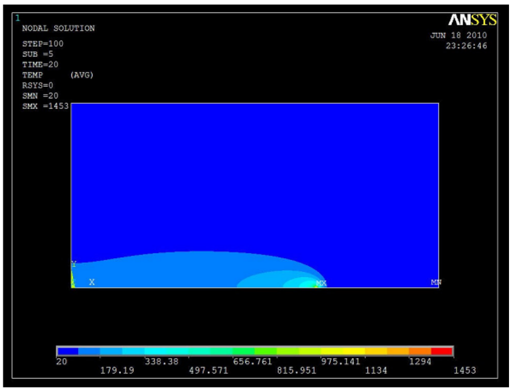


Figure 8.3 Temperature contour for C.S subjected to I=80-amp, V=16 volt at t=20 sec, at speed of 3 mm/sec.

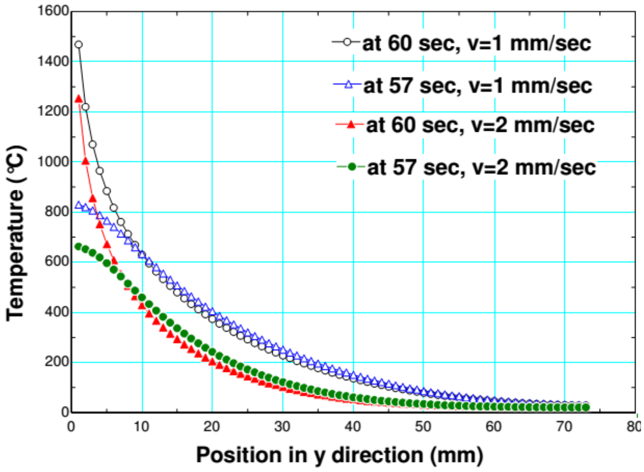


Figure 8.4 (a) Effect of welding speed on temperature (a) along transverse direction.

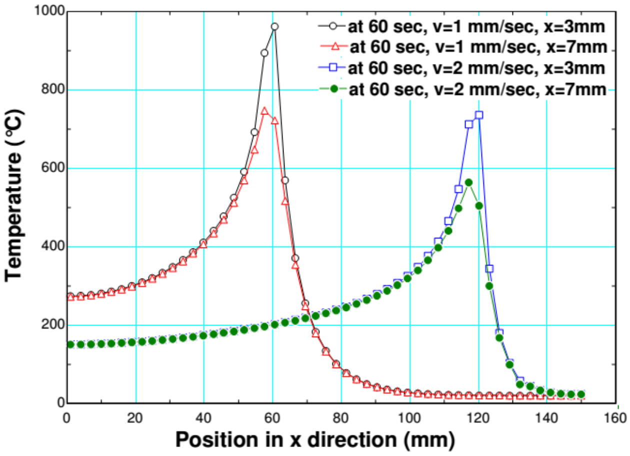


Figure 8.4(b) Effect of welding speed on temperature along longitudinal direction.

9. CONCLUSIONS

A Gaussian distributed moving heat source model based on Goldak's heat source model through author written APDL subroutines and Engineering Equation Solver (EES) scripts is implemented for the 2D finite element simulations of arc welding process. The influence of significant welding process, welding speed, heat input and heat source parameters on transient temperature histories, shape and boundary of the FZ and HAZ is successfully demonstrated. Based on the investigations from the present research work, the following important conclusions can be drawn

1. A moving distributed heat source model based on the Goldak's method has been implemented into FE thermal simulations to predict welding temperature distributions and variations. Further experiment is required in order to validate the proposed heat source model and to establish quantitative correlations between FE simulations and experiments.
2. The results demonstrate that the welding speed, energy input and heat source distributions have important effects on the shape and boundaries of FZ and HAZ. They also influence peak temperatures in FZ, which consequently affect the transient temperature distributions in the welded plate.

3. Energy input rate has an obvious effect on temperature values in areas closed to HAZ in the welded plate. There is an approximate linear relationship between the change of temperature and energy input. The increase of the welding speed causes temperature decrease mainly in FZ but has a less effect to the areas outside of FZ and HAZ.
4. FZ and HAZ boundaries are sensitive to the changes of heat source parameters. The change of heat source distributions/ magnitudes shows a non-linear effect on peak temperatures in FZ and temperature distributions in the areas close to HAZ. Therefore, it is important to define an accurate heat source model in order to predict the welding distortion and residual stresses correctly.
5. Comparing the temperature profile for c.s subjected to I = 80-amp, V = 16 volt at t = 20 sec, at speed of 1 mm/sec, 2 mm/sec, 3 mm/sec. The 3 mm/sec is best suite

References

1. D.H Tailor, *Development of code for the thermal analysis of welding using FDM*. Dissertation submitted to S.V.N.I.T., Surat.
2. Eager,T.W and Tsai, N.S. *Temperature fields produced by travelling distribution heat sources.* Welding journal, 62 (12): 346-s to 355-s, 1983.
3. Ihab F. Z. Fanous, Maher Y. A. Younan, Abdalla S. Wifi, *3-D Finite Element Modeling of the Welding Process Using Element Birth and Element Movement Techniques*, Journal of pressure vessels Technology 144 Vol. 125, May 2003