Numerical Simulation of Temperature Distribution in Robotic Arc welding by ARISTO™ Robot

Aman Sharma¹, Pradeep Kumar Singh¹ and Rohit Sharma¹

¹IET Department of Mechanical Engineering
GLA University Mathura 281406

Corresponding Author Email: meamansharma02@gmail.com

Abstract. The present analyses also studied a numerical simulation on the specimen of mild steel weld by robotic welding. A conical moving temperature source from Gaussian was applied to the current numerical simulation. ANSYS is also used for thermally mechanical weld tests by the ARISTO robot, with some variations. Taking into consideration the thermal and physical properties of mild steel that affect the welding thermal conductivity. The analysis of temperature distribution was defined according to robotic arc welding process parameters, such as welding temperature, welding current, and welding speed impact on the geometry of the weld bead was investigated. The temperature distribution based on numerical observations is associated with experiment results. This form is well in line with the results obtained by numerical simulation of the weld zone profile.

1. Introduction

Robotic welding is a high-density welding process, because of its smoothness, accuracy, and efficient process, it is a rising technology. The method of numerical simulation has been developed in this area since it is possible to explain physical phenomena during a complex welding phase and to optimize the parameters of the robotic welding procedure. Robotic welding is an automated weld technique in which a large range of materials, identical and unlike, is connected without human intervention. For several researchers over the past decade, Robot welding is becoming a significant field of research. The analyses and the numeric simulation process for robotic arc weld predicted the temperature profile and weld geometry. The robotic system started to shift, powered by emerging technologies and immense development needs. Technologists currently consider the development of arc solder robots in terms of design, control, and sensing capabilities as potential sources and will have a very positive effect on the rest of the manufacturing process. Another critical factor in creating an arc welding robot system is its sensing capability. The central soldering sensor will interpret data for quantitative data such as an Optical Signal, Voltage, and Current from the Parameters. Welding is a mechanism in which the localized (permanent joint) coalescence happens with or without the application of the heat-pressure alone or the filler material is applied with or without a separate filing joint. The links are typically fastener-lined. Rosenthal has developed a technique of analysis for resolving the temperature distribution of the sold joint that considers the heat source point, line, or plane. For a top temperature not as much of 30 percent of the melting point, Rosenthal solutions provide reliable results [1]. Pulsed laser soldering was studied, and a three-dimensional heat flow model of finite element developed using the subroutine of ANSYS APDL. [2]. Residual stresses residual in laser soldering of 304L 10mm thick plates with a laser beam strength limit of 15kW have been investigated by Carmignani et al.[3] in austenitic stainless steel.
During the laser soldering, the numerical temperature and stress simulation was determined using the soldering speed ABAQUS. T.sirkas et al. [4] have considered the computational simulation of the method of laser beam welding with transitory thermal analysis. The numerical simulation of laser pulse welding has been studied by Sabbaghzadeh et al.[5] by two methods such as finite element and finite differential weld temperature-geometric distribution methods; Balasubraman et al. [6] use FEA codes and compare the experimental results for different laser welding process parameters, and the measurement of the temperature profile and weld geometry bead length and penetration depth). Bag et al.[7] studied laser spot soldering heat flow with a combined effect from the volumetric heat source and surface heat flow concept. Capriccioli and Frosi [8] For INCONEL 625 and AISI316 researched TIG and laser-beam welding in a Birth and Death Technology software package for ANSYS[8]. The fusion zones of INCONEL 625 and AISI 316 were compared to experimental values during TIG and laser welding. The 3-dimensional FEM model has been developed for the simulation of the distribution of the magnesium-alloy alloy and the geometry of weld-beads in laser welding [9-10]. Kim et al. [11-12] studied simulation of the 304L pulsed-laser weld by computation using finite element code. Shanmugam et al. [13] To test the transient temperature distribution and welding perforation geometry of AISI 304L 1.6 mm thick laser welding T-joint sheet considering material properties as temperature-dependent, a FEM code was developed using the SYSWELD. Yilbas et al. [14-15] In the development of finite element patterns, temporary temperature profile, and 2 mm thick, low carbon mild stainless steel residual stress were analyzed using finite element code ANSYS. You found that firstly, the temperature drops rapidly and then slowly over the thickness of the substance. Casalino et al. [16] Present an equivalent (Ti6Al4V) and differential material (AA5754 alloy and T40 layer pure titane) finite element design for predicting thermal appearance and shape of the beads sold. Laser beam welding from three sources is examined by Chukkan et al. [17]. The goal of this research is to study the effect on the temperature distributions curve and welding geometry of the austenitic stainless steel 316L laser welding process parameters, i.e. the mean beam, soldering speed, and laser spot size, by using ANSYS APDL for assembly. Also for study purposes, the 1.4 mm thin sheet of 316L was considered thermally-physical features such as density, thermal conductance, and specific heat. This numerical simulation uses a conical Gaussian three-dimensional moving thermal source [18]. Numerical simulations and experimental deformations and rest stress studies are normally performed in large complex Mag welded panel structures which may be used in many industries, not just for the buttoned and T-joint welded structures listed above.[20] Deng et al. [19] The ISM method for soldering the deformations of a large panel structure has been determined. Calculated Data were obtained from a small scale model for ISM measurements using the complete thermal elastic plastics (TEPs) simulation process. Azad et al. [21], Zhang and al. [22-23], Podder et al. [24], and several other writers have employed a similar strategy. On the other hand, a simplified TEP approach in broad residual-stress welding and deformation calculations was proposed by PeriC et al.[25-26]. Heat input has not been used to simulate electrode motion with the heat flux to accelerate the measuring process by using the specified thermal boundary conditions. The Wu et al. [27] and Zhao et al. [28-29] and Lin et al. [30] were also tested for residues and strains in the soldered MAG lap joints for the remainder of stresses in the MAG butt-soldered pipes.

2. Experimental Methodology

2.1 Numerical Simulation

2.1.1 Heat Transfer Analysis

As in Eq 1, the basic control equation of the three-dimensional heat conduction is indicated for transient temperature. [1].

\[
\rho c \frac{\partial T}{\partial \tau} + \nabla \cdot (\rho c \nabla T) = \frac{\partial}{\partial x} (K_x \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y} (K_y \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z} (K_z \frac{\partial T}{\partial z}) + Q(x,y,z)
\]  

(1)
The welding temperature has been believed to obey the Gaussian distribution of the heat source of conical form, traveling at the velocity \( v \) along the \( y \) axis. Fig. 1 displays the robotic welding device schematically used in the current study, and Fig. 2 depicts the steps in robotic welding. Experimentally, 35.7\% of the overall power is lost and the remaining 70.4\% of the power in a mild steel workpiece is absorbed. It is expected to absorb 17.3\% power from 69.3\% of the total temperature on the top surface of the welding workpiece (\( Q_{\text{surf}} \)), while the rest 48\% power inside the material structure (\( Q_{\text{keyhole}} \)). Eq 2 is responsible for the heat distribution on the top surface.

\[
Q(x, y) = \frac{3Q_{\text{surf}}}{\pi R^2} e^{-\frac{3(x^2 + (y - vxt)^2)}{R^2}}
\]

(2)

“The plane heat source (17.3 percent) is where \( Q_{\text{surf}} \) is heat power. The simulation of the keyhole is supposed to be a cone, the Gaussian heat flux distribution being given as in Eq. 3.”

\[
Q(z) = \frac{2Q_{\text{keyhole}}}{\pi ro^2 H} e^{-\frac{(x^2 + (y - vxt)^2)}{ro^2}} (1 - z/H)
\]

(3)

Fig. 1 Representation of process in robotic arc welding [31]

Fig. 2 Steps in robotic welding [32]
The fusion of heat sources in surface and volume models expressed in Eq 4, represents the overall heat input provided to the model.

\[ Q_v(r, z) = Q(x, y) + Q(z) \]  

(4)

2.2 Finite Element Modeling

To simulate a robotic arc welding process with a commercial software package “ANSYS APDL 15”, the finite element model has been developed for a 3-dimensional transient analysis. For workpieces of 6 mm, 8 mm, or 10 mm, the finite element model was planned. The model is based on the temperature profile, the shape of the molded bowl, the peak temperature, and the weld process effect, including average strengths, welding rate, and the welding zone. Two element types are added for the geometry of the welding structure: 3 volume, 8-dimensional node(SOLID 70), and 4 two-dimensional nodes (PLANE 55). The small element is rendered very thin by the welding line and a gross mesh of an increasing element is removed from the weld line as shown in the figure. 2. Several trials for optimal grid size with different element sizes from 32,000 to 216,000 have been carried out in this simulation. The mesh convergence test was conducted and it was determined that after 69,650 elements the maximum temperature is regardless of mesh density. Size is 0.4 mm / 0.4 mm / 0.2 mm = 0.4 mm close to a welding line. In all the model comprises a total of 91,450 nodes and 69,650 elements shown in Fig 4.

For simulating the moving heat source, the thermal flow is applied to the element faces. ANSYS APDL language subroutine has been used to build the moving heat source. Some of the fundamental considerations were made to simplify the model of the finite element.

This model includes the following assumptions:

a. The original workpiece temperature is 40 °C.

b. The material's thermophysical characteristics are known as temperature dependent[15], including density, specific heat, and thermal conduction.

c. Take into account heat loss from radiation and convection on the workpiece surfaces.

d. The use of lumped heat transfer coefficient[2] considers combined radiation and convection.

e. The physical phenomena such as viscous strength, booster strength, convective melt flow, and the impact is ignored. Table 1 lists the parameters of the robotic arc welding mechanism considered in the current temperature distribution numerical simulation.

![Fig.3 CAD model of weld workpiece](image)
Table 1 Robotic arc welding process parameters

| Sl. No. | Welding temperature (°C) | Welding speed (mm/sec) | Welding current (A) |
|---------|--------------------------|------------------------|---------------------|
| 1       | 130                      | 27 mm/sec              | 90A                 |
| 2       | 220                      | 27 mm/sec              | 90A                 |
| 3       | 340                      | 27 mm/sec              | 90A                 |
| 4       | 420                      | 27 mm/sec              | 110A                |
| 5       | 130                      | 27 mm/sec              | 110A                |
| 6       | 220                      | 27 mm/sec              | 110A                |
| 7       | 340                      | 27 mm/sec              | 120A                |
| 8       | 420                      | 27 mm/sec              | 120A                |
| 9       | 420                      | 27 mm/sec              | 120A                |

3. Experimental Method

As shown in Figure 4, the experimental setup, consists of an information processing and signal measurement system. Robot arc welding was a bead during this test. The bead on the plate was held above the table in a level position. Fillet weld was made in the flat position on V-Groove. In this analysis, the ASTM A 36 was selected for welding with AWS A5.1 E 6013 coordinating filler material. The scale of the specimen was 6mm. Welding current at welding speeds of 27 mm/sec was set to 90A to 110 A. Sensors were operated by a microcontroller Arduino (AT Mega 328p) and linked for the processing and storing of data with a PC. Arduino has been further programmed depending on the sensor used and the continuous data is collected and processed for further analysis. Electrical arc weld with welding gripper with a maximum average current of 110 A to confirm A 6 mm thick, mild steel distributor numerical temperature simulation. The calculation of the temperature distribution at 4 different locations (X). “The thermostat is set at four thermostat-type thermocouple K places (-40-500 C), which are distant from welding lines (a) = 4 mm, x = 6 mm and X = -6 mm, −8 mm + Y = 10 and z + 2.2 mm)”. For the recording of the temperature, Data Logger Thermometer Center 309 is connected to the PC interface. Temperature-dependent, thermally-physical properties shown in Table 2[15] are thermal (W/m °C) conduction, density (kg/m3 and basic (J/kg °C) temperature. The robotic soiling procedure was carried out to verify numerical simulation results with a medium beam force of 435°C, a welding speed of 27 mm/s, and a weld bead of 8 mm.

Table 2 Thermophysical properties of Mild steel

| Temperature (K) | 273 | 373 | 673 | 1073 | 1523 |
|-----------------|-----|-----|-----|------|------|
| K               | 40.3| 39.5| 37.2| 26.9 | 33.1 |
| Density (Kg/m³) | 300 | 500 | 800 | 1000 | 1200 |
| Temperature (K) |     | 441 | 580 | 1013 | 1213 |
| Cr              |     | 120 | 1628|      |      |
4. Result and discussions

Using the finite element code ANSYS for a fluctuating average welding current, varying welding velocity, and welding temperature, the temperature distribution is determined numerically. Several numerical simulations have been carried out with the robotic welding process parameters as defined in Table 1. Figure 5 shows the transient range of temperatures of the robotic arc welding of mild steel along its weld zone at consistent welding speed (27 mm/s) and the welding bead output of 10 mm at different average temperatures (120–420 °C). Figure 4 shows the effect of constant welding speed (27 mm/s) with a peak temperature distribution with a weld area of 10 mm and a gap in the weld line mean weld strength. Figure 8 depicts the 3-D distribution of the thermal conductivity of widely varying welding current (120–420 W) at constant welding speeds of V = 27 mm/s. The effects of the welding current and the weld velocity on the weld bead geometry are shown in Figure 7 on a constant 10 mm weld bead scale. With increasing average beam power and welding speed, the weld bead geometry profile shifts. Also, at very high inputs (pressure speed) it was found that the geometry of weld beads was almost H-formed. The experimentally tested temperature distribution effects were numerically collected, with K-type thermocouples fixed in various positions. “Figure 8” 3-D temperature field distribution at constant welding speed V = 27 mm/s, Steady-state thermal with directional heat flux and total heat flux for varying average temperature the numerical distribution of the simulation temperatures. As well as Fig. 9 depicts the comparison of the distribution of numerical simulation temperature effects at various locations (X) away from the weld line with K-type thermo-pairs.

Fig. 5 Distribution of Temperature spread along the welding line at constant welding velocity for various average temperatures. a V = 27 mm/s and b V = 35 mm/s

Fig. 6 At constant welding speed away from the weld line, peak temperature distribution for varying average temperature
Fig. 7 Variation of peak surface temperature at constant velocity \( V = 27 \text{ mm/s} \) and welding temperature = 425 \( ^\circ\text{C} \) at 5 mm welding bead, b of 10 mm

Fig. 8 3-D temperature field distribution at constant welding speed \( V = 27 \text{ mm/s} \), (a) Steady-state thermal with (b) directional heat flux (c) total heat flux for varying average temperature.
5. Conclusions

The parameters of the method of robotics arc welding such as welding temperature, welding rate, and welding current and their effects on molten pond and bead geometry temperature profile, shape, and size were investigated. With a robotic welding value experimental with good agreement, the numerical results simulated were validated. The following conclusions can be taken from this inquiry:

- High temperatures increase at constant welding speed with an increase of the average power.
- At a welding speed of 27 mm/s with a typical welding at 110A and the minimum welding temperatures at 320°C at the welding speed at 35 mm/s and average power 120A the maximum welding temperature is measured.
- As we step off the weld line, the peak temperature decreases.
- At very high thermal input, the geometry of the weld beads becomes almost H.
- The top temperature of all four thermocouples of the K type was determined experimentally.

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