Thermal Analysis of Laser Welding of 304L Austenitic Stainless Steel

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Abstract

Austenitic stainless steel 304L high temperature applications steel used for different power plants, boilers, oil and gas industries etc. This paper investigates the FEM based thermal analysis of Nd-YAG Laser welding for 1 mm thick 304L stainless steel. FEM based thermo-elastic-plastic model is developed for thermal analysis of Laser welding using SYSWELD. Two different Gaussian distribution heat source models are used for heat source distribution. Initially heat source fitting of bead-on-plates was carried using two different models conical and combined Goldak double ellipsoidal plus conical heat source models then transient analysis of square butt joint was carried out using same models.

Keywords. 304L, SYSWELD, Laser welding, Thermal analysis.

1. INTRODUCTION

Laser beam welding using laser as the energy source is used to weld a variety of materials and composites available today. Laser beam welding can be precisely controlled in intensity and position for joining of metals. The laser beam focus to a small spot size to perform welding. Based on the power intensity and the resulting weld bead profile the laser welding can be classified as conduction mode and deep welding. The advantage of laser compared to Electron Beam (EB) welding process is that the laser can be welded in atmospheric condition whereas the latter needs a complicated vacuum environment.

M. Zubairuddin studied the FEM based analysis of Grade 91 steel using SYSWELD. Author studied the Heat Source Fitting (HSF) analysis on different bead-on-plate, further thermo-mechanical analysis of predicted results validated with measured values of residual stresses and distortion [1-5]. J. Chakkan studied the thermal plus mechanical analysis of 304L and 316L laser welding. Author compared the FEM based calculated residual stresses and distortion with experimental measured values [5-6]. Goldak et al discussed double ellipsoidal model for GTA welding [7]. Various authors discussed thermo-mechanical analysis of Mod 9Cr-1Mo steel, Al and austenitic stainless steel for different welding processes like GTA, EB and Laser welding analysis [8-15].

In this paper, stainless steel AISI 304 is selected for laser welding as this material has wide application. FEM analysis was carried out using SYSWELD. In this analysis two different heat source models were selected later predicted models were compare with experimental measured width. In second stage, FEM based transient analysis of square butt joint 304L steel plate was carried out.

2. EXPERIMENTAL WORK

The material selected for this experiment is AISI 304L thickness 1 mm. Initially bead on plate experiment was carried out using given below parameters later dimension of each 304L Stainless steel is 150 x 100 x 1 mm is welded using butt joint. The power parameters of Laser Welding, TruPulse 556 is as been given in Table. 1. Experimental setup of Laser welding is shown in Figure 1.

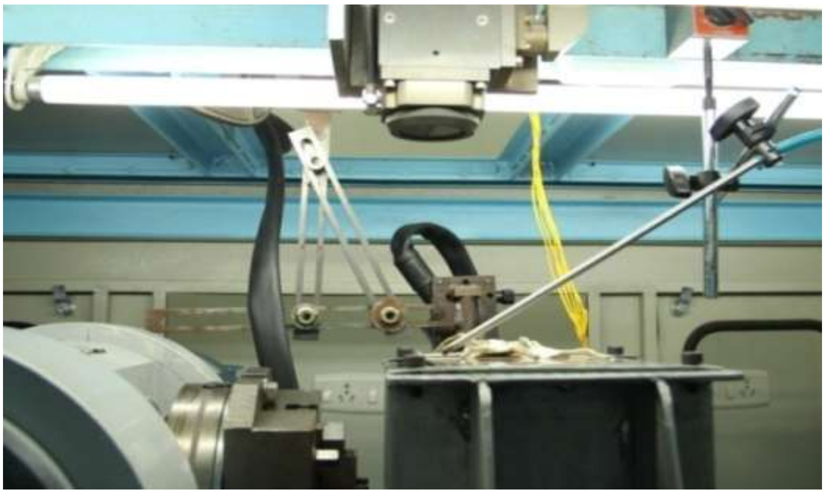


Figure 1. CNC based Laser welding machine

3. WELDING HEAT SOURCE MODEL

Selection of heat source model is a first criterion for finite element analysis and must be calculated to explain the practical physical phenomena in laser welding. Based on literature, it can be seen that defining a reliable and simple model for welding processes is very important step. Heat transfer is the main phenomena happening while welding. Modelling of heat source model for laser welding is a very challenging in finite element method. In this work, two different models have been selected as beam source model by investigating the bead cross section of bead on plate welding.

Table 1. Laser Welding Parameters

Parameters	Value
Peak Power	1.3k W
Average Power	240 W
Velocity	3 mm/s
Pulse Energy	15.1 J
Pulse Width	11 ms
Shielding Gas (Ar)	10l pm
Frequency	14 Hz

3.1. 3D Conical model

3D Conical model as shown in Figure 2 is reliable heat source model used for high depth of penetration of laser welding modelling. Heat power density is higher at the top surface of plate and lower at the bottom surface. The power density at any plane is expressed in Eq. 1.

$$Q_r = Q_0 \exp\left(\frac{-3r^2}{r_0^2}\right) \tag{1}$$

Where r and r_0 is given by

$$r = \sqrt{x^2 + y^2}$$

$$r_0 = r_e - \frac{(r_e - r_i)(z_e - z)}{(z_e - z_i)}$$

Where Q_r is heat source intensity, Q_0 is the maximum intensity, r_e and r_i are surface radius in planes $z=z_e$ and $z=z_i$ respectively.

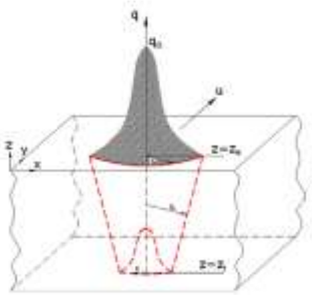


Figure 2. Conical heat source model

3.2. Combined Goldak's double ellipsoidal plus conical heat source model

Laser welded bead cross section shows an elliptical upper portion like a nail head. In order to account for that nail head shape a Goldak double ellipsoidal heat source is attached on top of 3D conical heat source. The power for each heat source is then distributed according to HSF. Figure 3 shows the combined double ellipsoidal plus conical model.

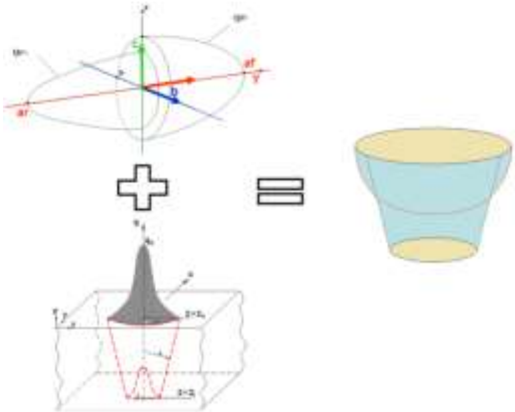


Figure. 3 Combined Goldak's double ellipsoidal plus conical model

4. GEOMETRICAL MODEL

For butt weld experiment, two plates dimensions 150 mm x 100 mm x 1 mm are used. Throughout meshing 8-node hexahedron elements of varying size has been used. Total number of nodes and element are 92123 and 113512. FZ and HAZ will be having a very high thermal gradient; hence, mesh in this zone is very fine. Element size in HAZ and FZ are 0.5 mm x 0.5 mm x 0.5 mm. Since temperature gradient is low in next to HAZ hence mesh is coarser. Visual Mesh, a sub package in SYSWELD has been used for creating the plate model and meshing. The meshed model used for simulation is shown in Figure 4.

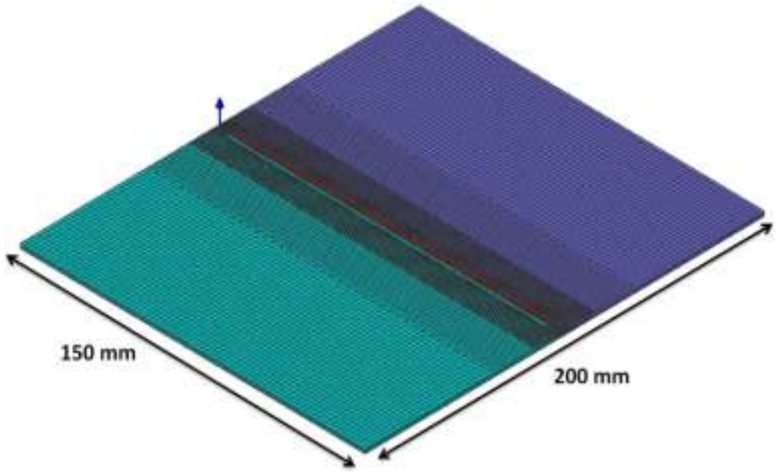


Figure 4. Meshing of butt joint plate

5. THERMAL ANALYSIS OF LASER WELDING

Heat flux distribution decides the accuracy of FEM analysis, based on right choice of model. HSF tool is used for predicting fusion zone. In SYSWELD software, HSF tool is used to calculate the parameters, based on number of trial close to predicted FZ nearby arc energy input to give the values of heat power density. Experimental based weld profile of bead on plate at 15.1 Joule heat input power is shown in Figure 5. FZ and HAZ of weld profile is measured using microscope.

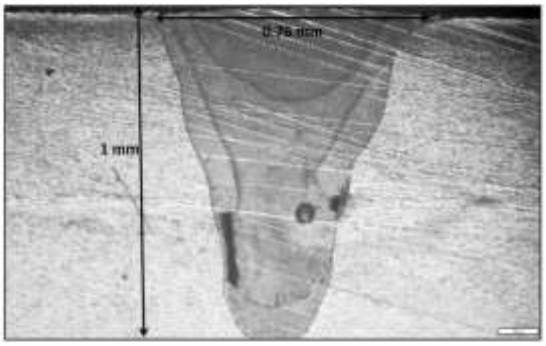
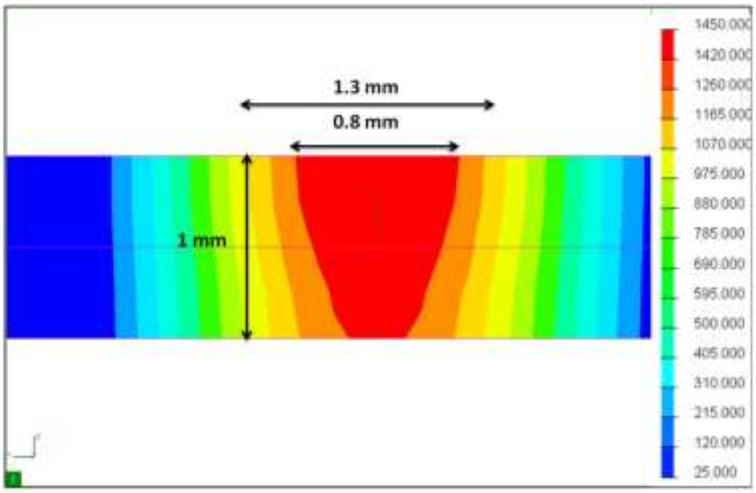
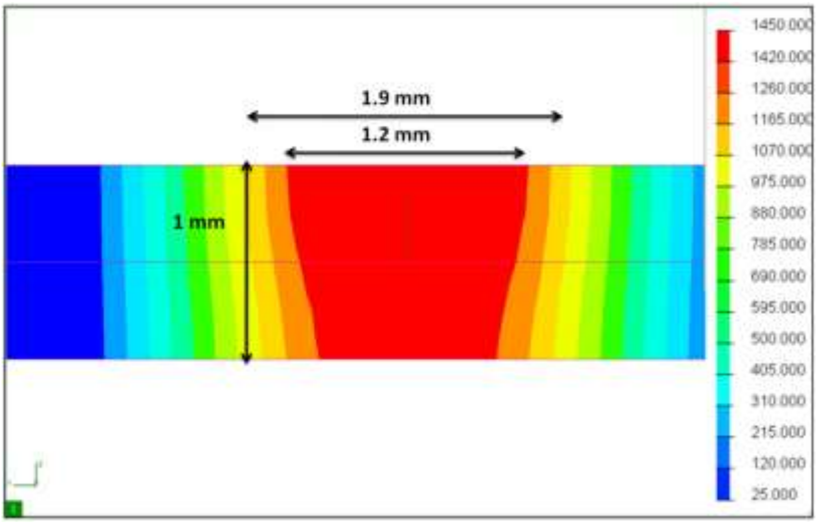


Figure 5. Weld profile of 1 mm thick 304L plate

The HSF analysis of considering conical and combined double ellipsoidal plus conical model heat source model keeping same heat input as bead on plate is shown in Figure 6 (a-b). Predicted FZ width size using conical model shown in Figure 6 (a) is 0.8 mm and depth of penetration is 1 mm, where experimentally measured value is 0.75 mm with 1 mm depth. In case of combined double ellipsoidal plus conical model predicted FZ width is 1.2 mm, where as experimental FZ width is 0.75. HAZ width in case of conical model is 1.3 mm while in case of combined double ellipsoidal plus conical model is 1.9 mm, where as experimental measured using optical microscope is 1.25 mm.



(a) Conical Model

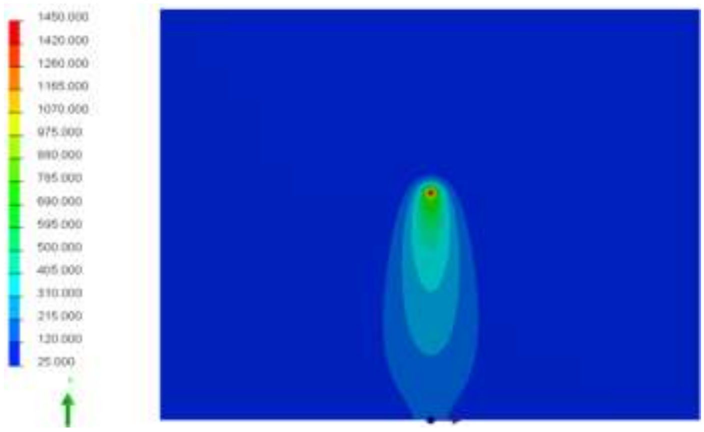


(b) Conical and Goldak's combined Model

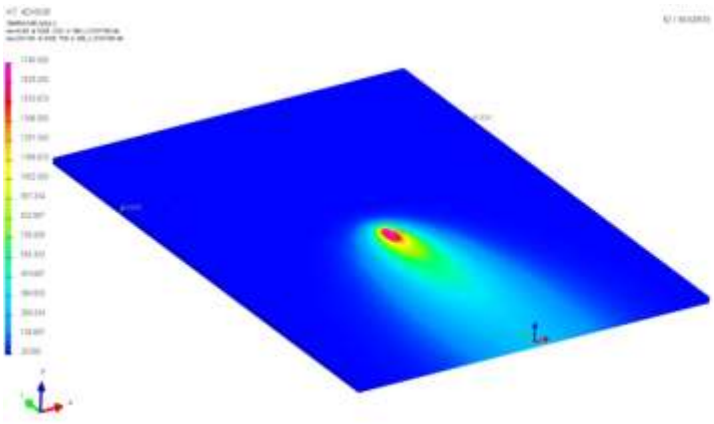
Figure 6. Heat Source fitting Analysis

Based on above results, it is observed that conical model is more accurate as compare to combined double ellipsoidal plus conical model, conical model shows 0.04 mm only, where as combined model shows 0.44 mm error. Transient analysis of butt joint plate considering same heat input parameters is carried put in welding advisor. Figure 7 (a-b) shows the thermal analysis of butt joint at the mid of weld plate. Peak temperature reached during welding analysis shows1450ºC in case of conical model as shown in Figure 7 (a), whereas in case of combined double ellipsoidal plus conical model as shown in Figure 7 (b) temperature is reached 1740ºC, above melting point of 304L (1410ºC value).

This high temperature is the main attribute in the formation of the FZ and converting solid to liquid and immediate vicinity of FZ (i.e. weld zone) is defined as HAZ.



(a) Conical Model



(b) Double ellipsoidal plus conical model

Figure 7. Thermal Analysis of laser welding of 304L butt Joint

6. CONCLUSION

In this study, initially work bead on plate welding is carried out in the next stage same heat input parameters was used for transient analysis.

- Comparison of predicted FZ and HAZ showed that conical model predicts more accurate as compare to combined double ellipsoidal plus conical models.
- FEM based steady state analysis of HAZ and FZ of bead on plate of 304L carried out using two different heat source models, results shows 0.8 and 1.3 mm, which is nearer to measured value 0.76 mm.
- Second stage of FEM analysis shows maximum temperature reached in case of conical model is 1450ºC as compare to combined model double ellipsoidal plus conical model is 1740ºC.

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Biographies

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