Finite Element Analysis of laser welding of 304L butt joint

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Abstract

Grade 304L is an Austenitic stainless steel, which is popular for different high temperature application like Nuclear power plants, thermal power plants and oil & Gas industries etc. In this paper, FEM based investigation was carried out for 1.2 mm thick 304L stainless steel welded using Laser welding process. Thermal cycle was measured at 10 mm distance from welding centerline using K type thermocouple compared with predicted values. FEM based thermal analysis was carried out using SYSWELD. Two different heat source models were selected for laser heat source distribution modeling, conical and double ellipsoidal model are selected.

Keywords: 304L, Thermal analysis, double ellipsoidal model, SYSWELD

1. Introduction

Laser beam welding is one of the preferable processes for welding stainless steel which is used for different power plants. It is high energy process allows deeper penetrations. Predicting distortion and stresses in weld plate at the early stage (design stage) helps reduction in cost of manufacturing. Number of researchers studied the laser welding analysis for different metals. M. Zubairuddin studied the FEM based analysis of Grade 91 steel using SYSWELD. Author has studied the Grade 91 steel welding for different welding process like MMA, GTA and Laser [1-5]. Thermal and mechanical analysis of laser welding has been studied and later it is verified with experimental recorded values. [4-5].

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 [8-13].

In this paper, stainless steel AISI 304L is selected for laser welding. In this analysis two different heat source models were selected later predicted models were compare with measured width. Validation of predicted thermal cycle at 10 mm distance from weld line is carried out.
2. Experimental and Simulation Work

The material selected for this experiment is AISI 304L with 200 x 160 x 1.2 mm dimensions. The welding parameters of Laser Welding, TruPulse 556 is as been given in Table. 1. Laser welding of square butt joint in clamped position is shown in Fig. 1.

<table>
<thead>
<tr>
<th>Table 1. Heat input values for Laser bead on plate welding.</th>
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<td>Welding Speed (mm/sec)</td>
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2.1 Heat Source Models

Modeling of heat source for laser welding is a very challenging in finite element method. In this work, two different heat source models have been selected as beam source model by investigating the bead cross section. Initially a conical model was used for heat source modeling and later for the same heat input parameters double ellipsoidal model was used.

3D Conical model as shown in Fig. 2, is reliable heat source model used for high depth of penetration of laser welding modelling. The power density is expressed in Eq. 1.

\[ Q_r = Q_0 \exp\left(-\frac{3r^2}{r_0^2}\right) \]  

(1)

Where \( r \) and \( r_0 \) is given by

\[ r = \sqrt{x^2 + y^2} \]
\[ r_0 = r_e - \frac{(r_e - r_i)(z_e - z)}{(z_e - z_i)} \]

**Fig. 2.** Conical heat source model

Combined Goldak’s model is used as a second heat source model. Fig. 3 shows the double ellipsoidal model.

**Fig. 3.** Goldak’s double ellipsoidal model

### 2.3 Geometrical model

For butt weld experiment, two plate dimensions 50 mm x 160 mm x 1.2 mm are used. Weld plate has been meshed with 8-node hexahedron elements. Combined number of nodes and element are 86123 and 793521. HAZ and FZ subjected to high heat transfer rate, hence it meshed with fine elements. The meshed model used for simulation is shown in Fig. 4.
3. Thermal Analysis

Weld profile of butt joint plate has been taken out by cutting across center of butt joint and dimensions of weld profile measured using microscope. The depth of penetration of weld profile is 1.2 mm and FZ is 0.88 mm and HAZ width is 1.15 mm. Double ellipsoidal model based heat weld profile using Heat Source Fitting (HSF) is shown in Fig. 5 (a) and conical based model predicted HSF of weld profile is shown in Fig. 5 (b). Both the models show full depth of penetration as per experimental measured weld specimen. FZ in case of double ellipsoidal model is 1.4 mm, while in case of conical model it is 0.91 mm only, which is nearer to experimental value.
Thermal results obtained during simulation for each heat source models are given below. Thermal simulation results provide a complete thermal history results at all the nodes of the work piece. Thermal transient analysis of square butt joint considering conical heat source is shown in Fig. 6. It shows 3D temperature field distribution on the plate during welding for the time 48 seconds.

Temperature distribution during welding of square butt joint is predicted using conical and double ellipsoidal heat source models. Temperature cycle at 10 mm distance from weld line is calculated using FEM and further compared with recorded values. Comparison shows a good accordance in temperature cycles. Peak temperature reached during welding is 512°C. Predicted temperature peak value using conical model is 532°C and predicted peak value using double ellipsoidal model is 550°C. Small variation in cooling rate between predicted and experimental temperature cycle is observed, it is due to inaccuracy in heat flux distribution. Laser welding being a high energy density process, material heated up at faster rate near the weld line. From thermal cycle, it is very clear that the heating and cooling rate is so high that it cooled rapidly within 300 seconds which indicates the laser welding characteristics.
5 Conclusion

In this work, two different heat source models were used for finite element analysis of laser welding of 1.2 mm thick 304L steel. Comparison between predicted and experimental values showed following conclusion.

1- Predicted weld profile using both double ellipsoidal model and conical model showed a good accuracy in terms of depth of penetration.

2- Heat source fitting using conical Model showed more accuracy as compare to double ellipsoidal model in terms of FZ value.

3- Predicted value of peak temperature in case of conical model is 532°C is nearer to experimental peak value 512°C.

4- Selection of conical model will be more accurate as compare to double ellipsoidal model.

References


