Journal of Materials Processing Technology 219 (2015) 48–59

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Simulation of laser butt welding of AISI 316L stainless steel sheet using various heat sources and experimental validation

Jazeel Rahman Chukkan[a], M. Vasudevan[b,*], S. Muthukumaran[a], R. Ravi Kumar[c], N. Chandrasekhar[b]

[a] Department of Metallurgical and Materials Engineering, National Institute of Technology Tiruchirappalli, 620015, India
[b] Advanced Welding Processes and Modelling Section, Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, India
[c] Innovative Design, Engineering and Synthesis Section, Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, India

ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form 2 December 2014
Accepted 10 December 2014
Available online 18 December 2014

Keywords:
FEM
Laser welding
316L stainless steel
Thermal cycle
Residual stresses
Distortion

ABSTRACT

The thermo-elasto-plastic analysis of type 316L stainless steel sheets during pulsed Nd-YAG Laser-beam welding was carried out using three different heat sources employing SYSWELD. The three heat sources employed were 3D conical, 3D conical with double ellipsoidal and 3D conical with cylindrical shell. The simulated thermal cycles, residual stresses and distortion were validated by experiments. The simulated thermal cycles were validated by thermal cycles measured using thermocouples at pre-defined positions. The simulated residual stress profiles were validated by residual stress profiles measured using ultrasonic technique (UT). The simulated distortion values were validated by distortion measured using vertical height gauge. There was good agreement between the model predictions and experimental measurements. It was found that the model using 3D conical with cylindrical shell heat source predicted the thermal cycles, residual stresses and distortion more accurately compared to that of the other heat sources.

1. Introduction

Simulation of the welding process using numerical methods can be employed to predict the joint geometry, microstructure and other weld attributes and thus can partially replace the expensive, time consuming experimental based trial and error method in the development of new welding procedures. Welding simulation is considered as one of the major thrust areas that will shape the future of the welding technology in the coming years. Computational weld mechanics consists of computer simulation and virtual welding techniques including an in depth analysis of heat flow during welding, microstructure evolution and distortion analysis and fracture of welded structures. In the recent years, there has been exponential growth in the high end computer capabilities which has favoured the development of computational weld mechanics. Choosing a right heat source is very important in welding simulation and it must be identified correctly to describe the physical phenomena occurring during the welding process. It is well established that the use of good welding heat source models is important in order to predict accurately temperature distribution and thermal cycles during welding. The temperature distribution in a weld joint provides the necessary data which can be used to determine the final residual stresses and distortion in the job. It also forms the basis of the metallurgical analysis and phase change analysis.

Rosenthal (1946) is one of the earliest to publish on analytic heat source models in welding and a point source moving on an infinite material was considered by him. Though surface melt runs relating to conduction welding were able to be simulated, the region where the point source is incident was inaccurate. Later on Rosenthal's solutions were approximated to predict the proportion of power needed to cause melting as a function of the incident power by Hook and Gick (1973). They represented the beam as a moving line source with full penetration under all welding conditions and estimated the weld dimensions as a function of laser power and beam velocity relative to the workpiece. A mathematical model for the simulation of weld pool during deep penetration laser beam welding based on a numerical solution has been reported by Dowden et al. (1983). He has developed a three dimensional simulation model in order to investigate the influence of the fluid dynamics in the fusion zone on the local temperature distribution. Goldak et al. (1984) proposed a nonaxisymmetric three-dimensional heat source model called double ellipsoidal model suited for simulating both shallow welds made by arc welding processes and deep penetration

* Corresponding author. Tel.: +91 44 27480500x21216; fax: +91 44 27480075.
E-mail address: dev@igcar.gov.in (M. Vasudevan).

http://dx.doi.org/10.1016/j.jmatprotec.2014.12.008

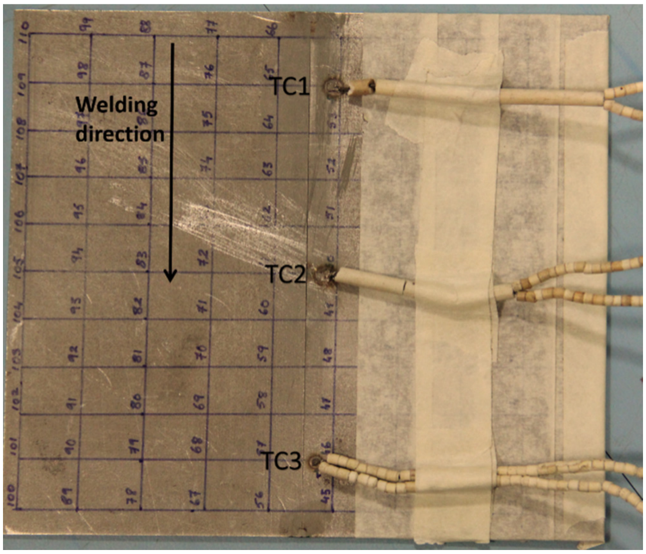

Fig. 1. Thermocouple positions and welding direction.

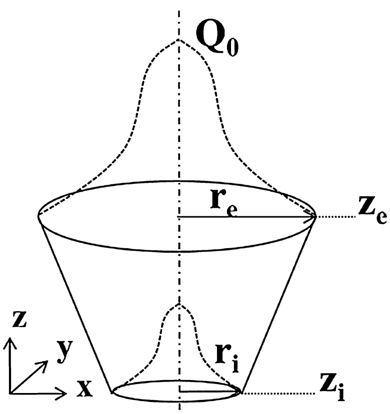

Fig. 2. 3D conical heat source.

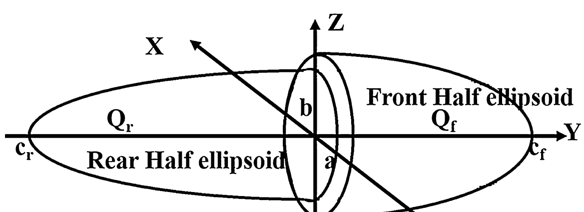

Fig. 3. Double ellipsoidal heat source.

welds made by high power density processes. Steen et al. (1988) combined both the point and line heat source to model a more effective keyhole weld. Frewin and Scott (1991) have developed a 3D heat source model for pulsed laser welding of AISI 1006 steel plates. The model was employed to calculate transient temperature profiles and the weld bead dimensions. They found that the temperature profiles and the weld dimensions are strong functions of absorptivity and energy distribution of laser beam. A mathematical model for describing the temperature field on a thin moving sheet heated by laser beam was developed by Brockmann et al. (2003). A three dimensional finite element model has been developed using SYSWELD for simulating laser welding of AH 36 ship building steel for predicting distortion by Tsirkas et al. (2003). They reported good agreement between the simulated and measured distortion values.

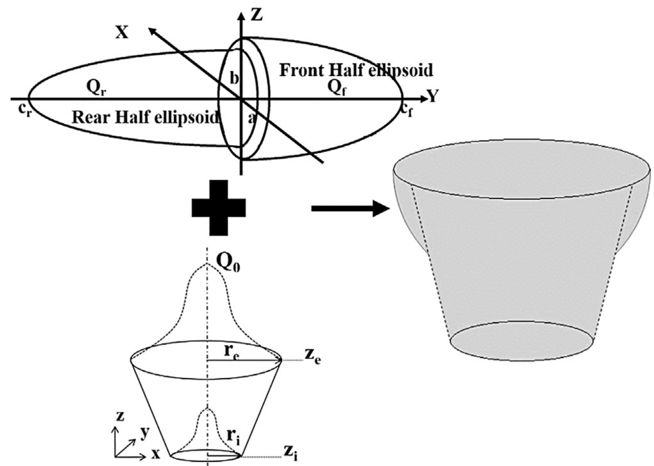

Fig. 4. Combination of double ellipsoidal with 3D conical heat source.

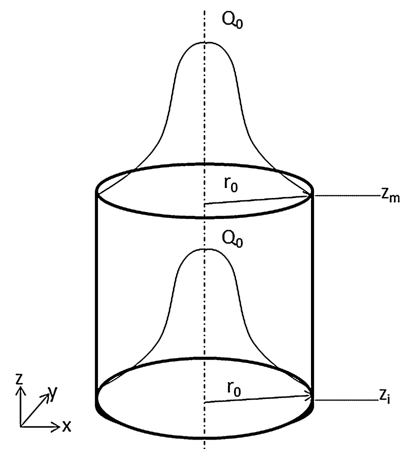

Fig. 5. Cylindrical heat source model.

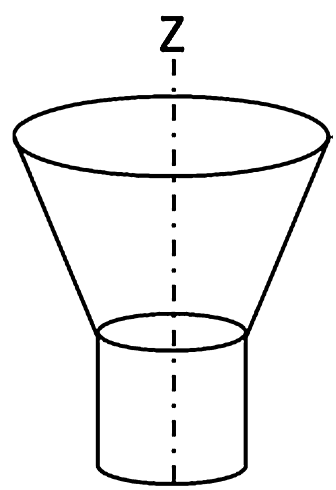

Fig. 6. Combination of 3D conical and cylindrical shell heat source model.

Jin and Li (2004) proposed a heat transfer model for full penetration laser welding with a cylindrical surface heat source. Spina et al. (2007) predicted the final distortion during laser welding of AA5083 thin sheets using Gaussian heat flux on top surface with a conical distribution along the depth direction.

Balasubramanian and Shanmugam (2008) employed SYSWELD for simulating thermal cycles, weld pool dimensions, depth of