Comparison of Heat Source Models in FEM-based Analysis of Electron Beam Melting of Steel Plate

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1. INTRODUCTION & OBJECTIVE

Heat transfer during electron beam melting and solidification takes place in the form of conduction, convection and radiation. Temperature distribution and cooling rate are the most commonly used parameters for studying heat transfer. The cooling rate may be defined as the rate of heat dissipation in a given amount of time. The microstructure, stress-strain values and different mechanical properties are observed to strongly depend on the thermal cycle and cooling rate. As a result, prior information of such crucial data becomes important from the point of obtaining defect-free melt with the desired properties. Moreover, precise prediction of thermal cycle and cooling rate minimizes the need for actual experiments, thereby reduces the effort, time and expenses. In the present study, ABAQUS Finite element model (FEM) package has been used for the simulations. The cooling rate between 800^0C to 500^0C is considered for analysis. A preliminary study was conducted by the authors [1], in which only conical model of heat source had been considered in the FEM. However, in the present paper, two more models of heat source, such as double ellipsoidal and cylindrical have been considered, and their performances have been compared among themselves. Moreover, their results have been further validated through real experiments using K-type thermocouples. The thermal profile and cooling rate, thus predicted through different heat source models in the FEM are observed to closely agree with the experimental results. FEM has been used widely in different simulations for the predictions of temperature distribution, cooling rate, geometries and many more [2, 3]. On the other hand, temperature profiles have been measured widely using thermocouples [4, 5]. The temperature profile prediction through FEM, and validation through thermocouple readings are not new. However, the nobility of this work lies with the comparison of thermal cycles predicted using three different heat source models in FEM and validation through actual experiments. Such comparisons are limited in the literature. Moreover, these accurate results prediction ensures a reliable substitute of huge experimentations.

2. DETAILS OF EXPERIMENTS

In the present study, electron beam melting is carried out in an electron beam welding facility, developed by Bhabha Atomic Research Centre (BARC), Mumbai, at IIT Kharagpur , India. A stationary beam with power of 2.4kW is allowed to fall on 10mm thick plate having length and breadth of 34mm and 30mm, respectively for a duration of 10 seconds. The thermocouples are press-fitted at a depth of 5mm from the surface, at a distance of 4.5mm, 6mm and 7mm from the point of beam incidence, for temperature measurement using a data acquisition system (DAS) panel. The DAS panel, used in the present study, is designed by Symbiotic automation systems (P) LTD, Bangalore, India, and manufactured by Vacuum Technologies (P) LTD, Bangalore, India.

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3. RESULTS & DISCUSSION

The time-temperature profile, predicted through different heat source models have been compared with the experimentally measured results. It is observed that during heating cycle, the temperature rises rapidly until the beam is turned off after 10 seconds. After that, a sharp drop in temperature is noticed till a steady state condition is obtained. During the steady state condition, the temperature reduces slowly until ambient temperature is reached. At a distance of 4.5mm, 6mm and 7.7mm from the point of beam incidence, the temperature profiles, predicted through different heat source models have matched accurately with the experimental readings. The average absolute percent deviation values of the conical, double-ellipsoidal and cylindrical models are found to be equal to 3.52%, 3.11% and 9.13%, respectively. However, at a distance of 4.5mm from the beam incidence only, the temperature is observed to exceed 800^0C, hence it is considered for cooling rate estimation in the present study, as shown in Fig. 1. The different model-predicted cooling rates are found to be very close to that of the measured one. All the FEM models are observed to overestimate the cooling rate. The conical, double-ellipsoidal and cylindrical models have predicted the cooling rate with percent deviation of -18.29%, -23.73% and -15.48%, respectively.

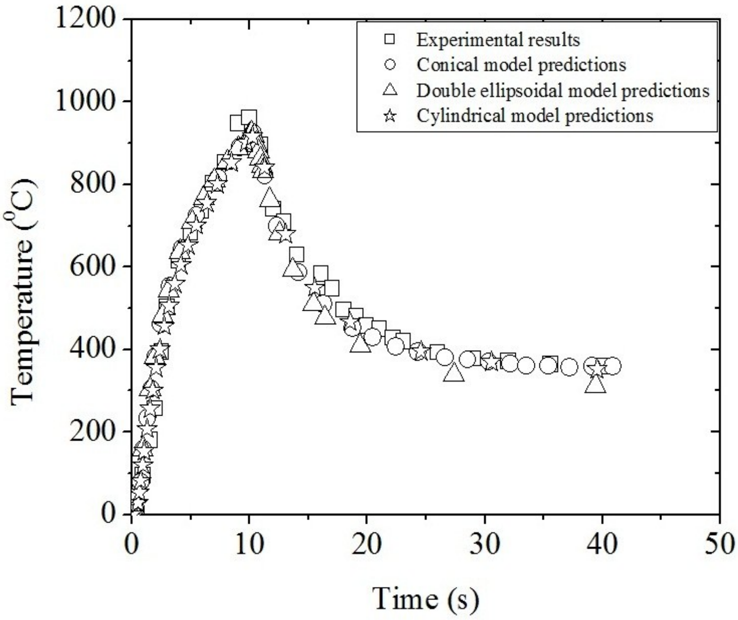

Fig. 1. Comparison of the results of temperature vs. time at 4.5 mm distance from melt zone.

REFERENCES

[1] D. Das, D. K. Pratihar, and G. G. . Roy, "Electron Beam Melting of Steel Plates: Temperature Measurement Using Thermocouples and Prediction Through Finite Element Analysis," in *CAD/CAM, Robotics and Factories of the Future*, 2016, pp. 579–588.

[2] A. De, C. A. Walsh, S. K. Maiti, and H. K. D. H. Bhadeshia, "Prediction of cooling rate and microstructure in laser spot welds," *Sci. Technol. Weld. Join.*, vol. 8, no. 6, pp. 391–399, 2003.

[3] M. Zubairuddin, S. K. Albert, M. Vasudevan, S. Mahadevan, V. Chaudhari, and V. K. Suri, "Numerical simulation of multi-pass GTA welding of grade 91 steel," *J. Manuf. Process.*, vol. 27, pp. 87–97, 2017.

[4] K. Poorhaydari, B. M. Patchett, and D. G. Ivey, "Estimation of Cooling Rate in the Welding of Plates with Intermediate Thickness," *Weld. J.*, vol. 84, no. 10, pp. 149–155, 2005.

[5] M. J. Attarha and I. Sattari-Far, "Study on welding temperature distribution in thin welded plates through experimental measurements and finite element simulation," *J. Mater. Process. Technol.*, vol. 211, no. 4, pp. 688–694, 2011.