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Numerical estimation of the shape of weld and heat affected zone in laser-arc hybrid welded joints

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Abstract

Numerical modeling of thermal phenomena with the motion of fusion zone in the welding pool taken into account is performed in this study for hybrid welding process using Yb:YAG laser with electric arc in GMAW method. New hybrid heat source model is developed on the basis of classical Goldak model for the electric arc and interpolation model for the laser beam with the experimental data of Yb:YAG laser beam distribution taken into account. Temperature field and melted material velocity field are calculated on the basis of numerical solution into mass, momentum and energy conservation equations in finite volume method with Chorin's projection method. Computer simulations of temperature field and melted material velocity field are performed in the welding pool for different distances between heat sources. The comparison of numerically estimated geometry of characteristic zones of joints with macroscopic pictures of cross sections of welds is made in order to evaluate the suitability of developed numerical model in industrial applications.

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Keywords: hybrid welding; numerical modelling; heat affected zone; welding pool;

1. Introduction

The combination of the laser beam and electric arc allows for the deep penetration of material and a good gap filling, which contributes to the improvement of weld quality and reduction of disadvantages of each method used separately [1]. However, the hybrid welding method involves a large number of technological parameters that should be correctly set to achieve stable process and best possible weld quality [2]. Understanding the thermal

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phenomena accompanying laser – arc hybrid welding process is required for appropriate use and optimization of this welding technique because heat transfer and convective motion of liquid material in the welding pool determine the size and geometry of the weld and heat affected zone (HAZ). Numerical analysis of thermal phenomena, including heat transfer and motion of liquid material in the welding pool, can be used as a cheaper alternative to experimental studies, allowing appropriate selection of process parameters used to obtain a desired geometry of the joint [3-11].

This paper presents a three-dimensional model of thermal phenomena in the laser - arc hybrid welding process. On the basis of elaborated mathematical and numerical models, computer solver was developed for simulation of hybrid welding process. Computer simulations are performed for different distances of heat sources acting in the tandem. A comparison is made between numerically predicted shapes of the weld and HAZ and macroscopic pictures of the cross section of real welded joints in order to assess the suitability of developed models in predicting the quality of hybrid welded joints.

Nomenclature

$\mathbf{v}$	velocity (m/s)	K	porous medium permeability (m^2)
T_s	solidus temperature (K)	$\tilde{Q}$	volumetric heat source (W/m^3)
C_{ef}	effective heat capacity (J/m^{3}K)	Q_L	laser beam power (W)
a, b, c_1, c_2	arc heat source geometry coefficients	z	actual material penetration depth for laser beam heat source (m)
f_1, f_2	arc power distribution coefficients	s	max. material penetration depth for laser beam heat source (m)
Q_A	electric arc power (W)	ρ	density (kg/m^3)
$\mathbf{g}$	acceleration of gravity (m/s^2)	β_T	expansion coefficient (1/K)
η	efficiency of the heat source	μ	dynamic viscosity (kg/ms)
T_0	ambient temperature (K)	λ	thermal conductivity (W/mK)
p	pressure (Pa)	T	temperature (K)
t	time (s)	∇	differential operator nabla

2. Mathematical model

2.1. Governing equations

Schematic sketch of considered system is illustrated in Fig. 1. The workpiece is melted by electric arc and laser beam acting in tandem. Liquid material flow is mostly driven by the buoyancy in the melted zone. In the mushy zone, liquid metal motion is assumed as a flow through porous medium between solidus and liquidus temperatures. Moreover, phase transformations due to material state changes are taken into consideration in the mushy zone (solid-liquid transformation) and in temperatures exceeding the boiling point of steel (liquid-gas transformation).

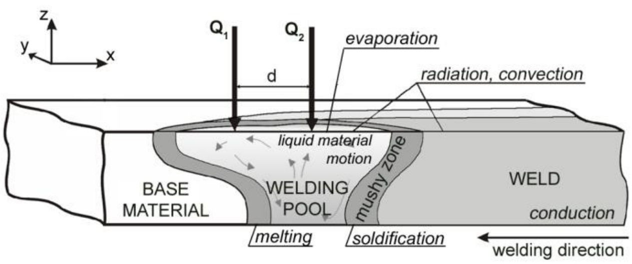

Fig. 1. Schematic sketch of laser-arc hybrid welding simulation.