NUMERICAL ESTIMATION OF THE INFLUENCE OF HEAT SOURCES RELATIVE ARRANGEMENT IN LASER-ARC HYBRID WELDING PROCESS ON THE FORMATION OF THE WELDING POOL

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Abstract

This paper concerns the mathematical and numerical modeling of thermal phenomena in the laser-arc hybrid welding process with the motion of liquid steel in the welding pool taken into considerations. Developed models are used in computer simulations of hybrid welding process with assumed different relative arrangement of heat sources in the process. The shape and size of the welding pool is numerically estimated. Numerical predicted hybrid welded joints are compared to macroscopic pictures of cross sections of experimentally obtained welds.

Keywords: Hybrid welding, relative arrangement, heat source, numerical modeling, welding pool

1. INTRODUCTION

The use of hybrid welding technique, involving a laser beam and electric arc, reduces a number of drawbacks of both methods used separately. The proper use and optimization of hybrid welding requires the knowledge about complex thermal phenomena accompanying this process and a number of technological parameters that need to be correctly set to ensure the process stability and proper quality of the joint - see **Figure 1** [1].

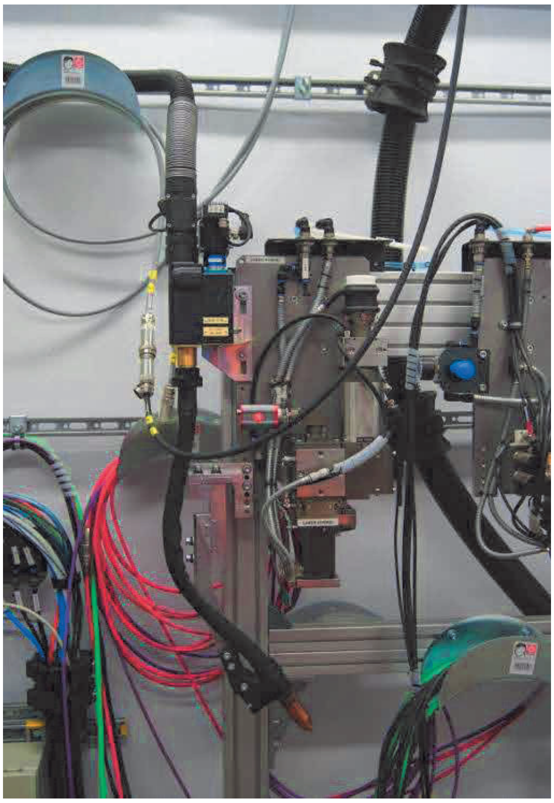

Figure 1 Yb:YAG + MIG welding head at Welding Institute in Gliwice

In addition to the parameters associated with separate arc welding and laser beam welding methods there are new technological parameters that have to be taken into account in the development of this welding process. The most important role plays here the relative arrangement of heat sources (a system with leading laser beam in the tandem or system with leading electric arc in the tandem) and the relative distance of heat sources that directly influence the shape and size of the welding pool [2, 3].

Numerical analysis of thermal phenomena, including heat transfer and motion of liquid material in the welding pool allows the proper selection of process parameters used to obtain a desired geometry of the joint. The computational complexity of this issue forces researches to use simplified mathematical and numerical models describing chosen phenomena [4, 5]. One of usually ignored phenomena in the numerical analysis of welding processes is the motion of liquid material in the welding pool. A very important issue in the modelling of laser beam welding is an appropriate selection of heat source power distribution. However, the laser beam intensity distribution models assumed in numerical analysis significantly differ from real Yb:YAG laser profile, obtained through experimental research [6].

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 is developed for simulation of hybrid welding process. A new interpolated model of hybrid heat source is proposed in this study taking into account the real measurement of Yb:YAG laser beam heat source power distribution. Computer simulations are performed for different realative arrangement of heat sources: with leading electric arc as well as the laser beam in the tandent. A comparison is made between numerically predicted shapes of the weld and HAZ and macroscopic pictures of the cross section of real welded joints.

2. NUMERICAL MODELLING

The differential governing equations based on continuum formulation consist of mass, momentum (Navier-Stokes) and energy conservation (heat transfer) equations (Eq. 1-3), expressed as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \tag{1}$$

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v}\mathbf{v}) = -\nabla p + \nabla \cdot (\mu \nabla \mathbf{v}) + \rho \mathbf{g} \beta_T (T - T_S) - \frac{\mu}{K}\mathbf{v} \tag{2}$$

$$\nabla \cdot (\lambda \nabla T) = C_{\mathrm{ef}} \left(\frac{\partial T}{\partial t} + \nabla T \cdot \mathbf{v} \right) - \widetilde{Q} \tag{3}$$

Governing equations are completed by the initial and boundary condition. Eq. (2) is completed by the initial condition $t = 0:\ \mathbf{v} = 0$ and Dirichlet type boundary condition $\mathbf{v}\big|_{T=T_S} = 0$ at the boundaries determined by the solidus temperature (melted zone boundary). Marangoni effect is considered [7] at the top surface of welded plate. Energy conservation equation (3) is completed by the initial condition $t = 0:\ T = T_0$ and boundary conditions of Neumann and Newton type taking into account the heat loss due to convection and radiation.

Defined by Goldak [8] 'double ellipsoidal' power distribution of the heat source bellow the welding arc is used in modeling of arc welding heat source (**Figuer 2a**). Kriging interpolation method of predicting the power distribution of laser beam heat source is used in numerical model (**Figure 2b**). Kriging method at the point (*x, y*) is described as a linear combination of observations in basic points (the actual power distribution). The estimate is a function of the weighted average [9]. The measurement of Yb:YAG laser power distribution, used in the interpolation model, is performed at the continuous power 900 W of the laser beam due to the limitations of the resistance of measuring needle and the detector of UFF100 system. Hybrid heat source adapted in this study (**Figure 2c**) is a combination of electric arc and laser beam heat sources acting in tandem.

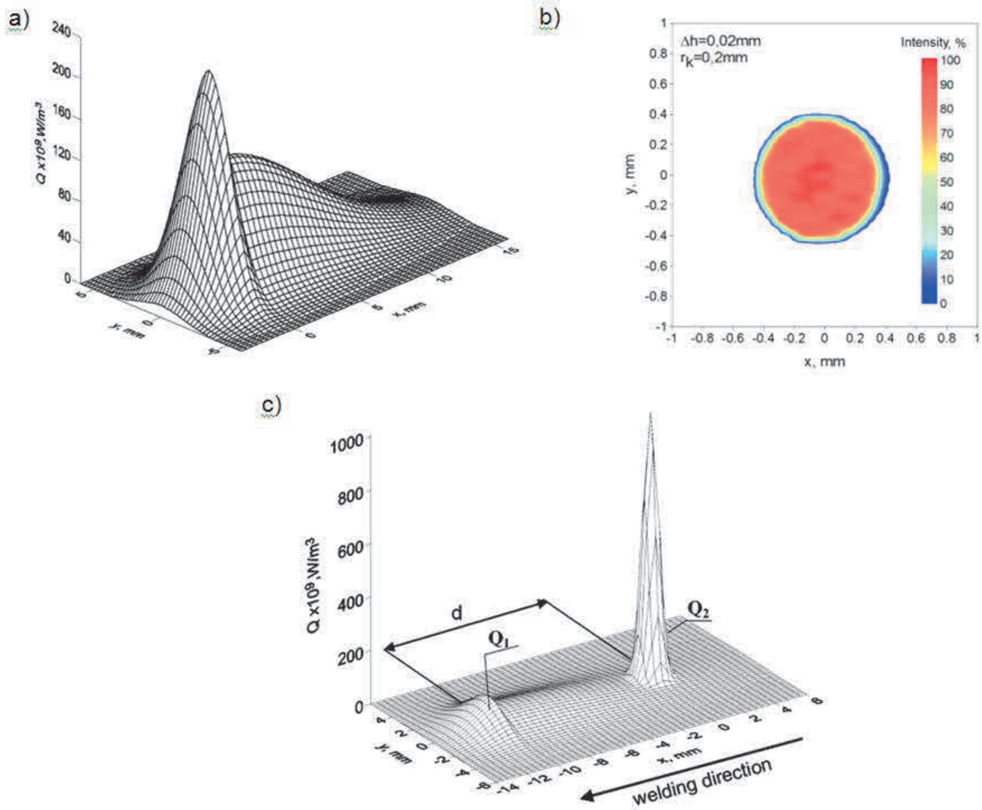

Figure 2 Goldak's heat source shape (a), percentage distribution of laser beam power interpolated by Kriging method (b) and hybrid heat source used in numerical model (c)

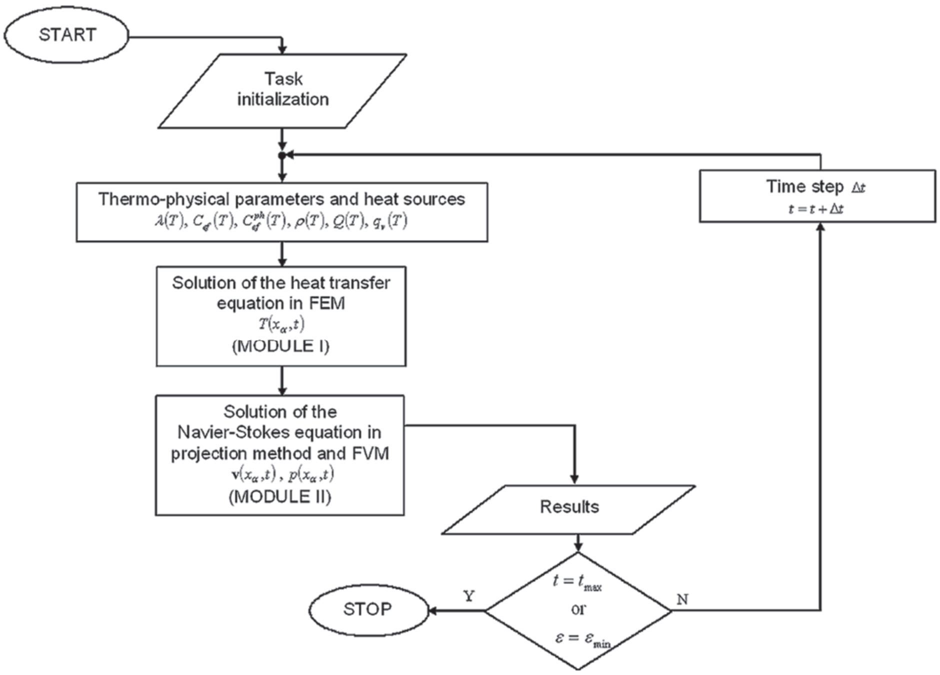

Figure 3 Numerical algorithm

Differential equations describing thermal phenomena in discussed welding processes are numerically solved using projection method with finite volume method (FVM) [10] and finite element method (FEM) [11, 12]. Numerical algorithm is presented in **Figure. 3**.

3. RESULTS

Computer simulations are performed for butt welded thin sheets made of S355 steel with dimensions: L = 150mm in length, a = 30 mm in width and thickness of g = 5 mm. Assumed boundary conditions are presented in **Figure 4**. The heat loss due to convection and radiation is assumed in every boundary of analyzed system (Γ_1). The heat flux due to evaporation as well as heat flux of a laser beam towards heated material (Γ_2) is considered from the face of the weld in the heat source activity zone. In the fusion zone, determined by solidus temperature (T_S) changing in time, Marangoni effect is considered (Γ_3) from the face of the weld and Dirichlet type boundary condition from the root side of the weld (Γ_4) [7].

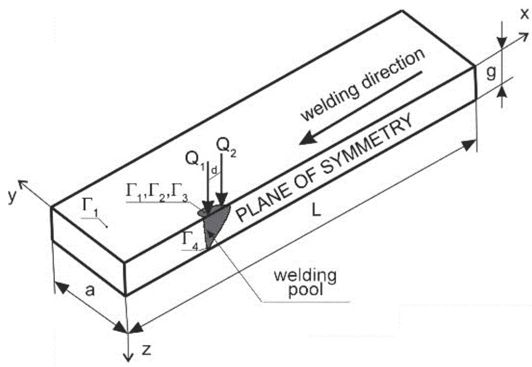

Figure 4 Sketch of analysed system with marked boundary conditions

It is assumed that welding process proceed without a gap. The following process parameters are accepted in computer simulations: laser focus diameter d_L = 0.8 mm, laser beam power Q = 3 kW, arc voltage U = 19 V and current I = 190A. Laser beam focusing is at the top surface of welded sheets (z=0). Welding speed is set to v = 1 m / min. Welded joint is performed for distance between heat sources d = 2 mm. **Figure 5** presents results of the simulation of hybrid welding process with leading electric arc in the tandem whereas **Figure 6** presents results for the system with leading laser beam in the tandem. Temperature distribution (**Figures 5a** and **6a**) and melted material flow velocity vectors in the fusion zone (**Figures 5b** and **6b**) are illustrated in the longitudinal section of the joint for y = 0. **Figures 5c** and **6c** presents the comparison of numerically predicted fusion zone boundary (solid line), determined by solidus isotherm (T_s = 1750 K) and heat affected zone boundary (dashed line), determined by austenitization temperature (T_A = 1000 K) with specific zones presented in the macroscopic pictures of the cross section of real welded joints made in Welding Institute in Gliwice.

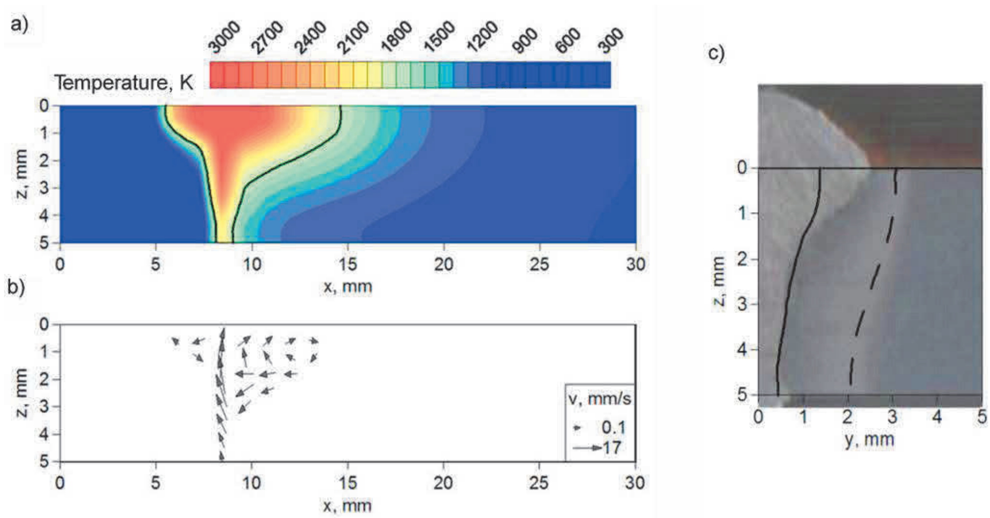

Figure 5 Numerically estimated a) temperature field, b) melted material velocity field in the longitudinal section (y=0) of hybrid welded joint with leading electric arc in the tandem and c) comparison of characteristic zones of the joint with the experiment

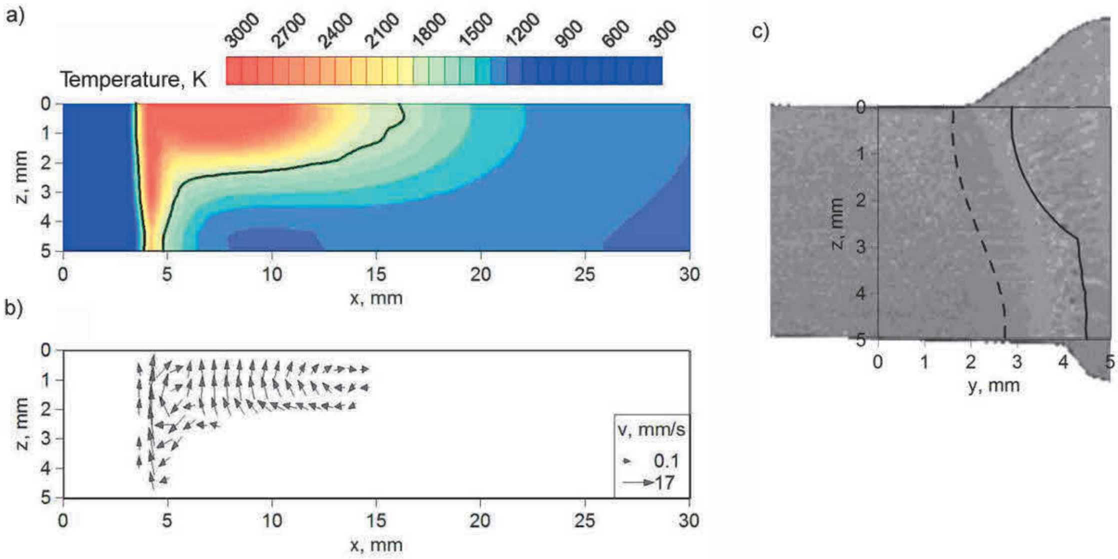

Figure 6 Numerically estimated a) temperature field, b) melted material velocity field in the longitudinal section (y=0) of hybrid welded joint with leading laser beam in the tandem and c) comparison of characteristic zones of the joint with the experiment

4. CONCLUSION

From performed analysis it can be observed that two heat sources in hybrid welding process determine mostly the fusion zone geometry. Laser beam heat source determines the penetration in the material, whereas the top surface of the joint is mainly dependent on the arc heat source.

Different relative arrangement of heat sources cooperating in hybrid welding process has a huge impact on the melting mechanism and the formation of the welding pool. As shown in above figures, the calculated geometry of the weld and heat affected zone agrees well with experimental results.

It can be observed that changing the relative arrangement of heat sources not only change the geometry of the fusion zone but also thermal cycles and corresponding cooling rates in the joint and heat affected zone, therefore further analysis of the influence of relative arrangement on the microstructure and mechanical properties of welded joint is desirable.

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