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Numerical simulation of welding parameters influence on temperature field during GMAW welding.

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Welding is the dominant method for joining materials by indissoluble bond in most industrial applications. The trend of automation and robotisation of welding processes is exponential, so the continued development requires understanding and modeling of welding parameters influence on the distribution of power in the electric arc, heat and mass transfer in the welding area and the geometry and structure of the weld. In this article, the results of temperature field simulations are interpreted for different values of input parameters. The influence of heat input, welding speed, thickness of welded plates, the coefficient of efficiency of electric arc and type of base material on the temperature field i.e. geometry of molten pool and HAZ during welding is shown.

Keywords: welding, simulation, temperature field, GMAW process

1.INTRODUCTION

Simulation modeling and analysis are the processes of creating and experimenting with mathematical models of physical processes adapted for computer use. System in this sense can be understood as a set of interrelated elements which give proper output based on input data. Systems that can be simulated are very different and thus may include simulation modeling of manufacturing systems, transportation systems, services, etc. Modeling of welding process is very complex and difficult considering nonlinearity and complexity of welding processes, and requires knowledge of several areas of science.

Development of simulation models on the macroscopic level is a thermo mechanical problem that involves temperature distributions, displacements, stresses and strains. At the microscopic level there are problems of phase transformation and microstructure of materials. Interaction of essential factors for the development of simulation models in welding is shown in Fig. 1.

Influence of microstructure and mechanical strain on the process of heat transfer during welding is not great but the reverse effect of the heat exchange process at the micro-structure of the welded joint and the stress-strain conditions is very important. In order to simplify the model, model shown in Fig. 1 does not include the impact of flow of molten metal on the process of heat transfer, microstructure and stress and strain states during the welding process. Velocity of transformations (development of microstructure of welds and heat affected zone) depends on the thermal welding cycle:

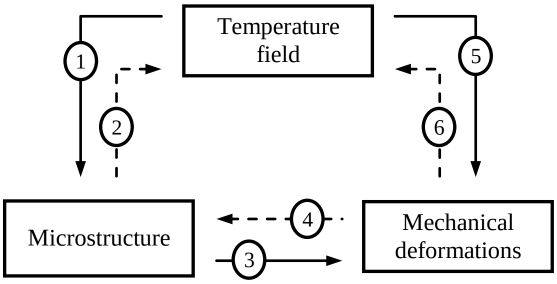

Fig 1. Interaction of factors [10]

1. latent heat,
2. phase transformation,
3. velocity transformation,
4. thermal expansion,
5. plastic deformation.

In the field of welding process modeling there are three basic approaches:

1. Analytical models
2. Numerical models
3. Experimental models

2. MODEL OF HEAT TRANSFER

This article shows a numerical model that was developed based on partial differential equations of heat transfer. Finite difference and finite element method can be used to obtain solutions which include complex geometry of welded parts, more complex initial conditions, the de-

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pendence of physical properties of materials on the temperature, the effect of latent heat of melting, etc...

Process of heat transfer during welding is a very complex problem. Its solution is associated with a number of difficulties related to the dependence of physical properties of welded materials on the temperature, the complexity of boundary conditions, the selected arc model, etc... Obtaining analytical solutions is conditioned by a number of simplifications of the model which results in less accurate solution. To obtain more reliable solutions it is necessary to use numerical methods. Partial differential equation of heat transfer during welding of thin sheets [5] is given below:

$$\frac{\partial T}{\partial \tau}=\frac{\lambda}{c\cdot\gamma}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\frac{q_l}{c\cdot\gamma\cdot t}-\frac{h_{uekv}}{c\cdot\gamma\cdot t}\left(T-T_a\right)$$

c – Specific heat capacity, J/kgK
γ - Material density, kg/m^3
λ - Thermal conductivity, W/mK
q_l – heat effect of arc, W/m^2
T_a – ambient temperature, K

Using finite differences, equation (1) becomes:

$$T_{i,j}=A\left(T_{i-1,j}+T_{i+1,j}+T_{i,j-1}+T_{i,j+1}\right)+$$
$$+B\left(T_{i+1,j}-T_{i-1,j}\right)+Cq_l+D$$

where coefficients A, B, C, D are equal to:

$$A=\frac{2\alpha}{8\alpha+2b\delta^2} \qquad B=\left(\frac{v\delta}{8\alpha+2b\delta^2}\right)$$

$$C=\frac{2a\delta^2}{8\alpha+2b\delta^2} \qquad D=\frac{2b\delta^2}{8\alpha+2b\delta^2}T_a$$

3.NUMERICAL SIMULATION

The shape and size of the molten pool influence on the mechanics and kinetics of crystallization and therefore structure and properties of the weld. Together with the shape and size of the heat affected zone, they affects at the formation and size of residual stress and strain. Understanding the impact of heat transfer and distribution of temperatures on the size and format of such zones has a crucial impact on the understanding, prediction and control characteristics of the weld. The shape and size of the molten pool depends on material properties, welding speed and heat input and can be measured from isotherms obtained by simulation. In order to show the influence of certain parameters on the formation of temperature fields during welding i.e. influence on geometric characteristics and properties of the weld, comparative results of simulations for different values of individual parameters are shown at Figures 2. to 9. The influence of five different parameters: welding speed, thickness of welded plates, efficiency of electric arc and type of welded materials Characteristic isotherms are especially prominent for easy visual comparison. isotherms for 100, 300, 500, 800 ° C are shown.

Figures 2. and 3. shows influence of welding speed on temperature distribution at top surfaces of welded steel sheets. In both cases the simulation was done for the power source q = 3 kW while the welding speed in the case shown in Figure 2. is v = 4 mm / s, and in the case shown in Figure 3. is v = 8 mm / s. It can be seen that increasing of welding speed leads to a narrowing of the characteristic isotherm and consequently it can be concluded that the width of the weld and heat affected zone compared to the speed of welding are in inverse relationship. This phenomenon is due to the fact that increasing of welding speed while keeping other parameters constant leads to reduction in line energy of the heat source. In the area in front of the heat source, there is a compression of isotherms as a result of the increase of welding speed. This actually means that the temperature gradient in the zone in front of the heat source increases with increasing of source speed. This increase in gradient may be explained by the fact that the welding speed exceeds the speed of heat transfer from the zone of welding.

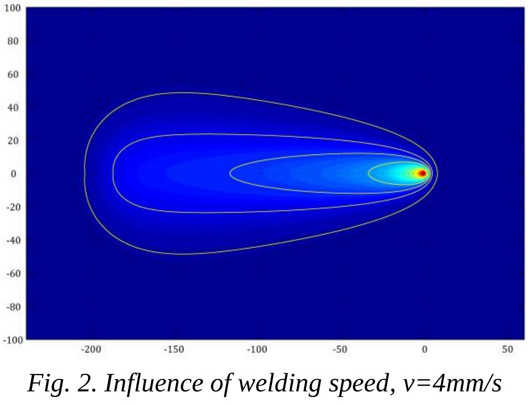

Fig. 2. Influence of welding speed, v=4mm/s

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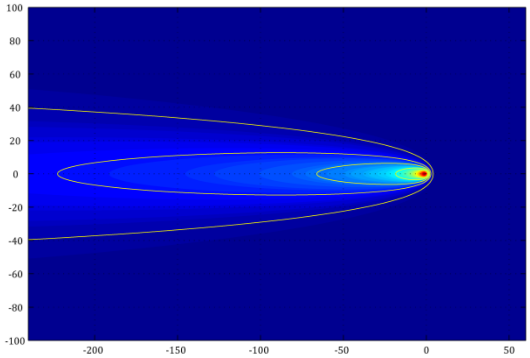

Fig. 3. Influence of welding speed, v=8mm/s

Figures 4. and 5. show the influence of sheet thickness on the temperature field. In both cases the simulation was done for the power source q = 3 kW and welding speed v = 8 mm / s. Thickness of the sheets in the simulation shown in Figure 4. is 3 mm, while in the simulation shown in Figure 5. is 6 mm. From the pictures can be seen that increasing of the thickness leads to a narrowing and shortening of the characteristic isotherms.

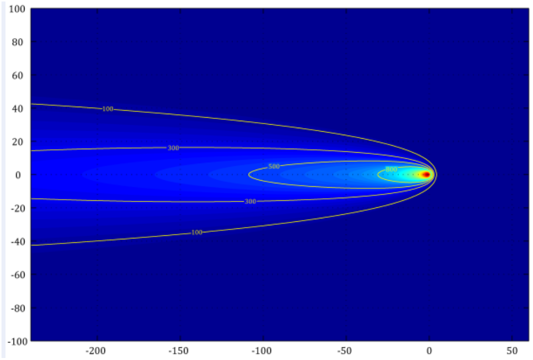

Fig. 4. Influence of sheet thickness, δ=3 mm

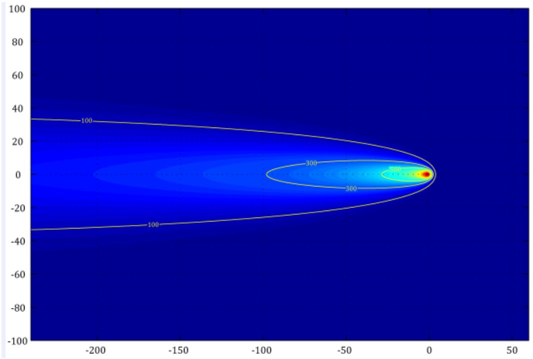

Fig. 5. Influence of sheet thickness, δ=6 mm

This phenomenon occurs because of increased volume of material. Due to the increased mass, at the same power and same welding speed, the amount of heat that can be given to unit of mass decreases. Likewise, the temperature gradient in the zone behind the heat source is higher in case of welding of thicker sheets. Results of simulation lead to conclusion that the smaller thickness of welded sheets under the same conditions results in higher weld seam width and greater width of the HAZ.

Figures 6. and 7. show the effect of arc efficiency coefficient η. The simulation was done for the power source q = 3 kW and welding speed v = 8 mm / s while η was varied between 0.65 and 0.85. Itmay be noted that due to the increase of the coefficient of arc efficiency leads to stretching and enlargement of typical isotherms, and that the temperature gradient behind the heat source is higher in case of smaller value of η. These changes come from the fact that increasing the arc efficiency coefficient leads to increase in the effective amount of heat generated by arc.

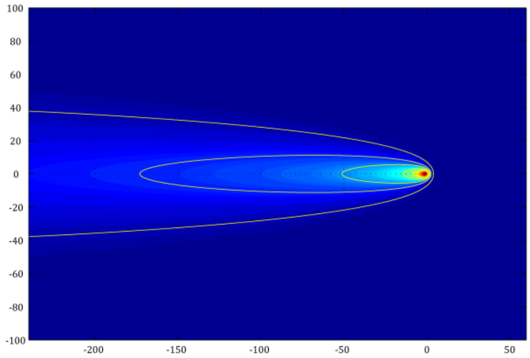

Fig. 6. Influence of arc efficiency, η=0.65

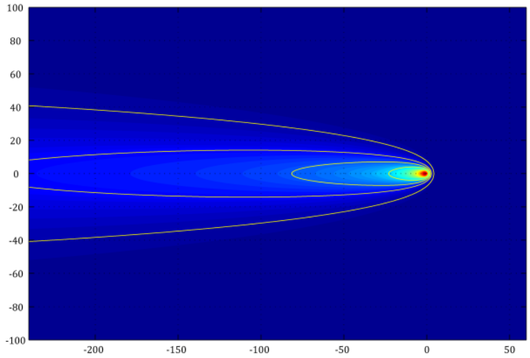

Fig. 7. Influence of arc efficiency, η=0.85

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Performed simulations indicate that the width of the weld seam and HAZ increase with increasing portof arc efficiency.

Figures 8. and 9. show the influence of the type of welded material for power source q = 3 kW and welding speed v = 8 mm / s. Materials used in the simulations are aluminum and low carbon steel. Simulation for aluminum welding shows that isotherms are much shorter and wider, and its shape is more elliptical than circular as in welding of low-carbon steel. In the area in front of the heat source, temperature gradient is lower during welding of aluminum sheets, while in the area behind the heat source temperature gradient is higher. These phenomena are due to the large difference in thermal conductivity of these two materials, ie, a consequence of the much larger thermal conductivity of aluminum compared to the low carbon steel. The weld seam and the HAZ during welding at the same conditions are wider at aluminum welding, i.e. they are proportional to the thermal conductivity of the material that is being welded.

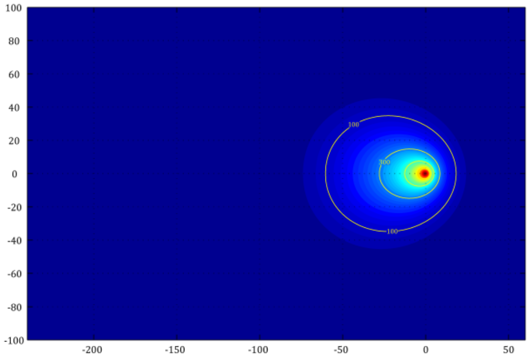

Fig. 8. Influence of welded material, Aluminum

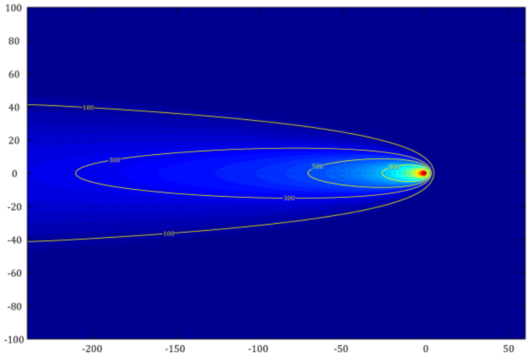

Fig. 8. Influence of welded material, Steel

4.CONCLUSIONS

Simulation models together with the corresponding experimental procedures are the basis for better understanding of the impact of welding parameters on the geometry of the weld and HAZ's. Based on the simulation results we can conclude that each of these parameters during arc welding of thin sheet metal have a significant impact on the temperature field in welded sheets and the geometry of the weld and HAZ's. Combination of simulation models and methods of artificial inteligence represents a solid base for formation of appropriate control systems.

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5. REFERENCE

[1] Goldak A. J., Akhlaghi M., Computational welding mechanics, Springer, New York, 2005.

[2] Lindgren E. L., Numerical modelling of welding, Computer methods in applied me¬c¬hanics and engineering (195) 6710–6736, Elsevier Applied Science, 2006.

[3] Özişik Necati M., Heat Conduction, Wiley-IEEE, 1993.

[4] Schäfer M., Computational Engineering – Introduction to Numerical Methods, Sprin¬ger, New York, 2006.

[5] Bjelić M., Simulacija temperaturskog poqa pri zavarivanju tankih limova MAG postupkom, Magistarska teza, Mašinski fakultet, Kraljevo, 2009