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Numerical simulation of molten pool flow for various welding parameters in V-groove GMA pipe welding†

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KEY WORDS: (Numerical simulation) (Abel inversion) (Molten pool flow) (V-groove Pipe welding) (Elliptic arc heat flux) (Bead shape)

1. Abstract

Normally many researchers used the axis-symmetric arc heat flux model in V-groove Gas Metal Arc welding simulations. In this study, however, the elliptic arc heat flux model was adopted to conduct the 3D numerical simulations by applying Abel inversion to the arc images captured with a CCD camera. Heat transfer and fluid flow in the weld pool were analyzed to examine the temperature distribution, flow velocity fields, and the solidified weld bead geometry during GMA V-groove welding of pipes. The model solved the equations of conservation of mass, momentum and energy with the VOF (Volume of Fluid) method which was adopted to calculate the shape of free surfaces. For various welding parameters such as welding position, torch angle, size of gap, wire feed rate, different molten pool flows and bead shapes (humping, burn through) could be visualized in the CFD numerical simulations. The results of simulation were compared with the experimental data, and showed a good agreement

2. Introduction

Previous V-groove or fillet joint simulations used the axis-symmetry arc heat flux model [1,2]. These studies, however, do not consider the effect of material shape, which can deform the arc plasma shape. Y.T.Cho calculated the arc heat distribution in a V-groove with CCD camera and the area matrix Abel inversion method and found out that the arc heat distribution had elliptic symmetry [1].

Optimizing the parameters in GMA(gas metal arc) pipe welding needs more effort than that in other cases because of the gravity force, which causes a molten pool to flow to the ground. So, it is better to use the VOF (Volume of fluid) model than the FEM to check the molten pool flow. The VOF technique has recently been used for some cases: in alloying elements in laser-hybrid welding [2] and in laser drilling [3].

3. Arc heat flux modeling in GMAW

Heat input from arc plasma to cathode is transferred by conduction, radiation and convection. These terms are calculated by equation (1), (2) and (3).

$$Q_{cond} = \frac{k_{eff}(T_{cb} - T_{ca})}{\delta} \quad (1) \qquad Q_{rad} = \int_{V_j} \frac{S_j}{4\pi r_{ij}^2} \cos\varphi dV_j \quad (2)$$

$$Q_{conv} = \frac{0.515}{\mathrm{Pr}_{ca}} \left(\frac{\mu_{cb}\rho_{cb}}{\mu_{ca}\rho_{ca}} \right)^{0.11} \left(\mu_{ca}\rho_{ca}\frac{u_{cb}}{r} \right)^{0.5} \bar{C}_p (T_{cb} - T_{ca}) \quad (3)$$

Heat transfer from radiation, however, is less than 5% of the total heat input, and can be neglected according to a realistic assumption [4]. So it is possible to assume that heat transfer from conduction and convection is proportional to the temperature difference between the cathode and the cathode boundary. In addition, the arc plasma in GMAW is in LTE (local thermodynamic equilibrium), where the gas temperature is the same as the electron temperature. Finally, the arc heat flux modeling can be completed by the irradiance of arc plasma because it is linear to the arc temperature [5, 6]. The area matrix Abel inversion method was used to obtain the irradiance of arc plasma. Cho obtained arc heat flux model from Abel inversion and found out that arc shape is elliptic rather than axi-symmetry. [7]

4. CFD pipe welding simulation

In this paper, the elliptic arc heat flux model (Eqn.4) is used to conduct numerical simulations. As the material has a 60 degree V-groove, the effective radii for each viewpoint are 0.89mm and 1.54mm (σ_x, σ_y)[7]. Other factors such as arc pressure, electro-magnetic force, droplet heat source, surface tension are considered in the numerical simulations. The VOF model equation is solved iteratively by a commercial simulation program FLOW-3D.

$$q(x,y) = \frac{\eta_A VI}{2\pi\sigma_x\sigma_y} \exp\left(-\left(\frac{x^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} \right) \right) \quad (4)$$

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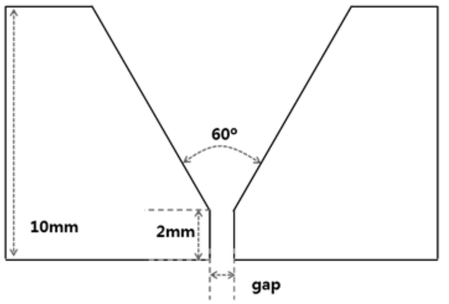

Fig.1 V-groove material shape (SS400 steel)

Due to different welding positions, molten pool flows make different bead shapes. **Figure 2** shows the molten pool flow before solidification and fusion zone in vertical-down position. **Figure 3** shows the result in overhead position.

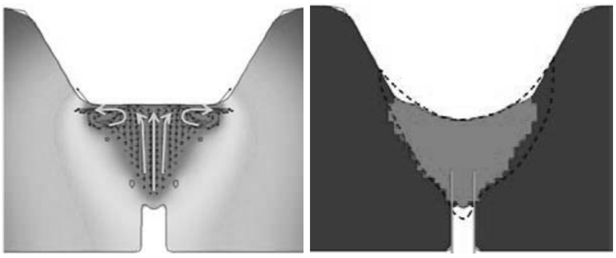

Fig.2 Molten pool flow and fusion zone in vertical-down position

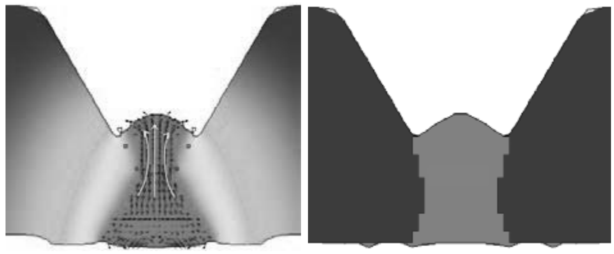

Fig.3 Molten pool flow and fusion zone in overhead position

5. Conclusion

(1) The elliptic symmetry arc heat flux model is proposed for CFD pipe welding simulation

(2) For different welding position, molten pool flows and fusion zones are different.

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