A STUDY ON THERMAL ANALYSIS OF HORIZONTAL FILLET JOINTS BY CONSIDERING BEAD SHAPE IN GMA WELDING

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ABSTRACT

In GMA(Gas Metal Arc)Welding, the weld size that is a locally melted area of a workpiece is one of the most important considerations in determining the strength of a welded structure. Variations in the weld power and the welding heat flux may affect the weld pool formation and ultimately the size of the weld. Therefore, an accurate prediction of the weld size requires a precise analysis of the weld thermal cycle. In this study, a model which can estimate the weld bead geometry and a method for thermal analysis, including the model, are suggested. In order to analyze the weld bead geometry, a mathematical model was developed with transformed coordinates to apply to the horizontal fillet joints. A heat flow analysis was performed with a two dimensional finite element model that was adopted for computing the base metal melting zone. The reliability of the proposed model and the thermal analysis was evaluated through experiments, and the results showed that the proposed model was very effective for predicting the weld bead shape and good correspondence in melting zone of the base metal.

KEYWORD

GMAW, Fillet welds, Finite Eement Aalysis, Molten metal, Weld pool

1. Introduction

GMAW(Gas Metal Arc Welding) is one of the most prevalently used processes for metal joining in heavy and ship building industries and is a process that produces coalescence of metals by heating them with an arc established between the continuous filler metal electrode and workpiece. Because of the large amount of the heat supplied at the weld site over a short period of time, there are many problems in and around a welded joint such as generation of distortion, residual stress, and reduced strength. Accurate predictions of weld size and the above problems require a precise analysis of the weld thermal cycle. The importance of a good model for the analysis of the thermal cycle has been emphasized by a number of investigators. However, the formation of bead due to the fed metal in GMAW is the prime obstacle to analyze the thermal cycle accurately. Molten metal on weld pool is depressed during welding and the final shape of weld bead depends on gravity, surface tension, arc pressure and geometry of weld part. So, in this study a model which can estimate the weld bead geometry and a method for thermal analysis considering weld bead were suggested. For analyzing the weld bead geometry, a mathematical model was developed to apply horizontal fillet joints. And the analysis of heat flow was performed with two dimensional finite element model adopted for computing the melting zone of base metal. The reliability of the proposed model and thermal analysis was evaluated through experiments.

2. Surface deformation

A mathematical model is required to estimate the weld bead geometry with considering the forces acting on weld surface. Gravity, surface tension and arc pressure are considered as the factors which affect weld surface deformation. Fig. 1(a) shows typical horizontal fillet weld and coordinate system. However, the weld bead geometry can be hardly determined in the case of excessive deformation such as an undercut at the toe on vertical plate. The analysis domain is thus defined by adopting the new coordinate system which rotates the weld joint by 45° to counter clockwise direction as shown in Fig. 1(b). The weld pool surface under arc pressure forms a shape which satisfies the equilibrium condition in the gravitational field. Hence, it is usually convenient to use the condition of equilibrium by directly solving the variational problem subject to constraint that volume of weld pool is constant.[1] Thus the total energy to be minimized includes the surface energy connected with the change in area of the weld surface, the potential energy in the gravitational field, and the work performed by the arc pressure displacing the weld pool surface. The total energy is therefore given by the following equation.

$$\begin{aligned} E &= \iint [\sigma(\sqrt{1+(\frac{\partial z'}{\partial x'})^2+(\frac{\partial z'}{\partial y'})^2}\ ) + \rho g(\frac{1}{2}z'^2\sin\theta - x'z'\cos\theta) + P_a z'\ ]\ \ dx'dy' \\ &= \iint F dx'dy' \end{aligned} \qquad (1)$$

where, σ : surface tension of molten metal (N/m), ρ : density (kg/m^3),

P_a : arc pressure (N/m^2), and θ : rotation angle of coordinates (°)

and the additional volume is equal to that of fed wire in GMA welding per unit weld length(V_w), the constraint equation is

$$\iint z'\ dx'dy' = \iint G\ dx'dy' = \frac{\pi r_w{}^2 f_r}{v_w} = V_w \qquad (2)$$

where, r_w : welding wire radius (m), v_w : welding velocity (m/sec),

f_r : feedrate of welding wire (m/sec).

Substitution of the eqn.(1), (2) in to Euler equation gives following complex form of equation;

$$\begin{aligned} &\alpha\{\frac{(1+z'^2_{y'})z'_{x'x'} - 2z'_{x'}z'_{y'}z'_{x'y'} + (1+z'^2_{x'})z'_{y'y'}}{(1+z'^2_{x'}+z'^2_{y'})^{3/2}}\} \\ &\qquad = \rho g[z'\sin\theta - x'\cos\theta] - P_a - \lambda\ . \end{aligned} \qquad (3)$$

In the computational procedure, the iterative method of finite difference has been used to solve this nonlinear differential equation. After these equation, the computational result is applied to the constraint prescribed. If it does not satisfy the constraining, the computation should be repeated after modification of Lagrange multiplier λ

in eqn. (3). The value of λ is modified by using the golden section search method.[2] Since the solution, z'(x', y'), from eqn.(3) is under transformed coordinates, that is retransformed to z(x,y).

3. Thermal analysis for fillet weld

Two dimensional transient thermal analysis was performed using three dimensional weld bead shape. F.E.A. package, 'ABAQUS', is used for the analysis. The analysis is performed using the method that element is added on two dimensional fillet weld with time. Heat source of an electric arc is assumed as it has Gaussian distribution as shown in eqn. (4)[3]

$$q(r) = (3Q/\pi r_b{}^2)\exp\{-3(r/r_b)^2\} \qquad (4)$$

$q(r)$: heat flux at the weld surface (W/m^2), Q : arc power (W),

r_b : effective arc radius (m), and r : distance from arc center(m),

Analysis model and boundary conditions are shown in Fig. 2.

4. Results and discussion

Figure 3 shows the bead shape and fusion lines at the cross section of fillet welds with the welding condition of 285A, 28V. In the Fig. 3(a), it was assumed that weld bead is just flat, i.e., a triangular section, which was frequently adopted by many other researchers.[4], [5] The comparison between analysis result and experiment shows much difference even in fusion line. However, using the model proposed in this study, the calculated weld bead shape and fusion line well correspond with those of experiment as shown in Fig. 3(b). It was thus revealed that the formation of weld bead and the bead shape play an important role in the heat flow of GMA welding process.

5. Conclusion

The main conclusion of this study can be summarized as follows:

(1) A mathematical model and analysis method were developed to estimate the weld bead shape of horizontal fillet joints.
(2) It was revealed that the proposed surface equation effectively predicts the weld bead shape.
(3) The formation of weld bead plays an important role in the heat flow of GMA welding process, and the results of thermal analysis show good correspondence with experiment by using the proposed model.

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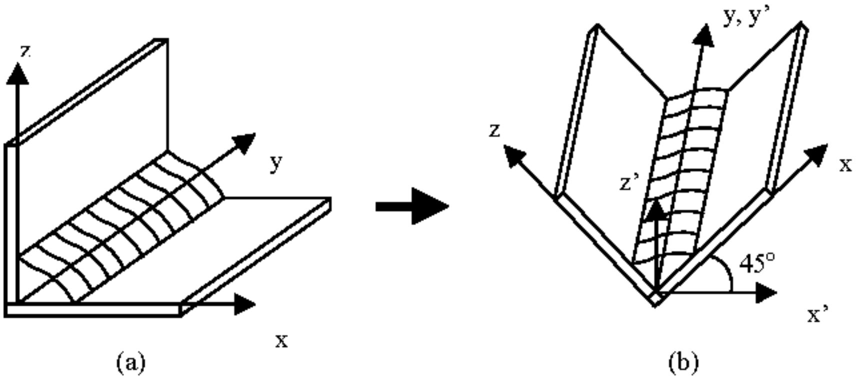
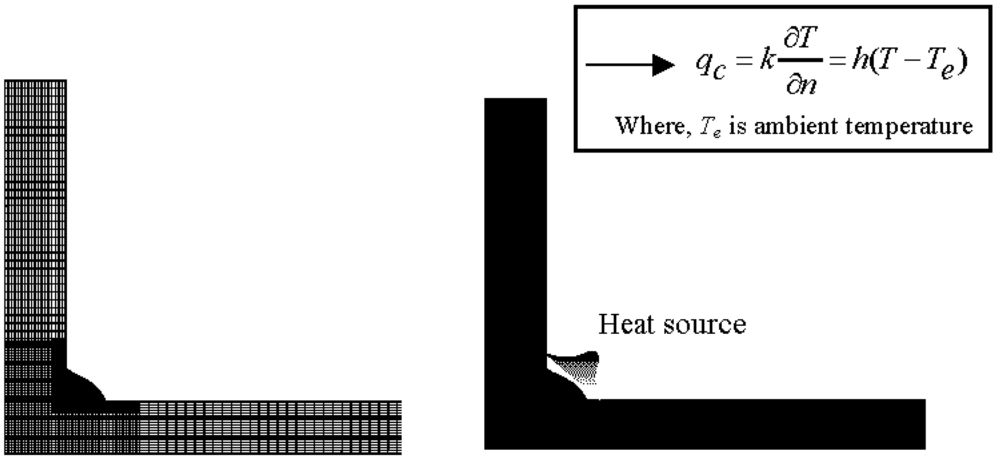


(a) (b)

Fig. 1 Horizontal fillet weld and coordinate systems



(a) (b)

Fig. 2 Analysis model (a) and boundary conditions (b)

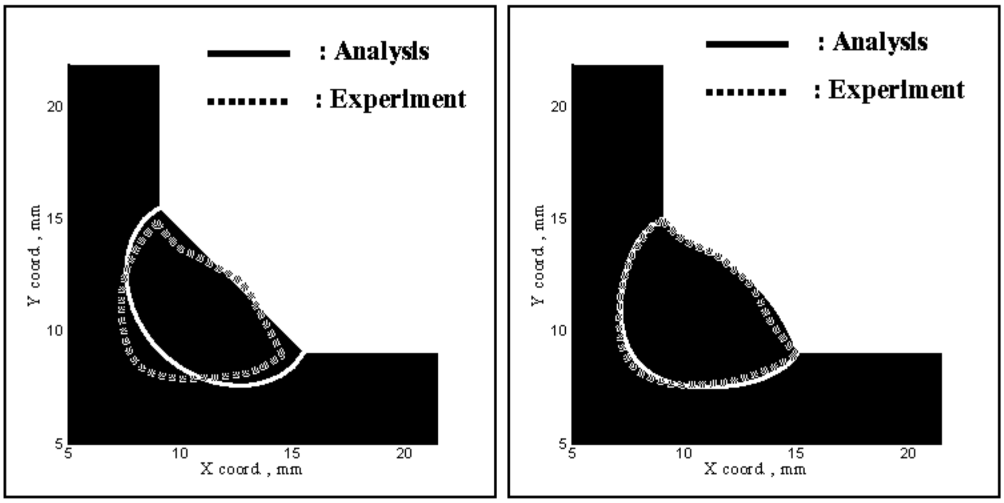


Fig. 3 Analysis results with simply assumed flat bead(a) and calculated bead by using the proposed model(b)