

A. Heat Transfer, Fluid Flow and Solidified Surface Profile during Gas Metal Arc Fillet Welding

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Introduction

Much of the previous research on understanding and controlling of weld bead geometry was limited to simple rectangular butt welds and, in most cases, did not consider filler metal additions. Due to the complexity of gas metal arc (GMA) fillet welding processes, a three-dimensional (3D) model for weld bead shape calculation based on numerical heat transfer and fluid flow has not been reported in the literature.

In the present study, a numerical heat transfer and fluid flow model is developed to quantitatively understand the temperature profile, liquid metal flow, weld pool shape and size, and the nature of the solidified weld pool reinforcement surface during GMA welding of fillet joints. The calculated fusion zone geometry and cooling rates were compared with the corresponding experimental data for various welding conditions.

Procedure

A 3D numerical model is developed to investigate the heat transfer and free surface flow during GMA fillet welding. The model uses a boundary fitted coordinate system to accurately calculate temperature and velocity fields in the complex physical domain considering deformation of the weld pool surface. The mass continuity, momentum conservation and energy conservation equations, and corresponding boundary conditions are transformed into a curvilinear coordinate. The transformed equations are discretized using the control volume method, and then solved using a modified Semi-Implicit Method for Pressure Linked Equations (SIMPLE). The additional heat from the metal droplets is simulated using a volumetric heat source. The free surface profile is calculated by minimizing the total free surface energy considering the addition of filler metal.

Results and discussion

The numerical model is used to study the heat transfer, fluid flow and solidified surface profile during GMA fillet welding of ASTM A-36 mild steel workpieces for various welding conditions. Dimensionless analysis is carried out to understand the relative importance of heat transfer by convection and conduction in the weld pool. The role of individual driving forces, namely Marangoni shear stress, buoyancy force and electromagnetic force, on the liquid metal convection as well as the weld pool shape and size is studied. The numerically computed fusion zone geometry, finger penetration characteristic of the GMA welds and the solidified surface profile of the weld reinforcement are in fair agreement with the experimental results for various welding conditions. The leg length, penetration and actual throat are found to increase with the increase in welding current. All these parameters decrease with the increase in welding speed. The predicted values of these three geometric parameters agree well with those measured experimentally. Both the experimental results and the model predictions indicate that the average cooling rate between 1073 and 773 K decreases with increase in heat input per unit length. The weld thermal cycles and the cooling rates are also in good agreement with independent experimental data.

Conclusions

The numerical model can provide detailed insight about the nature of heat transfer, fluid flow and evolution of free surface profile during GMA fillet welding. The fusion zone geometry and cooling rates can be satisfactorily predicted for various welding conditions. The model can be used to study the effect of important welding processing parameters such as welding current and welding speed on the fillet weld characteristics.