Modeling of Heat Transfer and Fluid Flow for Transient Welding Conditions

by W. Zhang, G. G. Roy, and T. DebRoy, The Pennsylvania State University;
and J. W. Elmer, Lawrence Livermore National Laboratory

Introduction

Transient welding conditions are encountered in many everyday welding situations such as weld starts and stops, tack-welding routines, stationary 'spot' welds, and solidifying weld craters. These types of welds behave differently than their moving weld counterparts because the thermal profiles never reach a steady state value. The heating and cooling rates for these welds are often much higher than that of steady state welds, and can lead to solidification cracking and formation of non-equilibrium phases. Therefore, it is important to understand how the weld thermal profiles change as a function of time. Due to the complexity of this problem, very few studies have been performed to investigate transient weld solidification behavior. In this study, mathematical modeling using a coupled heat transfer and fluid flow method is developed to provide detailed insight about the nature of heat transfer and fluid flow during arc spot welding of 1005 steel.

Procedure

A three dimensional transient numerical model has been developed to investigate heat transfer and fluid flow during spot welding. Electromagnetic, surface tension and buoyancy driving forces were considered for the calculation of transient weld pool convection. The liquid / solid interface, i.e., the weld pool boundary, is represented by using an enthalpy-porosity technique in a fixed Cartesian coordinate system. The governing equations, i.e., continuity, momentum and energy equations, in three dimensional transient form are discretized using a finite difference method, and solved by the Semi-Implicit Method for Pressure Linked Equations (SIMPLE). Upon convergence of the solution, the temperature and velocity fields at every time step are obtained, which can be further used to calculate other important parameters, such as solidification parameters.

Results and Discussion

We use this numerical model to study the evolution of temperature and velocity fields during Gas Tungsten Arc (GTA) spot welding of 1005 steel. Verification of the model is performed through comparing the calculated results with metallographic weld cross sections and weld thermal cycles measured by thermocouples. Dimensionless analysis is carried out to understand the relative importance of heat transfer by convection and conduction, and the significance of the various driving forces in the liquid pool. The calculated temperature distributions, and heating and cooling rates are useful for understanding phase transformation kinetics. Results also reveal information about the solidification parameters, such as the liquid / solid interface velocity (R), and temperature gradients at the liquid / solid interface (G) as a function of time. These data are then further analyzed to determine the solidification morphology and the scale of the solidification substructure in the 1005 steel welds.

Conclusion

The three dimensional transient model can accurately predict the weld pool geometry and weld thermal cycles. It is found that the mushy zone, i.e., liquid + solid two phase region, grows during solidification due to the effect of latent heat. The solidification velocities (R) of the liquid/mushy and mushy/solid interfaces increase, while the temperature gradients (G) ahead them decrease, with the solidification time. The combination of solidification parameters G and R can result in spatial variation of solidification morphology and substructure. The cooling rates are almost independent of position between 1073 K and 773 K (800 ^{o}C and 500 ^{o}C) temperature range. The average cooling rate between this temperature range has an inverse relationship with the net heat input.