

E. Modeling of Momentum, Heat and Solute Transport in Aluminum Alloy Welds to Prevent Liquefaction Cracking

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Introduction

Transport phenomena based computational models have been used in recent decades to achieve significant insight about fusion welding processes and welded materials. However, these models have not been used to understand solidification processes in details because of the difficulties in coupling complex physical processes in solidification with thermo-fluid calculations. With the recent advances in the computational hardware and software, it is now possible to develop large scale integrated models that include such complex physical processes. The purpose of the work was to develop a rigorous weld solidification model that takes into account non-equilibrium solidification where the partitioning of the solute is affected by the local interface velocity and the undercooling. The proposed model uses this approach while numerically solving mass, momentum, heat and solute conservation equations. The model has been applied to understand and prevent liquefaction cracking in commercial Al-Cu alloys.

Approach

Equations of conservation of mass, momentum, enthalpy and solute concentration are numerically solved considering non-equilibrium solidification to determine the solid and liquid phase fractions in the solidifying region. An effective partition coefficient is used that considers both the local interface velocity and the undercooling. The influence of convection-corrected partitioning on solute distribution is examined. Liquefaction cracking is predicted based on independent experimental observation that liquefaction cracking is probable if the solid fraction in the mushy zone is greater than that of the partially melted zone in the solid region. Numerical predictions of liquefaction cracking are compared with the corresponding independent experimental results in Al-Cu weldments.

Results/Discussion

The computed temperature and velocity fields show typical profiles characteristic of Marangoni convection. High values of Peclet number for heat and mass transport indicate that convection calculations are necessary to accurately predict the solute concentration distribution in the weld pool. The computed concentration profiles reflect the dissolution of the base metal at the melting front, the strong convection in the weld pool, mixing of the filler metal with the base metal and solute rejection at the solidifying interface. The predicted weld metal solute content agreed well with the independent experimental observations. Using the computed average composition in the two phase mushy region, the solid fraction in the solidifying weld metal was compared with that in the PMZ for various filler metal compositions. In each case, the susceptibility of liquefaction cracking was determined by Huang and Kou's criteria, i.e., by comparing the solid fraction in the solidifying weld metal with the corresponding value in the PMZ. The model predictions of liquefaction cracking susceptibility in Al-Cu alloy weldments were confirmed by independent experiments for various filler metal compositions.

Conclusions

A numerical model for non-equilibrium solidification in welds has been developed that considers momentum, heat and solute transport. The model uses an effective partition coefficient, which considers both the local interface velocity and the undercooling for accurate prediction of solid fraction in the weldment. The solute concentration distribution in the weld pool was effectively simulated and the calculated solid fraction in the two phase region accurately predicted liquation cracking in aluminum-copper alloys.