Microstructural Evolution During GTA Welding of 1005 Steel: Modeling and Real Time Mapping

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Introduction

Understanding the evolution of weldment microstructure has been an important goal in contemporary welding research. Much of the previous research has focused on the post-weld microstructural characterization, which provides no information about either how the final structure is attained or at what rate various phase transformations take place during heating or cooling. A recently developed spatially resolved X-ray diffraction (SRXRD) technique can provide real time phase mapping of the weldment surface. Analysis of the data collected by this technique to obtain phase transformation kinetics requires the knowledge of weld thermal cycles. Mathematical modeling of heat transfer and fluid flow can provide reliable thermal cycles in the entire weldment. By taking advantage of these two techniques, we seek to quantitatively understand the microstructural evolution, i.e., ferrite to austenite ($\alpha \rightarrow \gamma$) phase transformation during heating, γ grain growth, and γ decomposition during cooling, during GTA welding of 1005 steel.

Procedure

Microstructure evolution during GTA welding of 1005 steel was studied experimentally and theoretically. The experimental work involved real-time mapping of phases using the SRXRD technique. A three dimensional heat transfer and fluid flow model was used to calculate the temperature and velocity fields, thermal cycles, and the geometries of the FZ and HAZ. A non-isothermal kinetic equation considering the equilibrium γ fraction in the α+γ two-phase region was used to quantitatively describe the kinetics of $\alpha \rightarrow \gamma$ transformation during heating. A three dimensional Monte Carlo (MC) technique was used to obtain growth of γ grains. An existing phase transformation model was used to quantitatively describe the decomposition of γ into various ferrite micro-constituents during cooling.

Results and Discussion

The heat transfer and fluid flow model could satisfactorily predict the overall geometric features of the FZ and HAZ in 1005 steel welds. The kinetic parameters for $\alpha \rightarrow \gamma$ transformation, i.e., the exponent (n) and the pre-exponential constant (k_0), were calculated from the SRXRD kinetic data and computed thermal cycles using a known value of the activation energy (Q). These kinetic parameters were then used to reconstruct the $\alpha/(\alpha+\gamma)$ and $(\alpha+\gamma)/\gamma$ spatial boundaries during heating, and the results were compared with the experimental SRXRD phase map. The γ grain size distribution and topological parameters at different locations in the weldment were extracted from the three dimensional grain structure map obtained from MC simulations. Relationship between the topological parameters and the grain size was studied and compared with the experimental observations. The decomposition of γ during cooling was examined using an existing phase transformation model and the computed cooling rates. The calculated volume fractions of allotriomorphic and Widmanstatten ferrites were compared with the corresponding values determined by quantitative microscopy.

Conclusion

By the combination of SRXRD experiments and transport phenomena based modeling, the microstructural evolution during GTA welding of 1005 steel can be quantitatively understood. Results also reveal the insight about the mechanisms of phase transformations. The calculated kinetic parameters for $\alpha \rightarrow \gamma$ can be used to construct Time-Temperature-Transformation (TTT) and Continuous-Heating-Transformation (CHT) diagrams, as well as quantitatively describe this transformation kinetics under various thermal cycle in 1005 steel. The γ grain size distribution in the HAZ can be quantitatively calculated using the MC simulations. The resulted γ grain size can be used as an input to the phase transformation model to understand the spatial variation of final microstructures in the HAZ during cooling.