Modeling and Real Time Mapping of Phases during GTA Welding of 1005 Steel

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Introduction

Quantitative understanding of weldment structure based on scientific principles is an important goal of contemporary welding research. However, kinetic data on phase transformations at various temperatures are not readily available for most important engineering alloys. Furthermore, experimental measurements of the necessary thermal cycles in various locations in the weldment still remain impractical. A recently developed, synchrotron-based, spatially resolved, X-ray diffraction (SRXRD) technique has provided real time phase maps and phase transformation kinetics during welding of several important alloys. Furthermore, it is now established that three dimensional transport phenomena based models can provide reliable thermal cycles in the entire weldment. By taking advantage of these two recent developments, we seek to demonstrate that both the kinetics and mechanism of ferrite to austenite ($\alpha \rightarrow \gamma$) phase transformation during heating can be understood from scientific principles for the GTA welding of 1005 steel.

Approach

Microstructure evolution during GTA welding of AISI 1005 steel was studied experimentally and theoretically. The experimental work involved real-time mapping of phases in the heat-affected zone (HAZ) by 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 geometry of the FZ and the HAZ. The experimental SRXRD phase map and the computed thermal cycles were used to determine the kinetic parameters in the Johnson-Mehl-Avrami (JMA) equation for the $\alpha \rightarrow \gamma$ transformation during heating in the HAZ. Apart from enabling quantitative calculations of phase transformation kinetics under various conditions, these kinetic parameters also provide insight about the $\alpha \rightarrow \gamma$ phase transformation mechanism in 1005 steel.

Results and conclusions

The heat transfer and fluid flow model could satisfactorily predict the overall geometric features of the FZ and HAZ in the GTA welds of 1005 steel. The kinetics of the $\alpha \rightarrow \gamma$ transformation could be quantitatively described by the three JMA kinetic parameters, i.e., the activation energy (Q), the time exponent (n) and the pre-exponential constant (k_0), and the thermal cycles. Using a linearized non-isothermal JMA plot, the values of n and k_0 were calculated from the SRXRD kinetic data and computed thermal cycles using a known value of Q.

The time exponent of the JMA equation, n, was found to be 1.9 indicating a decreasing nucleation rate of γ with time. The growth of γ grain was found to be controlled by the diffusion mechanism. The accuracy of the JMA parameters was examined by comparing the calculated and experimental $(\alpha+\gamma)/\gamma$ phase boundary during heating. The values of the JMA kinetic parameters can be used to understand phase transformation kinetics under various thermal cycles or at various constant temperatures. The results demonstrate that by applying the spatially resolved, X-ray diffraction (SRXRD) technique to welding and analyzing the results by advanced numerical modeling, it is now possible to contribute to the growing quantitative knowledge base in phase transformation kinetics.