Kinetic Calculations of the Ferrite/Austenite Phase Transformation in the HAZ of a 2205 Duplex Stainless Steel Weldment

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Introduction

Phase transformations occurring in the heat affected zone (HAZ) of a 2205 duplex stainless steel (DSS) GTA weld have been directly observed in real time using spatially resolved x-ray diffraction (SRXRD) with high intensity synchrotron radiation. Both the ferrite (δ) and austenite (γ) present in the duplex microstructure undergo transformations during heating and cooling, altering the base metal δ/γ phase balance. These changes in the δ/γ phase balance have been tracked throughout the HAZ. Based on these results, the kinetics of the δ/γ phase transformation during the heating and cooling cycles typical of welding can be modeled.

Procedure

SRXRD results are used as a basis for mapping the δ/γ phase balance in the HAZ of 2205 DSS during GTA welding. Using the kinetic information contained in this map, a model, which couples the calculation of the thermal history of the weld with the diffusion of both substitutional and interstitial alloying elements across the δ/γ interface, is developed. Calculations for the diffusion rates of these alloying elements between the δ and γ phases in the HAZ over the course of the weld thermal history, in conjunction with *in-situ* SRXRD and post-weld microstructural characterization data, are used to investigate the phase transformation.

Results and Discussion

SRXRD measurements have been used to monitor the δ/γ phase transformation during both the welding heating and cooling cycles. A semi-quantitative phase map of the HAZ in a 2205 DSS, constructed from these SRXRD scans, shows the evolution of phases across both the heating and cooling cycles of the weld thermal history. Most interestingly, a decrease in the ferrite volume fraction below the base metal value on heating followed by its recovery back to these levels during cooling is observed along a path parallel to the welding direction. These transformations are predicted by thermodynamic calculations but have only been observed using SRXRD. By combining the temperature, time, and phase balance values from this plot, important kinetic information about this series of transformations and others which occur in duplex stainless steels under both the heating and cooling cycles typical of welding can be determined.

The δ/γ transformation is driven primarily by the diffusion of alloying elements, such as chromium, nickel, molybdenum, and nitrogen, across the δ/γ interface. In the as-received condition, these alloying elements preferentially segregate or partition between the ferrite and austenite phases to near equilibrium values. During welding, the rapid heating and cooling cycles experienced in the HAZ drive the diffusion of these elements between the ferrite and austenite phases. Of these alloying elements, nitrogen, which diffuses much more rapidly, is the most important in furthering the understanding of the δ/γ phase transformations in the HAZ. Calculations for the diffusion of these alloying elements in the HAZ over the course of the weld thermal history, in conjunction with SRXRD and post-weld microscopy data, are used to develop a more complete model of the HAZ microstructure evolution in DSS welds.

Conclusions

SRXRD observations of changes in the δ/γ phase balance in the HAZ of a 2205 DSS weldment provide a basis for an in-depth study of the δ/γ phase transformation. A model of the kinetics of the δ/γ phase transformation in the HAZ is developed here and is based on the coupling of existing calculations of the thermal history of the weld with diffusion calculations for various alloying elements across the δ/γ interface. The role of each alloying element, in particular, nitrogen, and the effect of HAZ location on the δ/γ transformation behavior are investigated by modeling. When combined with *in-situ* SRXRD and post-weld microstructural characterization, a more complete understanding of the δ/γ phase transformation in the HAZ than previously possible is developed.

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