Time Resolved X-Ray Diffraction Observations of Ferrite/Austenite Transformations in the Fusion and Heat Affected Zones of 2205 Duplex Stainless Steel Spot Welds

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Introduction

Spatially resolved x-ray diffraction (SRXRD) experiments performed on 2205 duplex stainless steel (DSS) weldments have been used to monitor the δ/γ phase balance in the heat affected zone (HAZ) of GTA welds. These results yield evidence for previously unobserved low-temperature transformations, but they do not allow the phase transformations occurring in either the HAZ or in the fusion zone to be directly monitored as a function of time. Here, this investigation is continued using time resolved x-ray diffraction (TRXRD), which provides a real-time *in-situ* capability to monitor these phase transformations as a function of time. The data provided by these experiments is then used to model the kinetics of the δ/γ phase transformation during the heating and cooling cycles typical of welding and to shed light on the mechanisms for some of these phase transformations.

Procedure

TRXRD experiments have been performed at the Stanford Synchrotron Radiation Laboratory (SSRL) on gas tungsten arc (GTA) spot welds made on 2205 DSS. Measurements are taken during both the weld heating and cooling cycles for various welding conditions using a 540 μm diameter synchrotron x-ray beam at temporal resolutions of 100 and 200 ms. Locations in both the fusion zone and the HAZ have been monitored in separate experiments in order to document the solidification behavior of the alloy and the characteristics of the δ/γ phase transformation These results are then compared with both metallographic observations and the calculated weld thermal history, in order to further document and understand the transformation kinetics. Additional experiments are performed using Gleeble® thermomechanical simulator to characterize phase transformation strain and verify some of the observations made here.

Results and Discussion

TRXRD measurements are used to monitor the δ/γ phase transformation during the heating and cooling cycles in a 2205 DSS spot weld at multiple locations in the fusion zone and the HAZ. These observations are then subjected to a semi-quantitative analysis of each diffraction pattern in order to determine the volume fraction of each phase present at a given time. The measurements made in the fusion zone show that the weld metal solidifies primarily as ferrite and undergoes a transformation to austenite at lower temperatures. In the HAZ, measurements are made at locations where complete and partial transformation to ferrite and the low temperature $\delta \rightarrow \gamma \rightarrow \delta$ phase transformation are observed. The observation of this final transformation confirms the previous SRXRD results and extends these observations to higher heating and cooling rates.

Plots of the austenite volume fraction as a function of time are then constructed and combined with the calculated thermal history for the location where measurements are taken. These plots are then used to obtain kinetic information about the $\delta \rightarrow \gamma$ phase transformation for each of the various conditions studied here. In particular, the plot showing the progress of the low temperature $\delta \rightarrow \gamma \rightarrow \delta$ phase transformation provides insight into the mechanisms of this unexpected transformation. Previous modeling of the phase transformation has indicated that diffusion-based mechanisms cannot explain the transformation at these low temperatures in this short time scale. Additional Gleeble® simulations have been performed as additional verification for the TRXRD results and as an examination of the strains induced on the material by this transformation. These experiments have shown that the transformation strains measured in these simulations are anisotropic, indicating that the morphology of austenite grains has a large effect. When combined with the TRXRD results, further evidence for a strain induced phase transformation is obtained.

Conclusions

TRXRD-based measurements taken in the weld metal and various locations in the HAZ of a 2205 DSS spot weld show ferrite solidification of the weld metal, complete and partial transformation of austenite to ferrite, and the low temperature $\delta \rightarrow \gamma \rightarrow \delta$ phase transformation. Based on these observations, plots of the austenite volume fraction as a function of time at these locations have been constructed and compared with the appropriate calculated thermal history. Further verification of the low temperature transformation has been completed using Gleeble thermal simulations. The combination of the TRXRD and Gleeble observations supports the hypothesis of a strain induced mechanism for this phase transformation.

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