

## **E. Toward Understanding of Microstructure Evolution in Low Carbon Steel Arc Weld by Phase Mapping and Modeling**

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### **Introduction**

The final microstructure in the weldment results from a series of transformations during both weld heating and cooling. In the literature, although the transformations during cooling have been extensively investigated experimentally and theoretically, those during heating have received relatively little attention. The transformations during heating are important since they affect the kinetics of transformations during cooling. The objective of this work is to present a methodology to understand the microstructural evolution during welding based on experiments and modeling. In particular, the ferrite to austenite transformation during heating, the austenite grain growth, and the austenite to ferrite transformation during cooling were examined during GTA welding of 1005 steel.

### **Technical Approach**

The experiments included the mapping of phases presented at the surface of the 1005 steel arc welds using an X-ray diffraction technique with synchrotron radiation. The X-ray diffraction data were further analyzed to obtain relative fraction of phases during important phase transformations. The modeling involved the calculations of the weld temperature distribution and phase transformation kinetics. Particularly, a thermo-fluid model was used to calculate the thermal cycles, a Johnson-Mehl-Avrami (JMA) kinetic equation to predict the kinetics of ferrite to austenite during heating, a Monte Carlo model to calculate the austenite grain growth, and an austenite decomposition model to examine the kinetics of austenite to ferrite during cooling. The model predictions were compared with the experimental results.

### **Results and Discussion**

The X-ray diffraction technique was able to identify the distribution of various phases at the weld surface. The fine spatial resolution captured the changes of phase fractions during important transformations. The three-dimensional heat transfer and fluid flow model was used to predict the thermal cycles in the entire weldment. The geometry of the FZ and HAZ predicted from the thermo-fluid model were in good agreement with the experimental results. The JMA analysis was used to quantitatively investigate the ferrite to austenite transformation during weld heating. The kinetic parameters used in the JMA equation were determined from the experimental data obtained using the X-ray diffraction technique. These kinetic parameters allowed the determination of kinetics of ferrite to austenite under various heating rates. It was found that a significant level of superheat is required for the initiation and completion of the phase transformation under the heating rates common to arc welding. The growth of the austenite was simulated using the Monte Carlo model. It was found that significant austenite grain growth took place in the HAZ, particularly in the vicinity of the FZ. The computed maximum austenite grain size is about eight times larger than that of the base metal. The calculated prior austenite grain size was then used to understand the final microstructure in the HAZ. The transformation of austenite to various ferrite microconstituents during cooling was examined using the austenite decomposition model. The predicted final microstructure in the weldment is predominantly

allotriomorphic and Widmanstatten ferrites, which was consistent with the post-weld metallographic measurement. The spatial variation of the final microstructure in the HAZ was quantitatively determined. It was found that the volume fraction of allotriomorphic ferrite increased, while that of the Widmanstatten ferrite decreased, as the distance to the FZ boundary increased.

### **Conclusions**

In the present work, by a combination of real-time phase mapping, heat transfer and fluid flow calculations, and phase transformation modeling, the microstructural evolution in 1005 steel arc welds was studied. Particularly, the kinetics of ferrite to austenite transformation during heating, austenite grain growth, and austenite to ferrite transformation during cooling were quantitatively calculated. The predictions were compared with experiment results. The methodology reported in this work indicates significant promise for understanding microstructure evolution in steel arc welds by the combination of advanced welding experiments and modeling.