

# Investigation of Phase Transformations in the HAZ of Carbon-Manganese Steel Arc Welds using Spatially Resolved X-Ray Diffraction

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## Introduction

Phase transformations that occur in the heat affected zone (HAZ) of gas tungsten arc (GTA) welds in AISI 1005 carbon-manganese steel were investigated using real time Spatially Resolved X-Ray Diffraction (SRXRD) at the Stanford Synchrotron Radiation Laboratory (SSRL). The SRXRD experimental results were combined with a heat flow model of the weld to investigate transformation kinetics under both positive and negative temperature gradients in the HAZ.

## Procedure

*In situ* SRXRD experiments were performed to probe the phases present in the HAZ during welding of cylindrical steel bars. These direct observations of the phases present in the HAZ were used to construct a phase transformation map which identifies 5 principal phase regions between the liquid weld pool and the unaffected base metal: (1)  $\alpha$ -ferrite which is undergoing annealing, recrystallization and/or grain growth at subcritical temperatures, (2) partially transformed  $\alpha$ -ferrite coexisting with  $\gamma$ -austenite at intercritical temperatures, (3) single phase  $\gamma$ -austenite at austenitizing temperatures, (4)  $\delta$ -ferrite at temperatures near the liquidus temperature, and (5) back transformed  $\alpha$ -ferrite co-existing with residual austenite at subcritical temperatures behind the weld.

## Results and Discussion

Analysis of the characteristics of the diffraction peaks were further used to provide a semi-quantitative measure of the amounts of ferrite and austenite in the

regions of the weld undergoing the  $\alpha \rightarrow \gamma$  transformation on heating and the  $\gamma \rightarrow \alpha$  transformation on cooling. These experiments represent the first real time phase mapping performed on steel welds.

### **Conclusions**

The transformation from ferrite to austenite on heating was shown to require 3.0 s and 158°C of superheat to attain completion under a heating rate of 102°C/s. The reverse transformation from austenite to ferrite on cooling was shown to require 3.3 s at a cooling rate of 45 °C/s to transform the majority of the austenite back to ferrite, however, some residual austenite was observed in the microstructure as far as 17 mm behind the weld. Future work will utilize these data to develop comprehensive phase transformation kinetic models of the austenite to ferrite transformation in steel welds.

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