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TRXRD Observations of Microstructural Evolution in Self-Shielded Flux Cored Arc Weld Deposits

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Introduction

Inclusion formation and microstructure development in self-shielded flux cored arc welds has been investigated before [1, 2]. Results showed that the liquid metal reactions could promote either Al_2O_3 or AlN formation depending upon the aluminum concentration in the weld metal. The residual aluminum that remained in solution was found to modify the solidification behavior of liquid to δ-ferrite and subsequent transformation of δ-ferrite to austenite during weld cooling. In this work, the microstructure evolution in the heat-affected-zone (HAZ of self-shielded flux cored arc weld (FCAW-S) overlays were investigated using in-situ Time-Resolved X-ray Diffraction (TRXRD) with a high flux Synchrotron radiation beam [3, 4].

Experimental Procedure

The flux-cored arc welds with two different aluminum concentrations were deposited as overlays on a normal C-Mn steel bar. The nominal composition of the low-aluminum weld overlay was Fe - 0.15 C - 0.64 Mn - 0.30 Si - 0.53 Al - 0.058 Ti - 0.030 O - 0.033 N (wt. %). The composition of the high-aluminum weld overlay was Fe - 0.22 C - 0.56 Mn - 0.26 Si - 1.77 Al - 0.003 Ti - 0.006 O - 0.064 N (wt.%). Stationary GTAW 'spot' welds were made on these weld overlay surfaces by striking an arc on a stationary bar and then terminating this arc after the weld pool had achieved its maximum diameter (~ 9 mm). This required about 15 s of arc duration. TRXRD measurements were performed at the Stanford Synchrotron Radiation Laboratory [5] using a 0.05s time resolution.

Results and Discussions

Calculated quasi-binary phase diagrams for welds with two different aluminum concentrations are shown in Fig. 1. These calculations suggest that the HAZ of the low aluminum welds will become completely austenitized at temperatures above 1200K. On continued heating the austenite will transform to δ-ferrite at approximately 1750K, prior to melting at approximately 1800K. In the high-aluminum welds, the austenite will begin to form at temperatures above about 1000K [see Fig 1(*b*)], however, the weld will never completely transform to austenite;

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instead varying fractions of austenite and ferrite will be present up to 1750K. The above predicted transformation paths in the HAZs of both alloys were investigated using TRXRD experimental measurements. The diffraction measurements were made in the HAZ at a distance approximately 1-mm away from the fusion line. At this location the peak temperatures are expected to reach above 1473 K [4]. Selected diffraction patterns from a typical TRXRD sequence in the low-aluminum and the high-aluminum alloys are shown in Fig. 2.

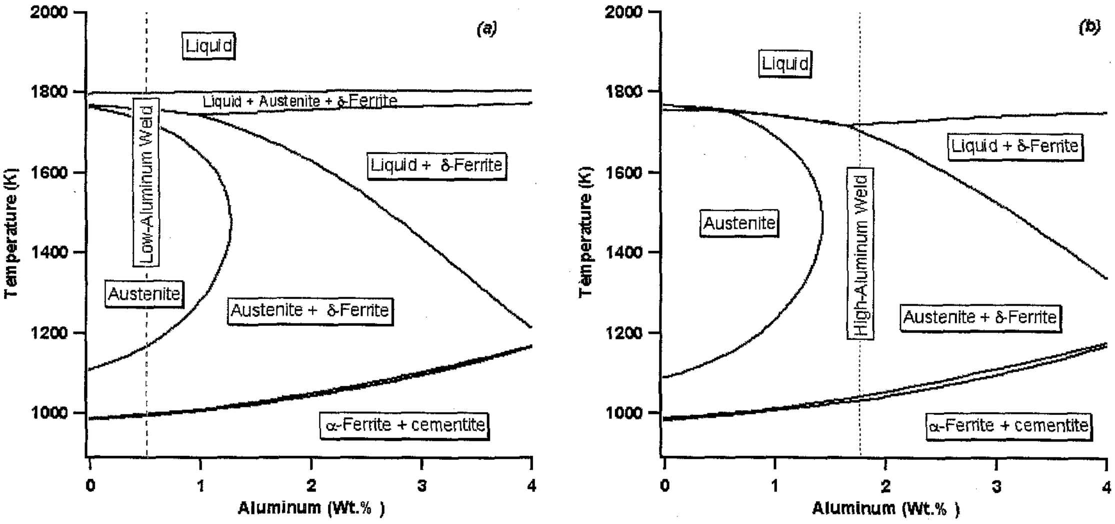

Figure 1. Calculated quasi-binary diagram of (*a*) the low-aluminum weld and (*b*) the high-aluminum weld.

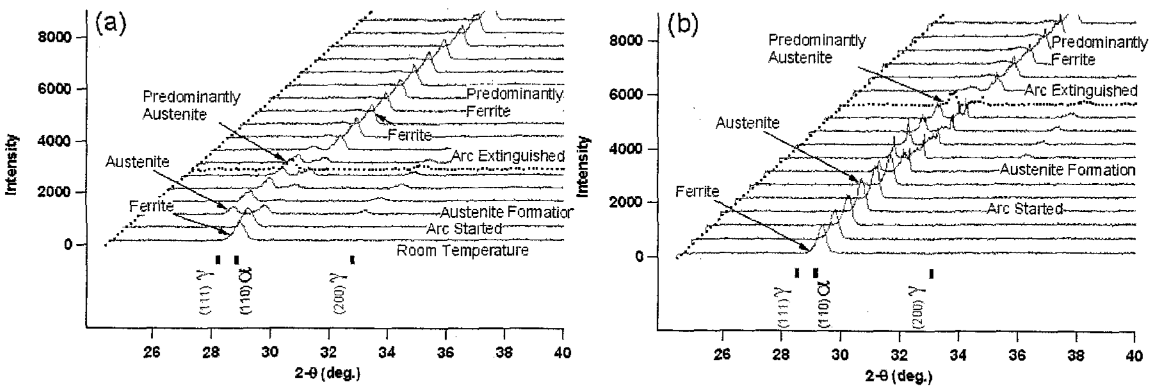

Figure 2. Selected TRXRD data obtained from (*a*) low-aluminum and (*b*) high-aluminum welds.

At room temperature the diffraction spectrum contained only the ferrite peaks. The diffraction pattern from the austenite phase was observed in low-aluminum alloy shortly after the arc was initiated. As the heating continued, the diffraction intensity of the austenite peaks grew at the expense of the ferrite peaks. During weld cooling, the austenite transformed to ferrite as indicated by the decrease in the austenite peaks and the growth of the ferrite peaks. In the case of the high-aluminum HAZ, the diffraction results also showed austenite growth [see Fig. 2(*b*)]. However, careful analyses of the results showed that the ferrite diffraction peaks with low-intensity were persistent throughout the entire heating cycle. These results show the enhanced phase stability of ferrite in high-aluminum weld deposits. The results are in agreement with phase diagram calculations shown in Fig. 1

Summary and Conclusions

The TRXRD technique with a 0.05s time resolution was able to track phase changes during rapid heating and cooling in the HAZ of steel spot welds. The present work demonstrates that state-of-the-art diffraction methods using Synchrotron radiation can be used to investigate microstructure evolution in multicomponent industrially relevant steel welds. The results provide information about the kinetics of austenite formation from ferrite during weld heating, and stability of austenite at high temperatures. The results are being used to evaluate thermodynamic and kinetic models of weld microstructure evolution.

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References

1. S. S. Babu, S. A. David, M. Quintana, and J. E. McLane 1999, "Microstructure development in self-shielded flux cored arc welds," AWS Convention 1999 Abstracts, page 191.
2. M. Quintana, J. E. McLane, S. S. Babu and S. A. David, 1999, "Inclusion formation in self-shielded flux cored arc welds," AWS Convention 1999 Abstracts, page 193.
3. J. W. Elmer, J. Wong and T. Ressler, 1998, "Spatially resolved X-ray diffration phase mapping and α-β-α transformation kinetics in the heat-ffected-zone of commercially pure titanium arc welds," *Metall. and Mater. Trans. A*, **29A**, 2761, 1998.
4. J. W. Elmer, Joe Wong and Thorsten Ressler, "In-situ observations of phase transformations during solidification and cooling of austenitic stainless steel welds using time-resolved x-ray diffraction," in press, *Scripta Materialia*.

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