In-Situ Observations of Phase Transformations in Ti-6Al-4V Alloy Welds using Spatially Resolved X-Ray Diffraction

by:
J. W. Elmer, T. A. Palmer, Joe Wong and S. S. Babu

Introduction

Spatially Resolved X-Ray Diffraction (SRXRD) is used for *in-situ* observations of the phases that exist in the HAZ of Ti-6Al-4Vduring welding. This technique reveals kinetic details about the microstructural evolution taking place in the weld at the welding temperature and under real welding temperature gradients that can not be obtained by other methods. Here, we investigate the transformation of a Ti-6Al-4V alloy, which is an α-Ti stabilized alloy that contains approximately 10% β-Ti at room temperature, to complete β-Ti in the high temperature region of the HAZ. Six different welding parameters, having different heat input per unit length, were studied to better understand the transformation to β-Ti under the non-isothermal heating conditions of welds.

Experimental Procedures

SRXRD measurements were performed on during gas tungsten arc welding of Ti-6Al-4V ELI bars at the Stanford Synchrotron Radiation Laboratory (SSRL). Details of similar welding experiments have been previously published for CP titanium [1-2], so only a brief description will be given here. The SRXRD experiments were performed by initially positioning the x-ray beam at a fixed distance from the electrode where it would be located in the liquid weld pool after the arc is struck. A typical SRXRD run consisted of gathering 40 diffraction patterns, each spaced 250 μm apart, along a pre-determined path to span a range of 10 mm through the HAZ. The resulting data were presented as a series of x-ray diffraction patterns along a given x-ray scan direction perpendicular to and away from the centerline of the weld, showing the phases that exist at each location in the HAZ.

Results and Discussion

One of the SRXRD data sets is shown in Figure 1, which shows the high temperature β-Ti phase forming from the liquid weld pool and the subsequent transformation of β-Ti to the low temperature α-Ti phase at further distances from the fusion line. All SRXRD data were taken in a direction perpendicular to the weld direction, starting at the weld electrode location.

The *in-situ* SRXRD experiments were then used to measure the width of the high-temperature single phase β-Ti region adjacent to the liquid weld pool for each of the six different welding heat inputs. The results of the SRXRD experimental data were then compared with the predicted locations of the β-Ti phase boundary as determined from calculated weld thermal profiles and equilibrium thermodynamic relationships as shown in Figure 2. Results of the comparison show a distinct offset between the experimentally measured and the calculated locations of the β-Ti boundary. This offset can be attributed to kinetics of the α-Ti →β-Ti phase transformation, which requires significant time to take place under the non-isothermal heating cycle of the welds. Thermocalc and Dictra calculations [3,4] are in progress to analyze these results.

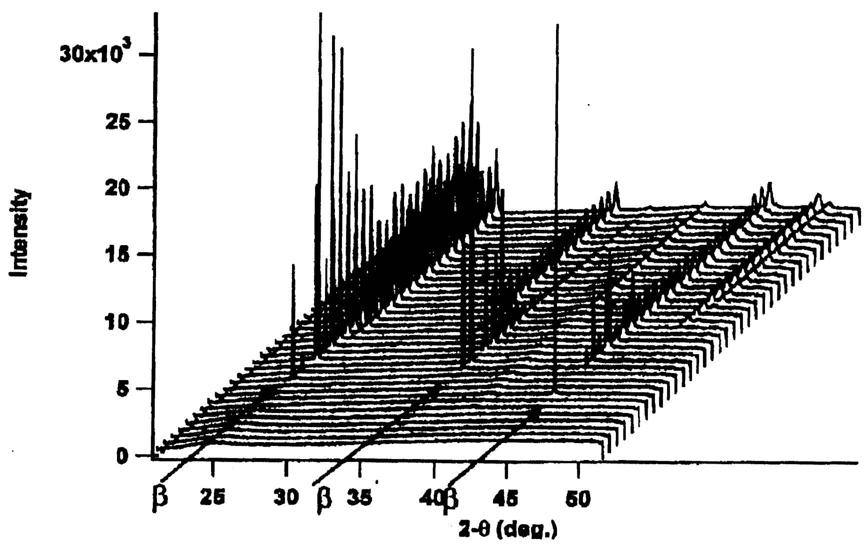

Figure 1: Real-time SRXRD patterns of a Ti-6Al-4V weld. The probe first traverses the weld pool (featureless diffraction) then the HAZ. The arrows mark the 2-θ locations of the three β-Ti peaks; all other peaks correspond to α-Ti.

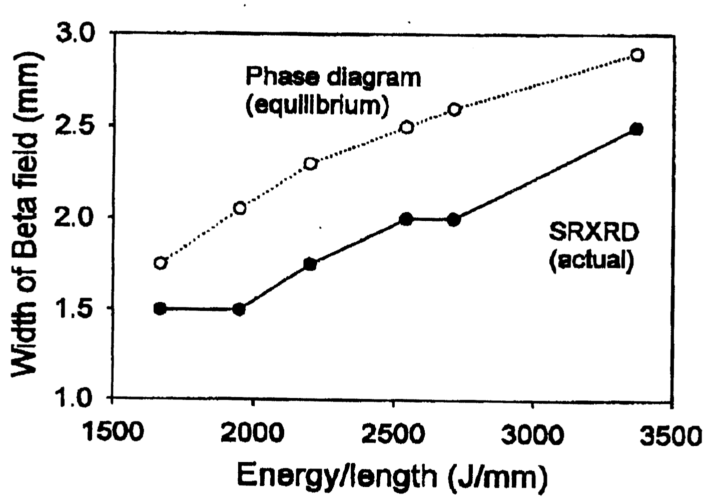

Figure 2: Comparison between the calculated and measured width of the single-phase β-Ti region. The open symbols represent the calculated values, the filled symbols represent the SRXRD measured values. The difference between the two contains the kinetic data regarding the α-Ti→ β-Ti phase transformation.

Conclusions

1. Spatially resolved x-ray diffraction experiments employing synchrotron radiation were performed *in-situ* on GTA welds of Ti-6Al-4V alloys for the first time.
2. These experiments were used to measure the width of the high-temperature β-Ti phase field for welds with varying heat inputs per unit length.
3. The measured width of the β-Ti phase field was compared to values calculated by heat flow modeling and equilibrium thermodynamics to determine the time required for the α-Ti →β-Ti transformation to take place under the non-isothermal heating cycle of the weld.
4. The kinetics of the α-Ti →β-Ti transformation were shown to be similar for each of the six weld heat inputs. On average, the transformation to β-Ti was shown to require 1.43s ±0.103s of time and 169°C ±25.7°C of superheat above the β-Ti transus under an average heating rate of 118°C/s.

Acknowledgments

This work was performed under the auspices of the U. S. Department of Energy, Lawrence Livermore National Laboratory, under Contract No. W-7405-ENG-48. This work was supported by DOE, Office of Basic Energy Sciences, Division of Materials Science. Synchrotron experiments were conducted at SSRL supported by DOE, Division of Chemical Science.

References

1. J. W. Elmer, Joe Wong and Thorsten Ressler, " Spatially Resolved X-Ray Diffraction Phase Mapping and α→β→α Transformation Kinetics in the HAZ of Commercially Pure Titanium Arc Welds," *Metall. and Mater. Trans. A*, 29A(11), p. 2761, 1998.
2. J. W. Elmer, Joe Wong and Thorsten Ressler, "Spatially Resolved X-Ray Diffraction Mapping of Phase Transformations in the HAZ of Carbon-Manganese Steel Arc Welds," *Metall. and Mater. Trans. A*, 32A (5), pp. 1175-1187, 2001.
3. B. Sundman, B. Jansson, and J.O. Andersson, "The thermo-calc databank system." *Calphad*, 1985, **9**, 1-153.
4. A. Engström, L. Höglund, and J. Ågren "Computer simulation of diffusion in multiphase systems," *Metall Mater Trans A*, 1994, **25A**, 1127-1134