Controlling Massive Transformations in Laser Welded Stainless Steels: Determination of Critical Cooling Rate

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INTRODUCTION

The absence of long range diffusion associated with the massive transformation implies that the massive product phase inherits the composition and chemical distribution of the parent, a potentially useful characteristic if this transformation can be controlled. The high cooling rates (10^4-10^5°C/s) in laser welds prepared on Mo-bearing stainless steels in a previous study produced a massive transformation to γ-austenite in samples exhibiting primary ferrite solidification. These results suggest the presence of a range of critical cooling rates rapid enough to suppress long-range diffusion mechanisms, but slow enough to provide sufficient short range atomic mobility to achieve the phase change.

TECHNICAL APPROACH

A series of Mo-bearing stainless steel compositions with Mo-contents ranging from 0 to 7 wt% and exhibiting primary δ-ferrite solidification were analyzed to evaluate the effect of composition on the critical cooling rates that determine the mechanism of the solid state transformation to γ-austenite. The selected compositions were based on calculated multi-component phase diagrams in the Fe-Ni-Cr-Mo system. Novel Gleeble thermo-mechanical simulator procedures were used to apply known cooling rates in excess of 7000°C/s to alloys prepared via the button arc melting process. The microstructures were then evaluated using standard metallographic techniques followed by SEM/TEM/EPMA analysis.

RESULTS/DISCUSSION

Previous work on the massive transformation from δ-ferrite to γ-austenite in laser weld fusion zones in this class of materials revealed the presence of increasing fractions of massive γ-austenite with increasing cooling rate. This trend suggests that a minimum cooling rate exists (for a given composition) below which the transformation mechanisms are dominated by long range diffusion. Consequently, the application of *known*, *controlled* cooling rates to a series of Mo-bearing stainless steels provides an avenue to evaluate the characteristics of massive transformation phenomena as a function of composition and cooling rate. This approach is a significant departure from welding studies that rely on dendrite arm spacing measurements to estimate cooling rate, usually with accuracy only within an order of magnitude. The challenges of developing a test procedure that can simulate solid state transformations in laser weld fusion zones without melting the sample will be discussed. Particular emphasis will be placed on efforts to characterize the thermal gradients across the sample, and development of pre-conditioning procedures that provide a pseudo-equilibrium starting microstructure and appropriate control of grain size.

A series of primary δ-ferrite alloys were chosen various "distances" from the eutectic composition (based on calculated multi-component phase diagrams). The thermodynamic criteria governing the choice of compositions for the experimental matrix will be discussed. The microstructures resulting from preliminary experiments contain a mixture (in varying amounts depending on composition) of δ-ferrite, γ-austenite, and σ-sigma. The difficulty in differentiating γ-austenite resulting from diffusional coarsening versus epitaxial massive γ-austenite growth in duplex structures will be addressed, and the disparity in chemical distribution in the product γ-austenite between mechanisms is shown to be valuable. The use of calculated multi-component phase diagrams to explain these observed phenomena in the context of thermodynamic driving forces and the conventional T_0 paradigm will also be presented.

CONCLUSIONS

The test procedures developed for this work allows for the application of known, controlled cooling rates in excess of 7000°C/s, and provide a method to examine solid state transformation behavior in laser weld fusion zones of Mo-bearing stainless steels. The massive transformation from δ-ferrite to γ-austenite was observed in several alloys, and results suggest that a critical cooling rate exists in the range of cooling rates studied thus far. Ongoing work will focus on broadening the range of compositions in order to elucidate the contribution of other elemental additions on this transformation behavior.

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