

C. Alloy Development of a Robust Filler Metal for the Superaustenitic Stainless Steel Al-6xn

by Matthew J. Perricone, Timothy D. Anderson, John N. DuPont PhD., and David Fischer, Lehigh University

Introduction

The non-uniform redistribution of critical alloying elements during weld solidification of superaustenitic stainless steels leaves regions of the fusion zone microstructure susceptible to preferential corrosive attack. High alloy Ni-base filler metals are often used to increase the nominal Mo-content of the fusion zone and to maintain the fully austenitic structure of the base metal, but these materials are extremely expensive and are therefore a major cost center for large structural systems. To reduce this cost, a robust Fe-based filler metal is being engineered to solidify as primary ferrite to capitalize on the higher diffusivity of elements like Mo, then transform to austenite in the solid state to take advantage of this phase's toughness and non-magnetic character. The high cooling rates associated with arc welding processes may create the opportunity to induce solid state transformation mechanisms that may aid in reducing or eliminating residual ferrite in the microstructure.

Technical Approach

Multi-component thermodynamic modeling was used to simulate the solidification and transformation conditions for a large set of Fe-Ni-Cr-Mo compositions ranging from 0 to 10wt% Mo. These simulations were used to identify the locus of compositions in this alloy system that exhibit primary ferrite solidification followed by a solid state transformation to austenite. Small ingots of the selected compositions were created from virgin elements using an arc-melting process in a reducing atmosphere. Microstructural analysis revealed the development sequence and transformation mechanism for each alloy based on the the location and morphology of the ferrite phase, respectively. EPMA was used to quantify the chemical distribution of alloys of interest. The ferrite content of each alloy was measured via a magnetic induction ferrite detector.

Results and Discussion

A series of Fe-Ni-Cr-Mo multi-component liquidus projections were calculated using computational thermodynamic software at constant Mo-contents of 0, 2, 4, 6, 8, and 10wt%. For each level of Mo-content, a series of isopleths were calculated at constant Ni + Cr contents from 5- to 50-wt% in increments of 5-wt%. By tabulating the vertices of the eutectic triangle (liquid, ferrite, and austenite all stable) in each diagram, this data could be combined with the appropriate liquidus projection to provide a clearer picture of the effect of composition on the width and symmetry of this multi-phase field around the line of twofold saturation. Vital to the engineering control of the microstructural development of a given composition, presenting this information in this manner provides a description of a large portion of the Fe-Ni-Cr-Mo alloy system. In contrast, the vertical isopleths routinely used in the literature can only describe the behavior of a much narrower set of compositions (with constant Mo *and* Fe). Furthermore, the use of vertical sections to describe microstructural development hinges on the assumption that tie lines lie in the plane of the diagram, which, for multi-component systems, is rarely the case.

A button arc melter was used to create small heats of 16 compositions chosen to experimentally verify the diagrams described above for each level of Mo-addition. Microstructural analysis of this array of 96 alloys provided insight into the effect of composition on the development of these alloys, and reasonable agreement was observed between thermodynamic simulation and experiment. This series of Fe-Ni-Cr-Mo alloys exhibited microstructural evolution consistent with that predicted by the combination of the constant Fe and Mo isopleths and constant Mo liquidus projection. The presence of martensite in a subgroup of these alloys, while not predicted by the thermodynamic simulations presented here due to its metastable (and therefore non-equilibrium) nature, was well described and predicted using the Schaeffler diagram. Near-complete transformation from primary ferrite to austenite in the solid state was observed for a subset of the alloys studied, indicated by ferrite measurements under 5%. Furthermore, the results presented here are encouraging because the cooling rate in the button arc melting is generally the same as conventional arc welding methods. This data thereby sets the stage for the next series of experiments that will examine the effect of welding parameters (current, travel speed) on the microstructural development and phase selection in the Fe-Ni-Cr-Mo.

Conclusions

Microstructural analysis of a series of Fe-Ni-Cr-Mo alloys produced with button arc melting methods demonstrates good agreement with computational thermodynamic simulations conducted to describe the microstructural development of this class of materials. The combined use of liquidus projections and constant-Fe-and-Mo isopleths provided a unique multi-dimensional perspective on the equilibrium behavior of these alloys. The results presented here provide a foundation for the next series of experiments designed to evaluate the effect of welding parameters (current, travel speed) on microstructural development and phase selection of these materials during weld solidification and all subsequent solid state transformations.