Microstructural Development of Mo-bearing Stainless Steels

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The excellent corrosion resistance of superaustenitic stainless steel (SASS) alloys has been shown to be a direct consequence of high concentrations of Mo. The presence of Mo can have a significant effect on the microstructural development of welds in these alloys in this compositional regime. In this research, the microstructural development of welds in the Fe-Ni-Cr-Mo system was analyzed over a wide variety of Cr/Ni ratios and Mo contents. Models were prepared that will predict not only the solidification mode, but also the solid-state phase transformations that might occur, as functions of composition.

The system was first simulated by construction of multi-component phase diagrams using the CALPHAD technique. Data gleaned from vertical sections of these diagrams were inserted in the compositional range of a liquidus projection to produce diagrams that can be used as a guide to understand the influence of composition on microstructural development. A large number of experimental alloys were then prepared via arc-button melting for comparison with the diagrams. Each button was characterized using various microscopy techniques. Phase identification was carried out using EBSD. A magnetic instrument was used to quantify the amount of ferrite in all alloys.

Multi-component thermodynamic diagrams were used to accurately predict the solidification mode and solid-state transformation behavior over a wide range of stainless steel compositions. A total of 20 possible microstructural development sequences were theorized based upon observations made of the experimental alloys. Four solidification modes and 3 different solid-state phase transformations acted in various combinations to create this variety in microstructure. The expected ferrite and austenite phases were accompanied by martensite at low Cr/Ni ratios and by sigma at high Mo contents. The ferrite, austenite, and sigma phases were all positively identified through Kikuchi pattern analysis. Several independent findings revealed that the sigma phase present was the result of a eutectoid transformation, not via solidification. Sigma phase emerged in primary austenite alloys at lower Mo concentrations (2wt%) than in primary ferrite-solidified alloys (>6wt%Mo). The results were used to construct a map of expected phase transformation sequence and resultant microstructures as a function of composition.

Magnetic ferrite measurements were also used to produce quantitative relationships between alloy composition and ferrite content, and the results were then plotted on the WRC-1992 weld constitution diagram. Good agreement was shown between the solidification mode of primary ferrite alloys and those predicted by the WRC-1992 diagram. However, the solidification mode of primary austenite alloys were shown to disagree, as numerous AF alloys were found in the A mode region. The shift in the A/AF boundary was believed to be the result of microsegregation of the excess Mo present in these alloys. Plotting of the martensitic alloys also corroborated the martensite boundary on the WRC-1992 diagram proposed by Kotecki. Several alloys did exceed the boundary, however, all contained greater than 8wt% Mo. The non-equilibrium solidification experienced by these alloys caused Mo contents in the cell cores to be lower than the nominal, exactly where the martensite was located.

The results of this work provide a working guideline for future base metal and filler metal development of these alloys. Fusion welding of Mo-bearing stainless steels can possibly bring about any of the described microstructural development sequences from diluting with filler metal. The martensite and sigma-phase transformation products will be detrimental to the mechanical integrity of such welds; therefore proper processing techniques are critical for controlling the weld dilution so as to avoid these compositional regimes. Awareness of the high segregation potential of Mo solute will allow usage of popular weld constitution diagrams for the prediction of microstructure.