Realization of an Fe-based Filler Metal for Superaustenitic Stainless Steels

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Welding of superaustenitic stainless steels (SASS) using Ni-base filler metals tends to cause solidification cracking and loss of corrosion resistance in the weld zone. These issues have been avoided through the use of a Fe-based filler metal that undergoes a ferritic primary solidification mode followed by a solid-state phase transformation to the austenite phase. Thermodynamic calculations of and experimentation on the Fe-Ni-Cr-Mo system showed that 6wt% Mo alloys that solidify via the FA solidification mode offer the best opportunity. In this research, the effects of additional elements on the 6wt%Mo system were studied in order to select final candidate filler metal compositions for further testing.

Multi-component thermodynamic modeling was used to simulate the solidification and transformation conditions for a large set of Fe-Ni-Cr-6Mo-X compositions, where X represented one of nine elements. Small ingots of the selected favorable compositions were created using an arc-melting process. Microstructural analysis and ferrite measurements were used to reveal the microstructural development of each button. Results showed that further study of the Fe-Ni-Cr-6Mo system was required, so 12 further alloys were generated from within the compositional range of interest. These were organized into two groups, one containing alloys of similar Fe content (64wt%) and another set containing an equivalent Cr_{eq}/Ni ratio (=1.57).

The chief goal of the thermodynamic modeling of the Fe-Ni-Cr-6Mo-X system was to observe its effects on the range of Cr and Ni compositions which will enable a ferritic-austenitic (FA) solidification mode. The addition of the X element led to several effects: shifting of the eutectic line, narrowing of the FA range by shifting the maximum solubility of Cr, or by shifting the martensite line defining the appearance of this phase. Only the elements Mn and Si were found to be useful in widening the range of available dilutions between the proposed filler metal and SASS base metal. The available dilution range over the entire FA mode range was calculated. A small matrix of experimental alloys was created using varying levels of these elements. Unfortunately, metallographic analysis showed that these elements increased the incidence of sigma-phase, a brittle intermetallic undesirable in a weld zone. Results from several of these alloys implied that further investigation was required for 6wt%Mo alloys in the compositional range of interest.

Several Fe-Ni-Cr-6Mo alloys were also created to investigate the progression of the ferrite-to-austenite solid-state phase transformation as a function of composition within the FA range. The constant Fe compositions were shown to increase in residual ferrite content as the Cr content was increased. This was shown to be not only a function of solidification mode (AF, FA, F), but also the solvus temperature at which the alloy entered the single phase austenite region of the phase diagram. The constant Cr_{eq}/Ni alloys, however showed a change in the residual ferrite content based on the degree of sigma-phase present. While the sigma-containing alloys contained the least residual ferrite, these alloys were eliminated from consideration due to the poor mechanical and corrosion resistance properties of sigma-phase.

The combined results of the alloys made in this study permitted selection of three candidate filler metal compositions for further testing.

Several steps have been taken to bring to market a filler metal for welding superaustenitic stainless steels that will allow several benefits over current filler metal solutions. The alternative microstructural development sequence improves the weldability and corrosion resistance while still generating a fusion zone composed predominantly of austenite, thus matching the toughness of the base metal. In addition to these engineering benefits, the Fe-based composition will see significant cost savings over Ni-base filler metals. The use of SASS metals is continuously growing, and the utilization of a more effective filler metal for joining will only enhance their range of applications.