B. Effect of HED Welding on the Microstructural Development of Superaustenitic Stainless Steels

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The use of conventional arc welding methods used to join the newest class of superaustenitic stainless steels (SASS) creates a weld microstructure susceptible to accelerated localized corrosion due to the microsegregation of molybdenum (Mo) during solidification. High energy density (HED) welding processes can potentially restore corrosion resistance in the fusion zone by inducing significant amounts of dendrite tip undercooling, which can cause solute enrichment of the dendrite cores without the need for expensive filler metals. The ability to reduce microsegregation in this manner hinges on identifying the proper set of processing parameters to provide the required weld performance. Because experimental process optimization to achieve this is time-consuming and cost prohibitive, a multi-tiered solidification model must be developed to predict the microstructural development and performance of these alloys as a function of the HED welding parameters.

In this study, the commercially available SASS alloy AL-6XN were tested along with three experimental SASS and Ni-base compositions chosen to simulate the solidification behavior of AL-6XN while isolating the contribution of individual alloying elements to the overall solidification behavior of the material. A series of electron beam welds were made over a range of powers and travel speeds to provide a variety of rapid solidification conditions. The experimental data collected during fusion zone characterization will be used to validate a weld solidification model being developed concurrently to describe weld pool dimensions, dendrite core composition, and microstructural development in SASS alloys as a function of composition and HED welding parameters. This information will be used to create process-microstructure maps for rapid solidification welding conditions, which will provide an avenue for control of weld performance for engineering applications in aggressive environments.

The preliminary results of weld pool and microstructural characterization of a series of electron beam welds prepared over a range of rapid processing conditions will be presented. Measurements of weld pool dimensions will be correlated with published heat flow models, which can describe weld pool shape as a function of welding parameters (power and travel speed). These heat flow models can be incorporated into a description of solidification velocity, which controls dendrite core composition and therefore fusion zone corrosion resistance, as a function of power and travel speed. The importance of including the crystallographic contribution of dendritic growth to the velocity of the solid/liquid interface during weld solidification in polycrystalline materials will also be made apparent. While increased solidification velocity can potentially enrich the dendritic core Mo-content, its effect on the microstructural development of the superaustenitic class of stainless steels (and Ni-base alloys with similar composition) must be analyzed, particularly to ensure the absence of ferrite in the microstructure for applications that require nonmagnetic properties. Modifications of solute redistribution models, previously presented for these materials under casting and conventional weld conditions, to describe rapid solidification behavior will also be discussed. Finally, the preliminary observations of material behavior for electron beam welding will be directly compared to the experimental results of the previous study of conventional arc welding conditions to demonstrate shifts in microstructural development. Combined with modeling results, these experimental data provide the validation essential to the development of process-microstructure maps that can describe microstructural development of SASS and Ni-base alloys as a function of welding parameters.

This study integrates experimental data and solidification modeling to describe and predict the microstructural development of SASS and Ni-base alloys under rapid solidification conditions. This work will provide the scientific understanding essential for the effective implementation of HED processing into the manufacturing of large-scale structures. These solidification simulations, combined with a detailed correlation between microstructural development and welding process parameters (power and travel speed), will result in a predictive model that will provide an avenue for engineering control of fusion zone properties. Furthermore, the technical approach presented in this study can be extended to other alloy systems to maximize material performance.