

B. Microstructural Characterization of Inertia Welded 21-6-9 Stainless Steel

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Introduction

Forged austenitic stainless steel of 304L composition fabricated using fusion welding processes is often used for the storage and handling of hydrogen gases. However, in a quest to improve the performance of relevant components, the use of both higher-strength stainless steels and welding processes that produce joints having a higher fraction of parent metal strength have been investigated. Specifically, the use of nitrogen-strengthened austenitic stainless steel alloys joined using the inertia welding process has been studied. The combination of rapid heating and cooling rates coupled with the highly localized plastic strain associated with inertia welding produce unique microstructural features.

Technical Approach

For this study, hollow cylinders were welded using a wide range of processing parameters. The cylinders were made of 21-6-9 stainless steel (Nitronic 40) from two different starting conditions: forged and annealed. The specimens were instrumented with thermocouples to measure the temperature profiles obtained during welding. After welding, microstructural characterization was performed using optical, scanning electron, and focused ion beam microscopies. Both single and dual stage upset welds were made. Fracture property measurements of the weld interface were made using both uncharged and hydrogen-charged three-point bend and notched tensile specimens.

Results/Discussion

The processing parameters were varied such that a large range of material upset was obtained. It was observed that varying the processing parameters had a significant impact on the resulting interfacial microstructure. While initially both the annealed and forged material microstructure had minimal amounts of ferrite (<1%), the resulting weld interface was observed to have a considerable amount of ferrite present at the grain boundaries of a very fine-grained austenite region. At the interface, the ferrite and austenite exhibited a Kurdjumov-Sachs orientation relationship, as noted through the use of electron backscattered diffraction. It was observed that the width of the weld joint interface could be varied by almost a factor of 10, and appeared to be a stronger function of the chosen processing parameters as opposed to the total amount of upset. There also appeared to be a relationship between the composition of the starting material and the formation of the ferrite at the interface. Specifically, compositional banding in the starting material appears to impact the post-weld ferrite morphology and quantity.

In addition to the microstructural characterization, mechanical properties of the weld joints were also studied. Full section weld specimens were tested in tension to evaluate the strengths of the resulting inertia welds. In addition, the fracture properties of the different weld joint interfaces were measured both in the absence and presence of hydrogen. The results of these tests were compared with the results obtained for this alloy joined by traditional fusion welding processes.

Conclusions

The inertia welding process was used to join 21-6-9 weld samples. The samples were found to have an unexpectedly large amount of ferrite at the interface that has the potential to be detrimental for hydrogen storage applications. Extensive microstructural characterization was performed to correlate the weld microstructural features to the processing parameters in an effort to control the morphology and quantity of ferrite. Furthermore, mechanical property measurements, in particular hydrogen-assisted fracture resistance, were examined.