Microstructural and Mechanical Characterization of Friction Stir Welded (FSW) Alloy 690

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Introduction

Friction stir welding is a relatively new solid state joining process where a non-consumable rotating tool is used to produce frictional heating and mechanical mixing of the joint. Friction stir welding offers many advantages relative to fusion welding including less compositional segregation, fewer weldability problems, lower residual stress, and decreased distortion. While this process has been used primarily for low melting point materials such as aluminum, the recent development of polycrystalline cubic boron nitride (PCBN) tools has enabled the FSW process to join higher melting point metals, such as ferritic, austenitic and duplex stainless steels. However, limited work has been done on these materials to date and research is needed to better define weld parameters and characterize the microstructure and properties of friction stir welds of these higher melting point alloys. The present work seeks to define suitable tool geometry and welding parameters for a Ni-Cr-Fe alloy, A690, and to characterize the microstructure and tensile properties of this weldment.

Technical Approach

A690 plates were joined in the butt weld configuration and FSW was performed using position control (constant displacement between tool and backing plate). This work investigated two different PCBN tool geometries and five different processing parameters to produce a “best effort” weldment. The mechanical properties were characterized using both micro hardness measurements and tensile testing. Tensile testing utilized a double reduced specimen design to ensure that the properties accurately reflected the weld nugget, and were not influenced by the heat affected zone or the base material. Microstructural characterization was performed using both light optical and scanning electron microscopy (SEM). (Note that all welds were done at MegaStir).

Results/Discussion

Tool geometry had a significant impact on weld consolidation. A frustum shaped tool with three flats produced voiding at the root of the nugget and wormhole defects along the advancing side for tool rotations between 200-450 revolutions per minute and 2 inch per minute (ipm) travel speed. These defects are a result of insufficient material flow in the nugget, which is due in part to the low thermal conductivity, and resultant flow stress gradient. A threaded frustum shaped tool (200 rpm, 1 ipm) resulted in a fully consolidated 24” long weldment with at least 3/16” depth of penetration. However, Vickers hardness testing of the fully consolidated weld revealed a hardness gradient within the nugget. The hardness within the nugget was at least that of the base metal (207 HV) and peaked at 355 HV. Microstructural characterization indicated that the hardness gradient was a function of grain refinement and redistribution of Cr rich second phase particles from predominantly intergranular to a uniform distribution. The yield strength and ultimate tensile strength (UTS) of the FSW nugget were 14% and 5% greater than that of the base metal, respectively, while the elongation (~55%) and reduction in area (~51%) remained nearly constant. Fractography performed on the tensile specimens revealed that in all cases the nuggets failed by a classical microvoid coalescence fracture mode.

Conclusions

For the range of parameters investigated, wormhole and voiding defects were present in all welds made using a frustum shaped tool with three flats. Conversely, a threaded frustum shaped tool produced a fully consolidated weld with 3/16” penetration. The Vicker’s hardness, yield strength and UTS of the nugget were all greater than that of the base metal, while the reduction in area and elongation remained nearly constant. This increase in mechanical properties was attributed to grain refinement and uniform distribution of Cr rich second phase particles. Consistent with the high tensile ductility, specimen fracture surfaces displayed microvoid coalescence.