

Microstructures and Mechanical Properties of Inertia Friction Welds Between 304 SS and 6061-T6

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Introduction

Efficient design strategies occasionally dictate joining of dissimilar metals and alloys to take advantage of their individual properties and performance in different locations of the assembly. An example of dissimilar joining for a design of current interest involves joining of 304 stainless steel to aluminum alloy 6061-T6. Conventional fusion welding is not feasible with this combination due to the formation of brittle intermetallic phases (ex. Al_3Fe and Fe_2Al_5) during solidification that limit joint properties. The objectives of this work were to characterize the microstructures and mechanical properties of inertia friction welds (IFRWs) of these materials.

Technical Approach

Two sets of IFRWs were produced between samples of 6061-T6 and 304 SS. Microstructural analysis was performed on welds made with 1" diameter solid bars of each material. Microstructures of the various weld regions were characterized using light optical microscopy (LOM), scanning-electron microscopy (SEM) and transmission electron microscopy (TEM). Microhardness traverses were performed across the weld region on polished, unetched samples.

Mechanical test samples were taken from welds produced on 7" diameter thick walled pipes. The weld tensile strength was evaluated using notched samples in order to focus the fracture location near the weld interface. Surfaces of the tensile samples were examined using SEM to characterize the fracture mode. Ductility of the weld samples was evaluated by bend testing of flat bars. Notched fatigue tests were run at a mean stress of 20 ksi and a frequency of 15 hz.

Results/Discussion

Defect-free welds were produced, and nearly all of the deformation occurred in the 6061. Examination of the weld area revealed evidence of sensitization and pitting in the 304 immediately adjacent to the weld interface. No evidence of liquation or eutectic melting was found in the 6061. These observations suggests that peak temperatures during IFRW were below the solidus temperature of the 6061 (597°C) and likely below the ternary eutectic temperature for the Al-Mg-Si system (559° C) but above ~500°C for sensitization to occur. Examination of the 6061 base metal and weld region revealed the presence of a considerable volume fraction of intermetallics rich in Fe and Si. However, it is not clear if the intermetallics found near the weld interface formed during welding or were just those already present in the base metal that were pushed to the interface as the 6061 deformed. Microhardness results indicated a region with reduced hardness in

the 6061 adjacent to the interface suggesting the presence of an overaged heat-affected zone (HAZ) region stemming from the effects of the weld thermal cycle.

The average tensile strength for four samples was 53.7 ksi with a standard deviation of 0.34 ksi. This value exceeded the typical UTS for 6061-T6 base metal (45 ksi) due most likely to constraint effects from the harder 304. All samples failed adjacent to the weld interface in the near HAZ of the 6061. A 1/8" thick sample bent through 180° to a strain of 5.25% without cracking. A partial S-N fatigue curve was established based upon the tensile and fatigue results.

SEM examination of the tensile samples indicated a dimpled fracture surface that suggested a ductile mode of fracture. Intermetallic particles were found at the bottom of each dimple. Two types of intermetallics were found: Al-Fe-Si rich and Al-Bi-Ca rich as seen in the EDS spectra. Failure was apparently dominated by decohesion of the particles from the 6061 matrix followed by coalescence of the dimples.

Conclusions

Defect-free IFRWs were made between 304 SS and 6061-T6. Nearly all of the deformation occurred in the 6061. A sensitized region was found immediately adjacent to the weld interface in the 304. The 6061 base metal and weld region contained considerable amounts of intermetallic phases. Microhardness results showed a drop in hardness in the HAZ of the 6061 indicating overaging. All tensile samples failed near the weld interface through the 6061 HAZ. Tensile strengths averaged nearly 54 ksi, much greater than that for the 6061-T6 base metal. Bend tests withstood elongations in excess of 5.25% strain. A partial S-N fatigue curve has been determined. Fracture surfaces of the tensile tests exhibited dimpled morphologies indicative of ductile failures. Failure was apparently dominated by particle decohesion.