Understanding the Material Flow Mechanisms, Microstructure Evolution, and Mechanical Properties in Friction Stir Welding of Dissimilar Metal Alloys

Xiangbin Wang

Abstract: Friction stir welding is a solid-state welding process that has demonstrated the ability to join dissimilar aluminum and other alloys that are unweldable by conventional fusion welding techniques. To optimize the process, it is imperative to develop a fundamental understanding of the material flow, microstructure evolution, and defect formation mechanisms, and establish correlations with the mechanical behavior and properties of the welds for a broad range of processing conditions. Dissimilar welds fabricated using multiple tool rotation and traverse speed combinations have been investigated for three heat treated wrought aluminum alloys (6061-T651, 2024-T351, and 7075-T735), located systematically on both the advancing and retreating sides of the weld. Flow stress difference between the two joining materials was found to be a critical factor impacting the material movement patterns. Tool rotation and traverse speeds affect the interactions between the two key weld material flows – shoulder-driven flow and pin-driven flow – that dictate the defect formation mechanisms in dissimilar friction stir welds. Microstructure evolution and process-microstructure relationships have been systematically studied with respect to their contributions to the micro-hardness variations and tensile properties of the welds. Residual stresses, which are critical to the performance and integrity of structural components, are inherently generated in friction stir welding due to the thermo-mechanical deformation. The effects of the residual stress distributions, characteristic microstructures, and hardness in different regions of the welds on the fatigue crack growth behavior of friction stir welds have been investigated to elucidate their individual and combined interactions. In addition to dissimilar aluminum alloys, friction stir welding opportunities for highly dissimilar alloy systems have also been explored. Friction stir lap welding was pursued for joining aluminum alloys (6061-T651) and steels (JAC 270 45/45), and the weld quality, strength, and failure mechanisms under varied processing parameters and tool penetration depths were evaluated. A novel double-pass welding method was successfully developed to eliminate interfacial defects and brittle intermetallic compounds and to optimize the weld strength as compared to the single-pass welds. The integrated findings from these studies will be presented and discussed from both process optimization and properties enhancement perspectives, for use in transportation applications where lightweight and structural integrity are critical design considerations.

Advisor: Professor Diana A. Lados

Committee Members:
Professor Richard D. Sisson
Professor Brajendra Mishra
Professor Anthony G. Spangenberger
Dr. Qigui Wang, General Motors
Mr. Alan Seid, Honda R&D