

# **Characterization and Modeling of Friction Stir Welds in Al 2519-T87**

*by R.W. Fonda and S.G. Lambrakos, Naval Research Laboratory*

## **Introduction**

Friction stir welding is a complex process that is typically modeled by what may be termed the direct-problem approach, where the temperature field across the weld is calculated from the heat and material flow induced by the stirring tool. This approach involves complex, interrelated calculations and an *a priori* knowledge of heat and material flow properties as a function of temperature. We will present an alternative approach, the inverse-problem approach, which uses many of the same calculations to define the problem, but uses data from the outer regions of the weld to constrain the possible solutions in a self-consistent manner.

## **Procedure**

The inverse-problem approach generates a temperature field from an effective distribution of heat sources which represent the friction stir welding process “as viewed” from positions within the heat affected zone (HAZ). This temperature field is scaled according to experimental information about temperatures achieved at specific locations within the HAZ. These locations were selected because heat conduction is the only mode of physical transport in the HAZ. From this information, the three-dimensional temperature fields across the HAZ and into the thermo-mechanically affected zone can be determined in an internally consistent manner.

## **Results & Discussion**

Friction stir welds in Al 2519 were prepared with systematically varied parameters to determine their microstructural variation with processing conditions and to compare those experimental results with the self-consistent predictions of an inverse-problem model of the friction stir welding process. A variety of microscopy techniques were used to identify the precipitation, defect structure, crystallographic texture, and grain size characteristics of the microstructure as a function of processing conditions and position within the weld. Maps of the microhardness across the transverse cross sections of the welds correlate these microstructural features to the local mechanical properties.

These friction stir welds were also modeled by an inverse-problem approach to simulate the thermal fields due to the welding process. Initial results showed a good qualitative agreement between the model predictions and the observed weldment microstructure. The thermal field model was subsequently enhanced by correlating the observed microhardnesses across the HAZ and between weldments to the microhardness variations resulting from thermal cycles simulating those experienced in

the HAZ. This data was used to scale the temperature field to produce an internally consistent, three dimensional temperature field across the heat affected zone and into the thermo-mechanically affected zone. These experimental and modeling results will be discussed in terms of their impact on the observed yield strength and fracture behavior of the friction stir welds.

## **Conclusions**

Thermal field modeling of friction stir welds in Al 2519-T87 by an inverse-problem approach produces good agreement with the experimental observations. This is an internally consistent model that can predict thermal cycles throughout the heat affected zone and into the thermo-mechanically affected zone. As such, it can be used to predict mechanical property variations within friction stir welds as a function of processing conditions, and could therefore be used to optimize the processing conditions and tool designs used in friction stir welding.