Characterization of Friction Stir Welding (FSW) Microstructure
Nanoscale Mechanical and Electrical Characterization using nanoECR®

Introduction

Eddy current measurements and Vickers indentation are commonly used at macroscale to assess the uniformity and identify the temper of bulk aluminum alloys, which are widely used in the aerospace industry. Most thermo-mechanical processing is done at a large scale where homogeneity of the metal is desired. However, there are fabrication and joining processes where the thermo-mechanical properties are non-homogenous. One such process is the solid state joining technique of friction stir welding (FSW). Numerous studies have been reported which identify the rotational tool velocity as the parameter with the most impact on the weld quality [1].

In an effort to improve characterization of FSW microstructure, a study of 3 cross-sectioned welds [2] formed at constant travel velocity with varying tool rotations (RPMs) was performed using nanoscale mechanical and electrical characterization techniques. Samples consisted of aluminum alloy AA2219 joined using FSW at rotational speeds of 150, 200, and 300 RPM.

Experimental

Indentation experiments were conducted using a Hysitron TI 950 TriboIndenter® nanomechanical test instrument equipped with nanoECR (Nanoscale Electrical Contact Resistance) and a conductive boron-doped diamond Berkovich probe.

First, lines of 10 mN indents were performed across the width of each sample to measure variations in mechanical properties.

To study electrical properties, an automated set of 100 indents were performed in the center of the weld nugget and at the outer edge of each sample. Each indent consisted of a 5 mN load and a constant applied voltage of 2 V. The resulting current was measured and the average current density was calculated.
Finally, Piezo Automation was used to specifically target precipitate and base aluminum regions within the Sample 200 nugget. This technique involved pre-scanning the sample surface using in-situ SPM imaging for identification and specification of target test sites, and was crucial for precise test placement in locations on the order of only a few microns in size. Reference grain size for the samples ranged from 2 to 4 µm. Nanoscale mechanical and electrical measurements were performed in specified areas.

Results and Discussion

Results show that the Sample 300 nugget has a significantly higher hardness than the 150 and 200 samples (Fig. 1). This is likely due to the effects of natural aging. At higher rotational speeds and higher resultant processing temperatures, it is presumed the precipitates are driven into solution during FSW, after the cooling and subsequent natural aging of five years leading to fine precipitates of the type GPI or GPII.

The current density measurements (Fig. 4) show the presence of high current density “outliers”, particularly within the Sample 150 and 200 nuggets. These values were presumed to be linked to the presence of coarse Cu-rich precipitates concentrated along the grain boundaries.

Post-study SEM and XRD characterization confirmed the presence of Cu precipitates in Samples 150 and 200.

The results of the Piezo Automation (Fig. 3) confirm the link between the precipitates and high current density. Indents placed on precipitate regions showed significantly higher current density than those on base aluminum. The deficiency of high-current measurements observed on Sample 300 could be due small precipitate size.

Conclusion

Results from nanoscale mechanical and electrical characterization show that processing temperature of FSW has a strong impact on precipitate position and dispersion, affecting localized mechanical and electrical properties.

The nanoECR package can be used to study electrical properties related to grain microstructure as well as precipitate position and concentration within non-homogeneous metallic structures such as FSW samples.

References: