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EDS (Elemental) and TKD (Crystallographic) Confirmation of Nanoscale Mg/Al Intermetallic Layers Formed During Linear Friction Stir Welding

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Vehicle lightweighting, to improve fuel efficiency, handling, and EV range, has led to interest in joining dissimilar metals. The interface of a linear friction stir weld (FSW), between 1.27mm thick 6022 Al and 1.5mm thick EK100 Mg sheet, was being studied to correlate lap shear strength with the evolved microstructure. Multi-length scale (cm to nm) multi-model materials characterization showed evolution of 2nd phase nanostructures (Mg_2Si), intermetallic growth, elemental segregation, and grain size refinement at the FSW Mg/Al interface. Xray CT, EBSD, SANS, transmission Kikuchi diffraction (TKD) and 200kV STEM/EDS data were combined to determine changes in grain size and 2nd particle morphology. A complex mixing of metals within the FSW, leaving ribbons of ~100nm thick Al_3Mg_2 and $Al_{12}Mg_{17}$ layers were discovered through correlation of the 30kV TKD/EDS data from site specific lamella samples from various locations along the Mg/Al FSW interface [1].

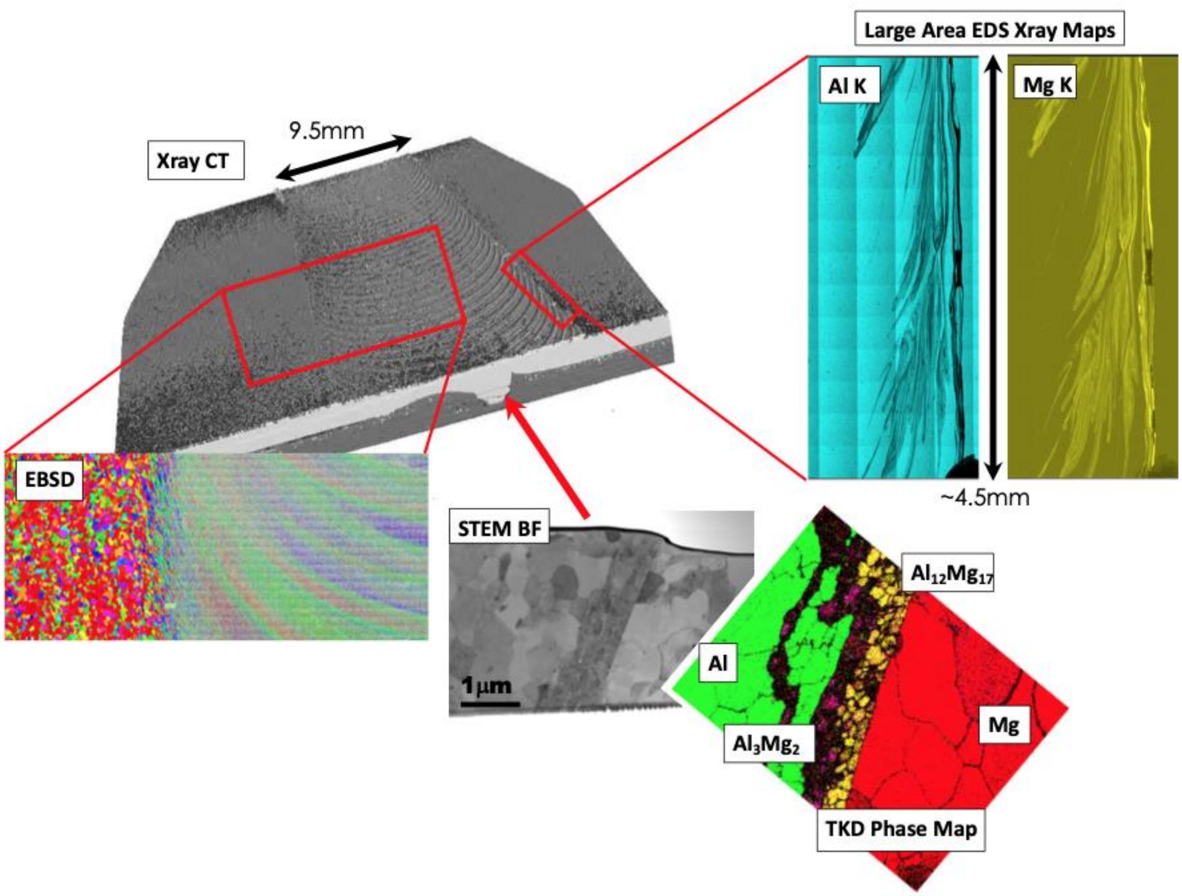

Figure 1. (Xray CT) This tomographic reconstruction from a 6022/EK100 Al/MG FSW lap sheer specimen shows the cross section of the weld interface at a 15um resolution. 6022 Al on top and EK100 Mg on the bottom of this lap weld, which is simulating a hem joint of a vehicle door frame, has a unique "hook" morphology at the interface indicated by the red arrow. This is the area where the light alloys mixed and formed nanoribbons of Al3Mg2 and Al12Mg17 intermetallics during the solid state joining. (EBSD) Large area mapping, with directly correlative EDS, FSD and EBSD on millimeter length scales, was used to understand the influence on morphology of FSW processing on 2^{nd} phase particles already present in the base metals. Unsupervised machine learning was used on high angle forward scattered micrographs, since this signal isolated the higher atomic number 2^{nd} phases without additional image processing of the 1024x768 images. The machine vision characterized size, shape of the 2^{nd} phases and also showed differences between base metal 2^{nd} phase particles and the 2^{nd} phase particles sampled in the dynamic re-crystallization zone of the FSW. (Large Area EDS Xray Maps) EDS mapping at the FSW interface, in the XY plane clearly highlighted the "swirl" of mixed Al and Mg metal present. Further site specific FIB prep and STEM/EDS of these swirls found them to be areas of ~4wt% Mg, but showed nanocrystalline layers of varying Mg/Al ratios. (STEM BF) Site specific FIB lift out, at the hook region interface was performed to identify phases that may have evolved during the FSW solid state processing between two immiscible metals. Peak temperature for this Al/Mg processing was temperature controlled at 380^{o}C by integrated thermocouple sensors integrated into the PNNL FSW tool. 200kV STEM/EDS was used to first asses the elemental composition and crystalline morphology of the interfacial layers present. The interface between the Al and Mg in this region, measured ~750nm thick and had a nanocrystalline appearance. STEM EDS maps showed ~10nm diameter Mg2Si dispersoids also involved in this region of the FSW interface. (TKD Phase Map) Further 30kV EDS and TKD confirmed that a nanoscale bilayer, composed of Al3Mg2 and Al12Mg17 existed at the hook region. The presence of this bilayer, and the large amount of it occurring at the swirled interfacial region have informed phase field models trying to model the corrosion response in these mixed metal/IMC regions and a decrease in lap sheer strength after corrosion testing of these FSW samples.

Reference:

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