APPLICATION NOTE

Aerospace aluminum alloy 2099 friction stir weld analysis

GKN Aerospace utilizes transmission electron microscopy to understand the processing-structure-property relationship

Introduction

Friction stir welding (FSW) is a joining technique that creates a weld by stirring solid metal between adjoining plates rather than melting it. This solid-state process will locally heat the metal to around the hot forging temperature, which is much lower than traditional fusion welding processes. One motivation to try FSW is precipitation hardened alloys like our Al 2099 which is not easily welded by fusion due to severe cracking. Other benefits of FSW include reduced distortion, lower residual stresses, and the simplicity of creating welds on common machining equipment.

The friction stir welding process has been tested by GKN Aerospace, at the facilities of TWI, Inc., with the goal of improving the manufacturing of stiffened wing structures by replacing rivets with non-traditional welding. Multiple weld tests were conducted with variables such as single- or double-sided FSW, machine speed and metal surface treatment. Test samples were provided to Warwick Manufacturing Group (WMG) for analysis by optical microscopy, electron backscattered diffraction (EBSD), and transmission electron microscopy, though a complete understanding remained elusive.

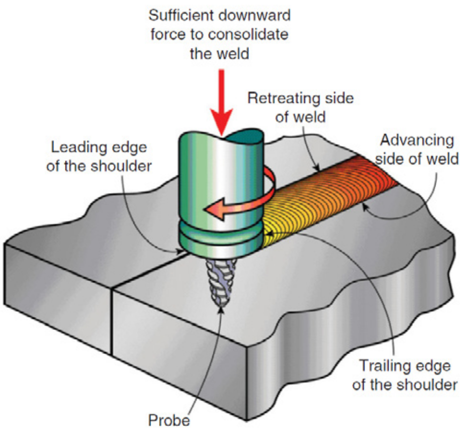

Figure 1: Single-sided stir friction welding site. Image courtesy of TWI.

Methods and results

Hardness mapping revealed to GKN Aerospace the impact of FSW on mechanical performance, where the weld region suffered about 18% loss of harness and strength.

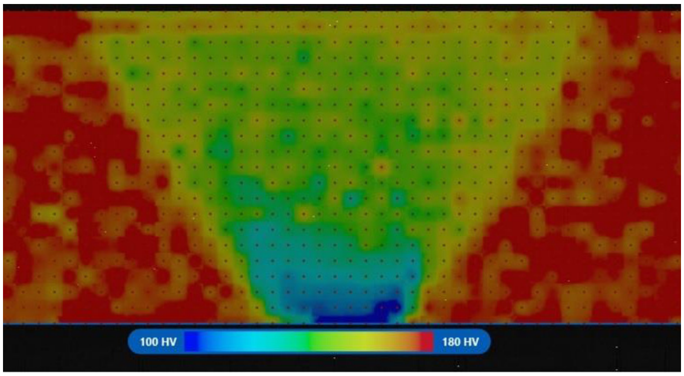

Figure 2. Hardness test mapping on a FSW cross section, courtesy GKN Aerospace.

WMG performed EBSD imaging using the Versa 3D DualBeam, formerly produced by FEI, which helped provide a deeper dive into the microscopic structure showing detailed differences in grain size in the different regions. GKN Aerospace could then see that the grain structure of the weld had been entirely changed. The stirred zone revealed a banded texture with grains finer than the base metal. The HAZ yielded a new grain orientation with some grain growth, and the base metal remained unaffected by the welding process.

The high misorientations of the base metal were indications

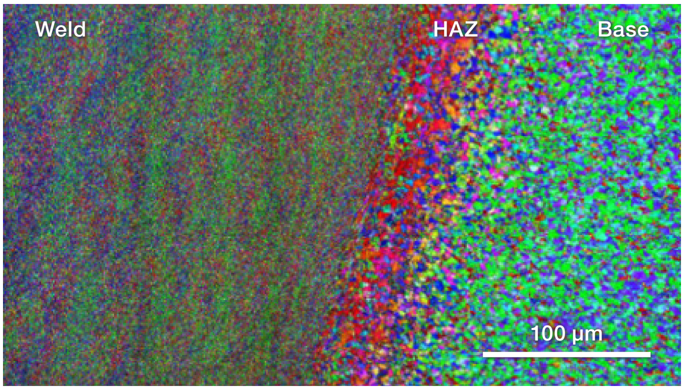

Figure 3. EBSD imaging of the weld, HAZ, and base metal regions, courtesy of WMG (Warwick Manufacturing Group), University of Warwick.

of plastic deformation, work-hardening, and accumulation of dislocations. These characteristics, which were responsible for the high strength of the Al 2099 base metal, were now absent within the stirred zone. While grain refinement is known to contribute to an increase in strength, the apparent loss of dislocations in the stirred zone will negatively affect the strength.

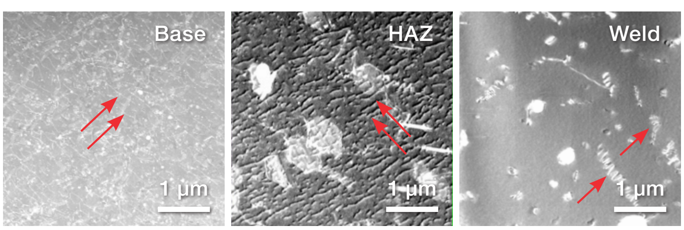

Figure 4: Thermo Scientific Talos F200X STEM mode imaging of dislocations.

The Thermo Scientific™ Helios™ 5 Laser PFIB was used to prepare TEM lamellae for nanometer-scale analysis.

TEM analysis using the Thermo Scientific Talos™ F200X TEM imaging in STEM mode across the different regions showed the change in dislocations from base to HAZ to weld.

GKN Aerospace concluded that the base metal and HAZ have a high density of edge dislocations, whereas the weld has lost these in favor of only a few screw dislocations.

Finally, chemical mapping by EDS and particle quantification by Automated Particle Workflow (APW) was conducted. Both the base metal and HAZ showed the T_1 (Al_2CuLi) type of precipitate, though they had become coarser in the HAZ. Conversely, the weld area had none of the T_1 precipitates, as the copper is now present in the T_β ($Al_{7.5}Cu_4Li$) precipitate. If the base metal was considered the optimum structure, then the HAZ retained some of the strengthening T_1 precipitates, and the weld had lost the T_1 precipitate altogether.

Conclusions

It was concluded that the friction stir welding of this alloy will destroy the dislocations and precipitates required for high-strength aluminum. This confirmation guided GKN Aerospace to not pursue FSW for this alloy or product. High-res TEM/EDS analysis of precipitates was made simple with the Talos F200X TEM and our Automated Particle Workflow (APW).

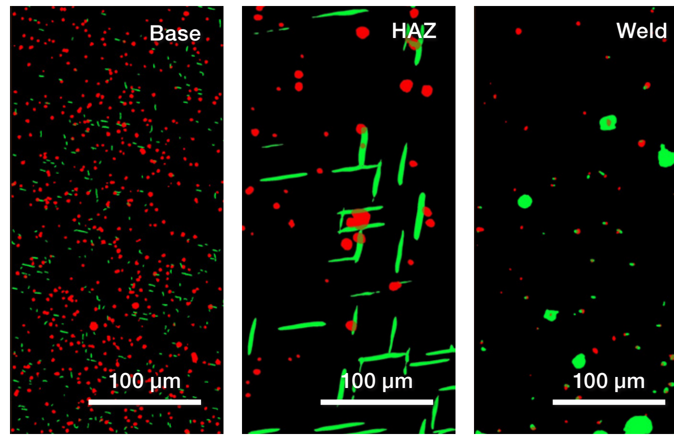

Figure 5: Friction stir welded Al 2099. The green represents copper, the red represents zirconium, and the green platelets are the T_1 precipitate in the base and HAZ.

Automated Particle Workflow on Aluminum 2099 alloy

Duration 0:53

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