Friction Stir Welding of ALMgSc alloy

U. Alfaro Mercado, H.W. Sauer
AlMgSc- Alloys

- Work hardened alloy ⇒ HX (strain hardened + partially annealed)
  - High microstructural stability due to coherent stable Al$_3$Sc-phases retarding the recrystallization and inhibiting grain growth [1]
  - Relaxation formable

AlMgSc vs. AA2024-T3[2]

+ 5% lower density
+ Excellent weldability (no hot crack sensitivity, high joint strength)
+ Excellent corrosion resistance
+ Reduced fatigue crack growth rate (-20% at ΔK=25 MPa√m)
- Reduced tensile strength (-10%)
- More expensive

Friction Stir Welding

- a solid state joining process
- welding temperatures up to 0.8 $T_m$
- Hot “metalworking” process → tailored welded blanks
- High static and dynamic mechanical performance
- Defect free joints
- Weight and (manufacture) cost reduction:
  - Elimination of riveted joints
  - Integral stiffened structures
Advantages of AlMgSc alloy for Aircraft structure manufacturing

- LBW of stringer (flat)
- Relaxation forming
- FSW of relaxation formed Panels
Parameter finding / Quality assurance

Initial parameter set

Visual inspection

Bending test
“coarse” welding flaws @ root

Ultrasonic test:
• Root flaws
• Lack of penetration (LoP)
• Tunnels

Hardness

Characterization

Mechanical:
• Hardness
• Tensile Strength
• Fatigue (SN-curve)
• Crack growth (uni- & biaxial)

Light Microscopy:
• Corroboration of the flaws

Microstructural:
• Light microscopy
• SEM (EBSD)
• TEM
FSW Parameters

**Alloy**

- Ko8242

**Butt Joints**

- 0.4 mm
- 1.6 mm
- 2.4 mm
- 3.2 mm
- 5.4 mm

**TWB- Geometry**

- 1.6 mm to 3.2 mm
- 2.4 mm to 3.4 mm

**Welding Equipment**

- CNC milling machine
- Position control
- Dynamometer for registering of welding loads

**Welding Tools**

- Scrolled Shoulder (φ = 12.5 mm and 18 mm)
- Conical profiled Pins (φ = 4.5 mm and 6 mm)
Microstructure (light microscopy)
Butt joints in several thicknesses

- **1.6 mm**
- **2.4 mm**
- **3.2 mm**
- **5.4 mm**

Nugget with onion ring pattern formed by plastic flow and mixing of both materials.
Microstructure (light microscopy)
Butt joints & TWB

Nugget with onion ring pattern formed by plastic flow and mixing of both materials
Microstructure
(common features: TMAZ)

- Nugget with onion ring pattern formed by plastic flow and mixing of both materials
- Grains several times deformed up to 90° at thermo-mechanical affected zone (TMAZ)
Microstructure (common features: TMAZ)

- **Weld nugget**: very fine grained structure of (grain size 1 to 5 µm)
- **Thermo-mechanical affected zone (TMAZ)**: mixture of elongated and equiaxial grains
Microstructure
SEM (EBSD)
Mechanical Characterization
(Hardness profile)
Mechanical Characterization
(Hardness profile)
# Mechanical Characterization (Tensile Strength)

<table>
<thead>
<tr>
<th>Joint geometry</th>
<th>Thickness [mm]</th>
<th>Ultimate Strength [MPa]</th>
<th>*FSW\text{index} [%]</th>
<th>Fracture site</th>
<th>Bending test</th>
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<tbody>
<tr>
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<td>1,6</td>
<td>304</td>
<td>78</td>
<td>Weld nugget</td>
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<tr>
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<tr>
<td>Base Material</td>
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</table>

*FSW\text{index} = \frac{UTS_{FSW}}{UTS_{BM}}
Mechanical Characterization
(Tensile Strength – local elongation measurements)
Mechanical Characterization
(Tensile Strength)
Mechanical Characterization
(Tensile Strength – local elongation measurements)
Mechanical Characterization
(Tensile Strength – local elongation measurements)
Gap Tolerance

**Material:**
- 2.5 mm Ko8242

**Welding tools:**
- φ12.5mm scrolled shoulder
- φ4.5mm conical profiled pin

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</table>
Gap Tolerance

- **Visual inspection:**
  - Completely closed gap
  - No open sites (LoP, Flaws at upper side or root)

- **Bending test:**
  - Passed
  - Bending angle: 60°
  - No cracks or open sites

- **Tensile Strength:**

<table>
<thead>
<tr>
<th>Probe</th>
<th>Gap [mm]</th>
<th>UTS [MPa]</th>
<th>Bending test</th>
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<td>BL990</td>
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</table>
Gap Tolerance

Graph showing hardness profile with different gap tolerances:
- 0 gap
- 0.25 gap
- 0.5 gap

The graph indicates the hardness variation at different distances from the weld center line for each gap condition.
Summary

High quality sound butt and tailored welded blanks joints of several thick sheets of aluminum-magnesium-scandium alloy Ko8242 were successfully produced using the FSW process

- Hardness drop in the weld nugget area most likely due to recrystallization
- Different fracture sites for butt joints and TWB during tensile test
  - Weld nugget of the butt joints resulted as the weakest link (80% to 95% of the UTS of the BM Ko8242)
  - The weak weld nugget of the TWB was reinforced with the increase in thickness causing the failure of the thinner base metal
- The Ko8242 alloy is a highly gap-tolerant alloy. Even welded with a 0.5 mm gap, the 2.5 mm thick butt joints did not exhibited any flaws maintaining similar tensile strengths.
Acknowledgement

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Thank you for your attention!