Parameter optimization of AA6061-AA7075 dissimilar friction stir welding using the Taguchi method

Luqman Hakim Ahmad Shah

Manufacturing Focus Group (MFG)
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
Introduction: Friction stir welding (FSW)

- Solid state welding process.
- Invented and patented by TWI in 1994.
- “A non consumable rotating welding tool is plunged into adjoining parent materials. Frictional heat generated by the tool shoulder during this process causes the materials to soften and local plastic deformation to occur” (Dressler et al, 2009)
- Proven to weld similar and dissimilar welding

Applications
- Aircraft and aerospace industry
- Ship building
- Train body frames (KTM)

Source: www.holroyd.com
Introduction : AA6061 & AA7075 Alloys

✓ ~99% of FSW process involves aluminium alloys
AA6061
✓ Contain major alloying elements of Al-Mg-Si
✓ Heat treatable, excellent corrosion resistance, high strength, good formability and weldability
AA7075
✓ Contain major alloying elements of Al-Zn
✓ Heat treatable, very high strength
Significant parameters in FSW

- Tool shape & geometry
- Material of tool
- Axial force
- Tranverse Speed
- Rotational Speed
- Single/multiple pass
- Tilt angle
- Revolutionary pitch
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Paper</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lakshminarayanan et al.</td>
<td>2007</td>
<td>Process parameters optimization for FSW of RDE-40 aluminium alloy using Taguchi technique</td>
<td>Rotational speed, transverse speed and axial force are key parameters</td>
</tr>
<tr>
<td>Jayaraman et al.</td>
<td>2009</td>
<td>Optimization of process parameters for FSW of cast aluminium alloy A319 by Taguchi method</td>
<td>FSW of A319 was optimized</td>
</tr>
<tr>
<td>Koilraj et al.</td>
<td>2012</td>
<td>FSW of dissimilar aluminium alloys AA2219 to AA5083</td>
<td>Dissimilar welding between AA2219-AA5083</td>
</tr>
<tr>
<td>Yashar Javadi et al.</td>
<td>2014</td>
<td>Taguchi optimization and ultrasonic measurement of residual stresses in the friction stir welding</td>
<td>FSW of AA5086 was optimized</td>
</tr>
</tbody>
</table>
Problems statement

Guo et al. (2014) successfully welded AA6061-AA7075 together. Some findings:
- Better results when AA6061 (weaker side) at advancing side.
- Three distinct sublayers
- Microhardness decrease

Motivation:
- Although results were promising, no mention of parameter optimization.
- To ensure replicability and robustness, a systematic parameter optimization approach is crucial.
OBJECTIVE

1. Fabrication and optimization of 6061-7075 dissimilar FSW.
2. Analyze the microstructure and mechanical properties of welded specimen

SCOPE

1. FSW of 6061-7075 by using H13 tool and milling machine while applying Taguchi method.
2. Investigate the specimen’s mechanical properties of the welds using Tensile test.
3. Analyze the microstructural changes of 6061 aluminum welds using optical microscope, SEM and EDX.
## Chemical composition of 6061 & 7075 aluminum alloy (mass %)

<table>
<thead>
<tr>
<th>Material</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA6061</td>
<td>97.7</td>
<td>0.54</td>
<td>0.40</td>
<td>0.24</td>
<td>0.01</td>
<td>0.84</td>
<td>0.006</td>
</tr>
<tr>
<td>AA7075</td>
<td>89.8</td>
<td>0.071</td>
<td>0.274</td>
<td>1.6</td>
<td>0.019</td>
<td>2.28</td>
<td>5.58</td>
</tr>
</tbody>
</table>

## Factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational speed</td>
<td>900</td>
<td>1000</td>
<td>1100</td>
</tr>
<tr>
<td>(rpm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse speed</td>
<td>90</td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td>(mm/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilt angle</td>
<td>3°</td>
<td>4°</td>
<td>5°</td>
</tr>
</tbody>
</table>
Taguchi technique

- Utilized L9 orthogonal array, i.e. 9 samples.
- Revolutionary pitch = TSpeed (mm·min⁻¹)/ Rspeed (rpm)
- Keep revolutionary pitch constant near 0.1 \((\text{Mishra & Ma, 2005; Cavaliere, 2008})\)
- S/N ratio calculated using

\[
S/N = \eta_{dB} = 10 \log \left[ \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right] = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)
\]

where \(n\): number of test, \(y_i\) is the experimental value.
RESULTS & DISCUSSION

- Optimum parameter
- Weld Appearance
- Microstructures
- Hardness Test
Weld Appearance and Taguchi

- Sound weld joint
- Minimal defects
- Tensile specimen cut using ASTM E8-09 standard
- All specimen break at Heat Affected Zone (HAZ) of AA6061 side (weak side)
Taguchi parameter optimization

<table>
<thead>
<tr>
<th>No.</th>
<th>Input parameter</th>
<th>Response</th>
<th>Mean value</th>
<th>S/N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rotation</td>
<td>Transverse</td>
<td>Angle</td>
<td>T1</td>
</tr>
<tr>
<td>1</td>
<td>900</td>
<td>90</td>
<td>3</td>
<td>187.69</td>
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<tr>
<td>2</td>
<td>900</td>
<td>100</td>
<td>4</td>
<td>193.84</td>
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<tr>
<td>3</td>
<td>900</td>
<td>110</td>
<td>5</td>
<td>193.52</td>
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<tr>
<td>4</td>
<td>1000</td>
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<td>4</td>
<td>188.40</td>
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<tr>
<td>5</td>
<td>1000</td>
<td>100</td>
<td>5</td>
<td>195.14</td>
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<tr>
<td>6</td>
<td>1000</td>
<td>110</td>
<td>3</td>
<td>208.94</td>
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<tr>
<td>7</td>
<td>1100</td>
<td>90</td>
<td>5</td>
<td>193.71</td>
</tr>
<tr>
<td>8</td>
<td>1100</td>
<td>100</td>
<td>3</td>
<td>167.72</td>
</tr>
<tr>
<td>9</td>
<td>1100</td>
<td>110</td>
<td>4</td>
<td>182.59</td>
</tr>
</tbody>
</table>

- L9 orthogonal array
- Highest mean tensile strength: **219.585 MPa**
- Optimum parameter: ROTATIONAL SPEED (1000 RPM), TRANSVERSE SPEED (110 MM/MIN) AND TILT ANGLE (3°).
- Calculated optimum tensile value: \( RS_2 + TS_3 + TA_1 - 2T = 209.735 \text{ Mpa} \) (Error: 4.49%)
Microstructure of AA6061-AA7075 joint

✓ MIXED REGION IN THE NUGGET ZONE
✓ NUGGET ZONE OF AA6061 EXPERIENCED REPRECIPITATION - MATERIAL UNDER HIGHEST TEMPERATURE AT THIS REGION.
✓ GRAIN STRUCTURE OF AA7075 NUGGET ZONE HAS BEEN REFINED FROM LARGE SCALE ELONGATED TO FINE EQUIAXED.
Typical dimple structure at fracture zone indicate ductile structure.

Presence of Mg and Si elements in fracture surface indicate AA6061 (Al-Mg-Si) composition.
FSW of AA6061-AA7075 were successfully welded with varying parameter conditions. The summary of the results are as follows:

- Good sound joints were obtained with minimal defects. Tensile fracture was at the HAZ of AA6061 side, i.e. the weaker side.
- Nugget zone of AA6061 experienced reprecipitation. The grain structure of AA7075 nugget zone has been refined from large scale elongated to fine equiaxed structure.
- SEM and EDX analysis indicate that ductile fracture occurred and fracture surface consists of AA6061 elements.
- The highest experimental value is 219.585 Mpa, whereas highest calculate value is 209.735 Mpa (4.49% error)
- The optimum parameter is 1000 rpm rotational speed, 110 mm/min transverse speed and 3° tilt angle.
Thank You
References


Advancing side VS Retreating side

- **Advancing side:** the side where the material weld enter a zone that rotates with the pin. Material at this side is highly deformed behind the pin to form curve shaped.

- **Retreating side:** the side where gaps are filled between the curve of advancing side. The material did not rotate around pin and results in larger grain.
Heat affected zone (HAZ): In this region, which clearly will lie closer to the weld centre, the material has experienced a thermal cycle which has modified the microstructure and/or the mechanical properties. However, there is no plastic deformation occurring in this area.

Thermo-mechanically affected zone (TMAZ): sufficiently heated and softened, process forces is high to result in plastic deformation of original grain structure. Low microhardness

Weld Nugget: The recrystallised area in the TMAZ called nugget. Compose of fine grain structure and have experienced severe plastic deformation due to pin interaction.