Friction Stir Welding of Automotive Aluminium Alloys

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  Weld appearance
  Microstructure
  Hardness Analysis
  Tensile properties

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Introduction

Nowadays reality
- Worldwide Market
- Demanding Customers
- Saturated Markets
- Competitors Aggressiveness

Main objective
Improve Competitiveness

Actions to develop
- Reduce production time/costs
- Improve production flexibility
- Increase quality
- Weight reduction

Promising solution
Friction Stir Welding

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Friction stir welding (FSW) process gives several benefits in welding difficult to weld aluminium alloys and allows joining dissimilar materials. Despite the evolution of the process in recent years, several difficulties continue constraining its generalization in industry:

- Limited knowledge in design of the welding tools;
- A strict control of the welding parameters is needed, chiefly in welding of very thin sheets;
- The reduction in mechanical properties in welds in some aluminium alloys.

The aim of this investigation is to study the effect of friction stir welding parameters on the microstructure and mechanical properties of welds in thin sheets (1 mm thick) of two automotive aluminium alloys.
Materials:

- Aluminium alloy AA 5182-H111 (provided by Novelis Switzerland SA)
- Aluminium alloy AA 6016-T4 (provided by Novelis Switzerland SA)

### Chemical composition (wt. %)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA 5182-H111</td>
<td>0.2</td>
<td>0.35</td>
<td>0.15</td>
<td>0.2</td>
<td>4.0</td>
<td>0.1</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
<td>0.5</td>
<td>5.0</td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
</tr>
<tr>
<td>AA 6016-T4</td>
<td>1.0</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>0.25</td>
<td>0.1</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
<td>max.</td>
</tr>
</tbody>
</table>

### Mechanical properties

<table>
<thead>
<tr>
<th>Alloy</th>
<th>R\textsubscript{p0.2} (MPa)</th>
<th>R\textsubscript{m} (MPa)</th>
<th>A\textsubscript{50} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA 5182-H111</td>
<td>114</td>
<td>275</td>
<td>24</td>
</tr>
<tr>
<td>AA 6016-T4</td>
<td>115</td>
<td>226</td>
<td>24</td>
</tr>
</tbody>
</table>
### Process parameters:

<table>
<thead>
<tr>
<th>Series</th>
<th>Rotation speed ( \omega ) (rpm)</th>
<th>Travel speed ( v ) (mm/min)</th>
<th>Tool angle ( \alpha ) (°)</th>
<th>Plunge depth (mm)</th>
<th>Rotation to travel speed ratio ( \omega/v )?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1rst</td>
<td>1800</td>
<td>160</td>
<td>2.5</td>
<td>0.95</td>
<td>11.25</td>
</tr>
<tr>
<td>2nd</td>
<td>1120</td>
<td>320</td>
<td>0</td>
<td>0.95</td>
<td>3.5</td>
</tr>
</tbody>
</table>

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**Tools**

- **1rst series**
- **2nd series**

**Welding parameters**

- **Experimental procedure**

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Weld appearance and cross section

1rst series

AA 5182-H111

AA 6016-T4

2nd series

AA 5182-H111

AA 6016-T4

✓ Results and Discussion
Distribution of precipitates in welds of first series in AA 6016-T4 alloy

Advancing side

Retreating side

Plate thickness

Polished weld surface

✓ Results and Discussion
### Microstructure of parent materials and nugget of welds

<table>
<thead>
<tr>
<th>Material</th>
<th>Parent Material</th>
<th>Nugget</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA 5182-H111</td>
<td><img src="image1" alt="Microstructure" /></td>
<td><img src="image2" alt="Microstructure" /></td>
</tr>
<tr>
<td>AA 6016-T4</td>
<td><img src="image3" alt="Microstructure" /></td>
<td><img src="image4" alt="Microstructure" /></td>
</tr>
</tbody>
</table>

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### Results and Discussion

- **Parent material**
  - AA 5182-H111: 250 µm
  - AA 6016-T4: 100 µm

- **Nugget**
  - AA 5182-H111: 100 µm
  - AA 6016-T4: 100 µm
Hardness analysis in welds in AA 5182-H111

- Hardness variation in welds in AA 5182-H111

- HAZ (Heat Affected Zone)
- TMAZ (Thermally Affected Zone)
- HAZ

- Advancing and Retreating phases

- Hardness HV0.05

- Distance (mm)
Hardness variation in welds in AA 6016-T4

- Hardness Analysis

![Graph showing hardness variation in welds in AA 6016-T4](image-url)
Tensile properties of welds in AA 5182-H111
Tensile properties of welds in AA 6016-T4
## Comparative analysis of tensile properties of welds

<table>
<thead>
<tr>
<th>Weld ref.</th>
<th>$R_{p0.2}$ (MPa)</th>
<th>$R_m$ (MPa)</th>
<th>$A_{50}$ (%)</th>
<th>$\eta_{R_{p0.2}}$</th>
<th>$\eta_{R_m}$</th>
<th>Fracture localization</th>
</tr>
</thead>
<tbody>
<tr>
<td>55S1</td>
<td>113</td>
<td>268</td>
<td>18</td>
<td>0.99</td>
<td>0.97</td>
<td>HAZ</td>
</tr>
<tr>
<td>55S2</td>
<td>117</td>
<td>282</td>
<td>23</td>
<td>1</td>
<td>1</td>
<td>BM</td>
</tr>
<tr>
<td>66S1</td>
<td>109</td>
<td>200</td>
<td>15</td>
<td>0.95</td>
<td>0.89</td>
<td>TMAZ/HAZ</td>
</tr>
<tr>
<td>66S2</td>
<td>116</td>
<td>185</td>
<td>9</td>
<td>1</td>
<td>0.82</td>
<td>TMAZ</td>
</tr>
</tbody>
</table>

**Tensile properties**

- **$R_{p0.2}$**: Yield strength at 0.2% offset strain
- **$R_m$**: Tensile strength
- **$A_{50}$**: Area reduction at 50% of original cross-sectional area
- **$\eta_{R_{p0.2}}$, $\eta_{R_m}$**: Notation for specific properties
- **Fracture localization**: Indicators for fracture localization in the weld zones.
The tool with scrolled shoulder allowed reducing the tool tilt angle to zero and the prominence in the advancing side of the welds;

This tool geometry allowed also to diminish the plate thickness reduction in the welds;

The decrease in heat-input refined the microstructure of the nugget and increased the hardness of the thermo-mechanically affected zone of welds in alloy AA5182-H111, without reducing joint efficiency;

On the contrary the welds of the second series in alloy AA 6016-T4 showed a reduction in hardness and joint efficiency.
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