Friction Stir Welding of Stainless Steel and Nickel Base Alloys

Acknowledgements

Material provided by:
  – Haynes International
  – Ulbrich
  – Sandvik
Outline

• Friction Stir Welding
• Polycrystalline Cubic Boron Nitride (PCBN)
• Experimental Approach
• Results
  – Stainless Steel
  – Super Duplex Stainless Steel
  – Nickel Base
• Tool Life
• Summary
Friction Stir Welding

- Solid state process
- Important tool features
  - Shoulder and Pin

[Diagram showing steps of friction stir welding process]
Tool Layout

- Locking collar to support PCBN
- Thermal barrier to slow heat transfer to shank
Tool Holder and Telemetry
Polycrystalline Cubic Boron Nitride (PCBN)

- PCBN is a Synthetic Super Abrasive Material
  - Created in HT-UHP presses (1450 °C, 870 KSI)
Experimental Approach

• **Basic parameter study**
  – Parameters found which produced fully consolidated welds
  – Parameters are not optimized

• **Post weld analysis**
  – Tensile testing in accordance with ASTM E8
  – Transverse metallographic samples removed from each weld
  – 2507 Super Duplex microstructure examined using Orientation Imaging Microscopy (OIM)™
## Materials

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>304 Stainless</td>
<td>0.250 in.</td>
</tr>
<tr>
<td>2507 Super Duplex</td>
<td>0.150 in.</td>
</tr>
<tr>
<td>Alloy 201</td>
<td>0.125 in.</td>
</tr>
<tr>
<td>Alloy 600</td>
<td>0.187 in.</td>
</tr>
<tr>
<td>Alloy 718</td>
<td>0.089 in.</td>
</tr>
</tbody>
</table>

- 40 CFH of Argon used in all welds
304 Stainless Steel

Welding Parameters:
Rotation:  400 rpm
Travel:  3 IPM
Load control:  9000 lbf

• Excellent weld appearance
304 Stainless Steel

Base material (500x)

Center of DXZ (500x)
304 Stainless Steel

- Sigma phase observed in bands
  - Also observed at grain boundaries between bands
304 Stainless Steel

304 FSW
Transverse Tensile Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Yield Strength 0.2 % offset KSI (MPa)</th>
<th>Ultimate Tensile Strength KSI (MPa)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 RPM, 3 IPM</td>
<td>51 (352)</td>
<td>95 (655)</td>
<td>54</td>
</tr>
<tr>
<td>Base Metal</td>
<td>55 (379)</td>
<td>98 (675)</td>
<td>56</td>
</tr>
</tbody>
</table>

• Tensile failures occurred in HAZ
304 Stainless Steel

- Reduction in area required for tensile specimens
2507 Super Duplex Stainless Steel

Welding Parameters:
Rotation: 450 rpm
Travel: 3.5 IPM
Load control: 7400 lbf

- Excellent weld appearance
2507 Super Duplex Stainless Steel

FSW produces fine microstructure in the stir zone.
2507 Super Duplex Stainless Steel

Ferrite : Red
Austenite : Green

- Austenite phase exhibits smaller grain size than ferrite phase
- No evidence of sigma phase
## 2507 Super Duplex Stainless Steel

### 2507 FSW

Transverse Tensile Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Yield Strength 0.2 % offset KSI (MPa)</th>
<th>Ultimate Tensile Strength KSI (MPa)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 RPM, 3.5 IPM</td>
<td>110 (762)</td>
<td>123 (845)</td>
<td>19</td>
</tr>
<tr>
<td>Base Metal</td>
<td>102 (705)</td>
<td>128 (886)</td>
<td>30</td>
</tr>
</tbody>
</table>

• Tensile failures occurred in DXZ
Alloy 201

Welding Parameters:
Rotation: 1000 rpm
Travel: 41 PM

After 12 in. of weld
• Tool previously used in alloy 718
Alloy 201

Base material (500x)  TMAZ (50x)  Center of DXZ (500x)

Fine microstructure exhibited in DXZ
Alloy 201

Ni 201 FSW
Transverse Tensile Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Yield Strength 0.2 % offset KSI (MPa)</th>
<th>Ultimate Tensile Strength KSI (MPa)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 RPM, 4 IPM</td>
<td>28 (193)</td>
<td>65 (448)</td>
<td>34</td>
</tr>
<tr>
<td>Base Metal*</td>
<td>15 (103)</td>
<td>59 (406)</td>
<td>50</td>
</tr>
</tbody>
</table>

* Nominal properties reported in literature

• Tensile failures occurred in DXZ
Alloy 600

Welding Parameters:
Rotation: 450 rpm
Travel: 2.25 IPM

After 6 feet of weld
Alloy 600

Grain refinement exhibited in weld region
Alloy 600 FSW
Transverse Tensile Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Yield Strength 0.2 % offset KSI (MPa)</th>
<th>Ultimate Tensile Strength KSI (MPa)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>450RPM 2 ¼ IPM</td>
<td>54 (374)</td>
<td>104 (719)</td>
<td>27</td>
</tr>
<tr>
<td>Base Metal (annealed condition)</td>
<td>38 (263)</td>
<td>92 (631)</td>
<td>50</td>
</tr>
</tbody>
</table>

- Tensile failures occurred in the DXZ
Alloy 718

**Welding Parameters:**
- Rotation:  500 rpm
- Travel: 2 IPM

- Excellent weld appearance

After 4 feet of weld
Grain refinement exhibited in weld region
### Alloy 718 FSW

#### Transverse Tensile Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Yield Strength 0.2 % offset KSI (MPa)</th>
<th>Ultimate Tensile Strength KSI (MPa)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>500RPM, 2 IPM</td>
<td>97 (668)</td>
<td>143 (986)</td>
<td>16</td>
</tr>
<tr>
<td><strong>Base Metal * (Annealed)</strong></td>
<td>67 (462)</td>
<td>130 (896)</td>
<td>41</td>
</tr>
<tr>
<td><strong>Base Metal * (precipitation hardened)</strong></td>
<td>170 (1172)</td>
<td>202 (1392)</td>
<td>22</td>
</tr>
</tbody>
</table>

- Tensile failure in DXZ

* Nominal properties reported in literature
Review

- FSW exhibited feasibility in various different stainless steel and nickel base alloys

- Excellent mechanical properties

- Grain refinement exhibited in DXZ
  - Wrought microstructure
Tool Life

- Tool Life is always the big question
  - Life test under taken on 304 stainless steel and 1018 mild steel
    - 0.600 in. diameter shoulder with 0.085 in. length on pin
    - FSW machine capable of 40 in. of travel
Tool Life

100 feet of weld produced in 304 Stainless Steel

• 30 tool plunges

Bead on plate performed for life study
Tool Life

260 feet in 1018 mild steel

- Solved design issue in driving PCBN
- 78 tool plunges
- No visible wear
- Pin fractured at 262 feet

Bead on plate performed for life study
Tool Life

• PCBN grade development ongoing
  – Current grade being used is commercial machining grade

  – Ongoing program to develop FSW grades

  – Potential to tailor grades for different alloys
Summary

• PCBN proved to be viable FSW tool material for higher temperature materials

• Stainless steel and nickel base alloys can be successfully friction stir welded
  – Excellent weld quality and mechanical properties
  – Fine grain size in weld

• Tool life constantly improving