Fatigue Crack Growth in Peened Friction Stir Welds

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Overview

- Aluminum alloys and testing conditions
- Friction stir welding aluminum
- Laser and shot peening
- Fatigue crack growth testing
- Observations
Aluminum alloys

♦ **7075-T73 aluminum**
  - Common alloy used in planes, trains, and automobiles

♦ **2195-T8**
  - Common alloy in space applications (External Tank)

♦ **Welding and Peening**
  - Two plates 90 x 15 x 1.25 cm
  - Butt-weld, single pass, tool speed 300 RPM CCW, 15 cm/min
  - Tool shoulder dia. 3.3 cm, probe dia. 0.92 cm
  - Glass shot peening 0.008-0.012A, 200% coverage
  - Laser peening rastered, 3% overlap, 5 GW/cm² for 18 ns, 3 layers offset 33%
Specimen Design and Measurement Locations

Contour measurement plane

Retreating Side

Advancing Side

Weid Nugget

100 mm

20.5 cm

1.25 cm

41 cm

-10 cm

400 mm

1.25 cm

0.135 cm

0.135 cm

1.25 cm

1.9 cm

10 cm

20 cm

40 cm

3 cm

2 cm

4 cm

3 cm
Residual Stress Measurements – 7075

- Hardness testing performed for reference
- Residual stresses measured using X-ray diffraction and contour method (shown)
- Three dimensional stress field through the specimen thickness
- Stress intensity solution is two-dimensional
- Residual stresses **not** modeled in stress intensity calculations
Fatigue Crack Growth Rate Post-Weld

\[ \Delta K_{\text{applied}} \text{ (MPa m}^{1/2}\text{)} \]

\[
\begin{array}{c}
da/dN \text{ (meter/cycle)} \\
\hline
10^{-5} & 10^{-4} & 10^{-3} & 10^{-2} \\
\hline
\end{array}
\]

Baseline
FSW

7075-T73 Aluminum Alloy
Room Temp., Lab Air
FSW - Friction Stir Weld

R = 0.7
R = 0.1
Fatigue Crack Growth Rate Post-Weld, Shot Peened

\[ \Delta K \text{ (MPa m}^{1/2}\text{)} \]

- Baseline
- FSW
- FSW, SP

7075-T73 Aluminum Alloy
Room Temp., Lab Air
FSW - Friction Stir Weld
SP - Shot Peened

R = 0.1
R = 0.7
Fatigue Crack Growth Rate Post-Weld, Laser Peened

\begin{align*}
\Delta K (\text{MPa m}^{1/2}) \\
\text{da/dN (meter/cycle)}
\end{align*}

- **Baseline**
- **FSW**
- **FSW, SP**
- **FSW, LP**

- **7075-T73 Aluminum Alloy**
- **Room Temp., Lab Air**
- **FSW - Friction Stir Weld**
- **SP - Shot Peened**
- **LP - Laser Peened**

\( R = 0.1 \)
\( R = 0.7 \)
Crack Length versus Cycles

- Acceleration from welding
  - evident at $R = 0.1$
- Retardation from peening
  - unclear at $R = 0.1$ for shot

7075-T73 Aluminum
Room Temp., Lab. Air
$R = 0.1$, $P_{\text{max}} = 88.9$ kN

7075-T73 Aluminum
Room Temp., Lab. Air
$R = 0.7$, $P_{\text{max}} = 133.4$ kN
Fracture Surfaces – 7075 Aluminum

Base Material

As-welded

Welded, Shot peened

Welded, Laser peened
Fracture Surfaces – 7075 Aluminum

- Baseline
- Friction Stir Weld
- FSW, Shot Peened
- FSW, Laser Peened

7075-T73 Aluminum
Room Temp., Lab. Air
R = 0.1, P_{max} = 88.9 kN

Cycles (thousands) vs Crack Length, c (mm)
Effect of Temperature - 7075

7075-T73 Aluminum Alloy
Lab Air, R = 0.1
FSW - Friction Stir Weld
SP - Shot Peened
LP - Laser Peened
Residual Stress Measurements – 2195

- Hardness testing performed for reference
- Residual stresses measured using X-ray diffraction and contour method (shown)
- Three dimensional stress field through the specimen thickness
- Stress intensity solution is two-dimensional
- Residual stresses not modeled in stress intensity calculations
Crack Growth Rate Data - 2195

- 2195 Aluminum
- 25°C, Lab. Air
- R = 0.1, M(T)

**Graph Details:***
- **da/dN (meter/cycle)**
- **ΔK_{applied} (MPa m^{1/2})**

**Data Points:**
- Base Material
- As-welded
- Shot Peened
- Laser Peened
Effect of Temperature - 2195

\[ \Delta K_{\text{applied}} \quad (\text{MPa m}^{1/2}) \]

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Base Material</th>
<th>As-welded</th>
<th>Shot Peened</th>
<th>Laser peened</th>
</tr>
</thead>
<tbody>
<tr>
<td>23°C</td>
<td></td>
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<tr>
<td>182°C</td>
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<tr>
<td>-140°C</td>
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</tbody>
</table>

\[ \frac{\text{da/dN}}{\text{(meter/cycle)}} \]

2195 Aluminum
Lab. Air, R = 0.1, M(T)
Fracture Surfaces - 2195

(a) Base -140°C

(b) FSW -140°C

(c) Laser Peen FSW -140°C

(d) Shot Peen FSW -140°C
Fractography – Peening 2195

- Photographs from 182° C
- As-welded to the left, laser peened below
Fractography – Temperature 2195

- Photographs from laser peened
  Room temperature $23^\circ C$ to the left, $182^\circ C$ below
Observations

♦ Friction stir welding induces residual stresses that accelerates fatigue crack growth in the weld nugget

♦ Shot peening over the weld had little effect on growth rate

♦ Laser peening over the weld retarded the growth rate
  • Final crack growth rate was comparable to the base, un-welded material
  • Crack tunneling evident from residual compressive stresses

♦ 2195-T8 fracture surfaces were highly textured
  • Texturing makes comparisons difficult as the material system is affecting the data as much as the processing
  • Material usage becoming more common in space applications requiring additional work to develop useful datasets for damage tolerance analyses