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

[Diagram showing specimen design with measurement locations and dimensions.]
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

As-welded

Shot Peened

Laser Peened
Fatigue Crack Growth Rate Post-Weld

Baseline
FSW

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

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

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

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

- **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

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

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

7075-T73 Aluminum Alloy
Room Temp., Lab Air
FSW - Friction Stir Weld
SP - Shot Peened
LP - Laser Peened
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
$R = 0.1$, $P_{\text{max}} = 88.9 \text{ kN}$

7075-T73 Aluminum
Room Temp., Lab. Air
$R = 0.7$, $P_{\text{max}} = 133.4 \text{ kN}$
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
\( R = 0.1, P_{\text{max}} = 88.9 \text{ kN} \)
Effect of Temperature - 7075

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

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

-140°C
23°C

ΔK (MPa m^{1/2})

da/dN (meter/cycle)
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)

Base Material
As-welded
Shot Peened
Laser Peened
Effect of Temperature - 2195

-140°C
23°C
182°C

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

Base Material
As-welded
Shot Peened
Laser peened

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

\[ \Delta K_{\text{applied}} \, (\text{MPa m}^{1/2}) \]
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° C to the left, 182° 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