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

- 10 cm
- 20.5 cm
- 41 cm
- 1.25 cm

Retreating Side
Advancing Side

Weid Nugget

400 mm
100 mm

ADVANCING SIDE

0.035 cm
1.9 cm
0.035 cm
0.125 cm

RETEATING SIDE

20 cm
40 cm

Weid Region

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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

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

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

Baseline

FSW

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

R = 0.1

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

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

Baseline
FSW
FSW, SP

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

$\Delta K$ (MPa m$^{1/2}$)

$\frac{da}{dN}$ (meter/cycle)

- 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
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
Effect of Temperature - 7075

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

**Baseline**

FSW
FSW, SP
FSW, LP

**ΔK (MPa m\(^{1/2}\))**

**da/dN (meter/cycle)**

-140° C
23° C

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Residual Stress Measurements – 2195

- As-welded
- Shot peened
- Laser peened

- 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

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

\( \frac{da}{dN} \) (meter/cycle)
Effect of Temperature - 2195

- Base Material
  - As-welded
  - Shot Peened
  - Laser peened

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

-23°C
-182°C
-140°C

(da/dN) (meter/cycle)

\( \Delta K_{\text{applied}} \) (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