Overview of Fatigue and Damage Tolerance Performance of Powder Bed Fusion Alloy N07718

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MSFC PBF Capability

- Selective Laser Melting (SLM)
  - Heat source is a 200 W laser
- Concept Laser M1 Cusing SLM machine
  - 250 x 250 x 250 mm³ build volume
SLM 718 Post-Processing

- Stress Relief: 1065°C for 1.5 hours; furnace cool.
- HIP: 1165°C, 100 MPa, 3-4 hours
- Solution (AMS 5664): 1066°C for 1 hour; air cool.
- Age (AMS 5664): 760°C for 10 hours; furnace cool to 650°C; treat for total of 20 hours.

As-built microstructure

Heat treated microstructure
Typical Build Properties

• Typical tensile witness test curve for SLM 718.
  • Ultimate Tensile Strength: ~ 1380 MPa
  • Yield Strength: ~ 1170 MPa
  • Fracture Elongation: > 20%
Defective Build

- A build of test specimens was produced; all indications were that the build was successful.
- Witness tensile testing revealed lower than expected material properties.
Defective Build

- Metallographic examination revealed lack of fusion defects in the material.
- Source was eventually determined to be a clogged ventilation duct that was allowing combustion by-products to settle on the powder bed.
Low Cycle Fatigue of SLM 718

Plotted fits are power-law fits of the form $Y = ax^b + c$

- “Reference” data – Low Stress Ground, $R = -1$, Defect-free build
Low Cycle Fatigue of SLM 718

Plotted fits are power-law fits of the form $Y = ax^b + c$

- Compare to build with defects – slightly lower fatigue life
Low Cycle Fatigue of SLM 718

- Defect-free build with as-built surface finish; fatigue life even lower
Low Cycle Fatigue of SLM 718

- As-built surface finish, with defects; surface finish has more effect than internal defects.
High Cycle Fatigue of SLM 718

• Key Variables
  • Orientation
    • Z – loading axis perpendicular to powder bed plane.
    • XY – loading axis parallel to powder bed plane.
    • 45° – loading axis 45° from powder bed plane.
  • Surface Finish
    • Low Stress Ground – ASTM E466 finishing procedure
    • As-Built – Surface finish from the SLM machine
  • Temperature
    • Room Temperature (RT) – nominal lab conditions, 70-75°F
    • Liquid Nitrogen (-320°F)
Low stress ground; minimal effect from orientation
Reference data – Low Stress Ground, Room Temperature, R = 0.1

MMPDS reference curve is wrought N07718 bar stock, heat treated to AMS 5662, from MMPDS-08 Figure 6.3.5.1.8 (f).
Plotted fits are power-law fits of the form $Y = ax^b+c$
- Z-oriented, As-built surface finish; decreased fatigue life
- 45°-oriented, As-built surface finish; similar fatigue life, 45° tend to be rougher than Z
High Cycle Fatigue of SLM 718

- Z-oriented, lathe-turned surface finish; quicker machining turnaround, slight decrease in life from low stress ground.
Z-oriented, Tumbled then Electropolished; investigated for part finishing.
High Cycle Fatigue of SLM 718

MMPDS reference curve is wrought N07718 bar stock, heat treated to AMS 5662, from MMPDS-08 Figure 6.3.5.1.8 (f). Plotted fits are power-law fits of the form $Y = ax^b + c$

- Z Oriented, Tumbled then Chem Milled; investigated for part finishing.
High Cycle Fatigue of SLM 718

- Fatigue life decreases with increasing surface roughness.
Tests in LN₂ (-320°). Some increase in life for as-built surfaces; more increase for low stress ground.
- Identical builds were procured from three third-party SLM vendors; one build was provided by MSFC.
- The specimens were heat treated per MSFC guidance, although allowances were made for vendors with existing mature processes.
- A series of comparison testing was done to evaluate the quality of the material.
- Z-oriented, low stress ground surface finish; compared to M1 and wrought reference curves
- Z-oriented, “as-provided” surface finish; compared to M1 and wrought reference curves
Fatigue Crack Growth Results

• Round Robin Results
  • 3 specimens from each build
  • Z-XY test orientation
  • Post-processing same as fatigue specimens

• Testing Methodology
  • Tested according to ASTM E647
    • “Standard Test Method for Measurement of Fatigue Crack Growth Rates”
  • R = 0.1 and R = 0.7 data shown
  • Compression pre-cracking procedure (CPC)
Compression Pre-Cracking

- Compression-compression loading used to generate a crack at the notch root of a c(T) specimen.
- May produce more conservative threshold and near-threshold crack growth rates.
- Following CPC procedure detailed by Newman and Yamada.
• Wrought Inconel-718 alloy obtained from Boeing-Rockwell. Tested using the ASTM LR test method and CA loading.

Fatigue Crack Growth

- Wrought Inconel-718 alloy obtained from Boeing-Rockwell. Tested using the CPLR test method and CA loading.

Fatigue Crack Growth

- SLM 718 M1 Machine included as a reference. This data is not part of the Round-Robin.
- Produced using ASTM LR and CA loading.
Fatigue Crack Growth

- MSFC Round-Robin data. Consistent with M1 data.
Fatigue Crack Growth

- Lab B - Higher observed growth rates than M1 data.
Fatigue Crack Growth

- Lab C - Consistent with M1 data.
Fatigue Crack Growth

- Lab D - Consistent with M1 data. CPLR only.
• Only Lab B had any distinction from the M1 data.
Fatigue Crack Growth

- Wrought Inconel-718 alloy obtained from Boeing-Rockwell. Tested using the ASTM LR test method and CA loading.

Fatigue Crack Growth

- Wrought Inconel-718 alloy obtained from Boeing-Rockwell. Tested using the CPLR test method and CA loading.
Fatigue Crack Growth

- Higher observed growth rates compared to wrought 718 near-threshold.
Fatigue Crack Growth

- MSFC - Consistent with M1 data.
Fatigue Crack Growth

- Lab B - Consistent with M1 data.
• Lab C - Lower crack growth rates near-threshold compared to M1 data. More closely follows Newman data.
Fatigue Crack Growth

- Lab D - Lower crack growth rates near-threshold compared to M1 data. More closely follows Newman data.
Fatigue Crack Growth

- MSFC & Lab B: Consistent with M1 data
- Lab C & Lab D: Consistent with Newman data
Fracture Toughness Results

- Round Robin
- SLM 718
  - Stress relief, HIP, ASM 5664 Heat Treatment
- ASTM E1820
  - J-R vs Δa
  - Legend lists $J_{IC}$ value obtained from ASTM E1820
Fracture Toughness Results

M1 Machine

$J (\text{KPa} \cdot \text{m})$ vs. $\Delta a (\text{mm})$

- $J_C = 92.7$
- $J_C = 98.2$
- $J_C = 89.1$
- $J_C = 79.5$
Fracture Toughness Results

- Fits are power law regression line specified in ASTM E1820.
- Fits of highest and lowest $JIC$ value obtained from M1 machine for reference.
Fracture Toughness Results

Round Robin - MSFC

J (KPa*m) vs \( \Delta a \) (mm) for different \( J_C \) values:
- \( J_C = 98.2 \)
- \( J_C = 79.5 \)
- \( J_C = 111.7 \)
- \( J_C = 103.2 \)
Fracture Toughness Results
Fracture Toughness Results

Round Robin - Lab C

![Graph showing Fracture Toughness Results with J_c values and Δa values.](image)
Fracture Toughness Results

Round Robin - All Labs

- J (KPa•m)
- Δa (mm)