Effect of Pre-Strain on Nitinol Fatigue Life

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Duty Cycle – Crimp, Deploy, and Pulse

Credit: Craig Bonsignore
Duty Cycle – Definition of Pre-, Mean, and Cyclic

Engr. Stress (MPa) vs. Engr. Strain (%)

- Pre-Strain
- Crimping
- Cycling
- Deployment

Cyclic Stress vs. Cyclic Strain

- Cyclic Modulus
- Mean Strain
Outline

• Pre-Strain and ε – N Plot
• Macroscopic Changes
• Microscopic Changes
• Possible Mechanisms
• Punch Line
Fatigue Test – Parameters

- Material: Ni$_{50.8}$Ti$_{49.2}$ Wire; Af: 8°C
- Dogbone Samples
  - Diameter: 0.22 mm
  - Gauge Length: 27 mm
- Loading Type: Tension – Tension
- Mean Strain: 2%
- Test Temperature: 37°C
- Sample Size: ≥ 5
- Run out: 10M Cycles
Fatigue Results – Effect of Pre-Strain on $\varepsilon$ – N

Shamimi et al., Unpublished Data, 2015
Fatigue Improvement – Possible Mechanisms

• Change in Residual Stress
  – Stress State
  – Inclusions

• Change in Properties
  – Hysteresis
  – Cyclic Modulus
  – Mean Stress
Possible Mechanisms – Change in Residual Stresses

Inclusion Size: 4 μm x 4 μm x 4 μm
Mesh Size: 1 μm x 1 μm x 1 μm

Credit: Karthikeyan Senthilnathan
Change in Residual Stresses - Comparison

6% Pre-Strain

10% Pre-Strain

Engr. Stress (MPa) vs. Engr. Strain (%)

1st Cycle - Pre-Strain to 10%
2nd Cycle - Pull to 6%
Change in Residual Stresses – Pre-Strain

6% Pre-Strain

Max. Stress
790 MPa

10% Pre-Strain

Max. Stress
1757 MPa

Shamimi et al., Unpublished Data, 2015
Change in Residual Stresses – Released

6% Pre-Strain

Max. Stress
0 MPa

10% Pre-Strain

Max. Stress
-715 MPa

Shamimi et al., Unpublished Data, 2015
Change in Residual Stresses – Pull to 6%

6% Pre-Strain

Max. Stress
790 MPa

10% Pre-Strain

Max. Stress
614 MPa

Shamimi et al., Unpublished Data, 2015
Possible Mechanisms – Change in Properties
DSC – Effect of Pre-Strain

Heat Flow (mW/g) vs. Temperature (°C) for different pre-strain levels: 11%, 10%, 6%, and 0%. The graph shows the heating process with temperature markers at -14°C, -16°C, -19°C, and -19°C for each pre-strain level.

Shamimi et al., Unpublished Data, 2015
Cyclic Hardening – Strain Controlled

Shamimi et al., Unpublished Data, 2015
Cyclic Modulus – Effect of Strain Amplitude

Engr. Stress (MPa)

Engr. Strain (%)

9% Pre-Strain

61 GPa
52 GPa
47 GPa
37 GPa

0.25% Strain Amplitude
0.30% Strain Amplitude
0.45% Strain Amplitude
0.55% Strain Amplitude

Shamimi et al., Unpublished Data, 2015
Mean Stress – Effect of Pre-Strain

Shamimi et al., Unpublished Data, 2015
Mean Stress– Effect of Pre-Strain

Shamimi et al., Unpublished Data, 2015
Conclusion

• Pre-Straining (up to 11%) Improves Fatigue life in Tension-Tension

• Pre-Straining Generates Compressive Residual Stresses around Inclusions Resulting in a Reduced Stress State, Hence Delaying Crack Initiation Process

• Pre-Straining Decreases the Mean Stress
Pre Straining Significantly Affects the Strain Limit Diagram

Stay Tuned!…”Sensitivity of Nitinol Fatigue Strain on Material Inputs in Finite Element Analysis” On Wednesday @ 12:00