Study of Retained Martensite in Shape Memory Alloys

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Presentation Outline

• Motivation
• Test Methodology
• Experimental Results
• Examples of Retained Martensite
• Summary & Conclusions
Cyclic Behavior of SMAs

- Transformation behavior of SMA shows cyclic dependency
  - Retained martensite
  - Transformation Induced Plasticity (TRIP)

- Retained martensite results from
  - Stress localizations
  - Pinning due to point defects
Motivation to Study Retained Martensite

- Critical for the stability of cyclic SMA actuator behavior
- Limited understanding on the factors that influence its formation

Objectives
- Study the influence of applied stress and temperature on retained martensite formation
- Investigate effect of retained martensite on local material behavior
SMA Alloy Chosen

- Equiatomic NiTi, Cold drawn
- Parametric heat treatment study
  - 350-500°C temperature variation
  - 5-15 minutes time variation

Chosen heat treatment condition = 400°C for 5 mins
NiTi Wire Heat Treated at 400°C, 5 mins

- Transformation temperatures as measured by the Differential Scanning Calorimeter.
- Uniaxial behavior of the SMA wire heat treated at 400°C for 5 minutes.
Experimental Setup

Thermomechanical test setup for pseudoelastic training of the SMA wires

Test setup for flash heating the SMA wires and recording recovery
Flash Heating of Heat Treated, Untrained Wire

- No recovery observed upon flash heating
- Untrained wire did not exhibit any Two-way SME

Flash heating of SMA wire after heat treat at 400°C, 5 mins
Thermomechanical Test Matrix

- Stress (MPa)
  - 800
  - 900
  - 1000
  - 1100
  - 1200

- Temperature (°C)
  - 80
  - 100
  - 120
  - 140

The diagram shows a matrix of stress values against temperature values, with data points plotted at various intersections of the axes.
Pseudoelastic Cycling 80°C, 800 MPa

Stress – Strain response for 20 pseudoelastic cycles

Strain recovery upon flash heating

Recovered strain

200°C

300°C
Pseudoelastic Cycling 100°C, 1000 MPa

Stress – Strain response for 20 pseudoelastic cycles

Strain recovery upon flash heating
Data Comparison – Plastic & Recovered Strain

- **80°C, 800 MPa**
  - Test 1
  - Test 2
  - Test 3

- **80°C, 1000 MPa**
  - Test 1
  - Test 2
  - Test 3

- **100°C, 1000 MPa**
  - Test 1
  - Test 2
  - Test 3
XRD Characterization

- Use XRD Analysis to determine composition of specimen loaded 20 times to 800 MPa at 80°C

- Experimentally observed retained martensite
- ~3.8% Volume Fraction
Local Effect of Retained Martensite

• Need to assess how retained martensite influences behavior of SMAs
• Irrecoverable strains lead to residual stress state
  – Irrecoverable transformation strains act as eigenstrains
  – Elastic mismatch
• Impact on effective transformation behavior
Residual Stress State and Effective Irrecoverable Strain

- No retained martensite leads to full recovery
- Retained martensite leads to irrecoverable strains

- Residual stress fields around retained martensite alter local transformation behavior
Comparison of Stress States

- Final stress fields upon unloading with and without retained martensite
  - No retained martensite
    - No residual stress field
  - With retained martensite
    - Nonuniform residual stress field
Fracture Toughness

- Retained martensite is unable to transform
  - Does this influence fracture toughness?

- Need to determine if transformation increases toughness

- Small-scale transformation assumption

- Crack-tip energy release rate criteria

- BCs from LEFM far-field strains

- Virtual crack closure technique (VCCT)
Fracture Simulation Results
Transformation Zone (Martensitic Volume Fraction) through loading
Fracture Simulation Results

Start of Crack Propagation

End of stable crack growth

MVF, $\xi$

(Avg: 75%)

+1.056e+00
+9.900e-01
+9.093e-01
+8.267e-01
+7.450e-01
+6.633e-01
+5.817e-01
+5.000e-01
+4.183e-01
+3.367e-01
+2.550e-01
+1.733e-01
+9.167e-02
+1.000e-02
-3.182e-04

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Increase in Fracture Toughness

Increasing Crack Length

- As crack grows, phase transformation increases fracture toughness

Increasing Crack Length

- Increased enhancement with increasing transformation strain
Summary & Conclusions

– Quantity of retained martensite is dependent on the maximum applied stress

– Presence of retained martensite confirmed via XRD

– Retained martensite influences effective transformation strain and fracture toughness