Phase Transformations in Nitinol and Challenges for Numerical Modeling

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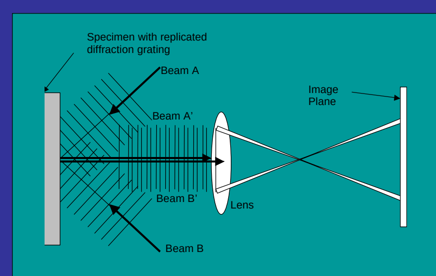
Overview

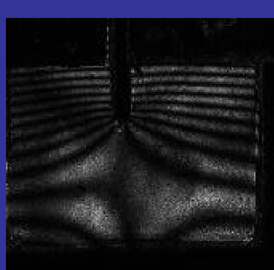
- Motivation
  - Understand the mechanics of phase transformations in Nitinol
  - Improve engineering design and verification methods
- Moiré interferometry
- Results
  - Uniaxial tensile specimens
  - Compact tension specimens
  - (Four-point bend specimen)

Moiré Interferometry



Typical Moiré interferometry fringe pattern

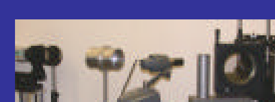
horizontal displacement field

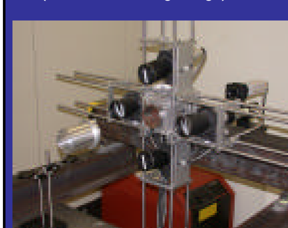


Intensity = A + B cos(f)

Phase-Shifted Moiré Interferometry

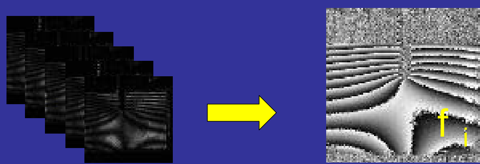
- Four-beam fiber optic interferometer
- Variable frequency adjustable (120–1200 l/mm gratings)





- Phase-shifted moiré (Perry, 1993)
  - Enhanced noise reduction
  - Preserves fine spatial resolution
  - Automated fringe processing
- Photoresist diffraction gratings
  - Spin coated resist
  - Ronchi ruling exposure
- Optical filtering at multiple diffraction and image planes

Phase Shifting and Unwrapping



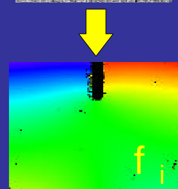
$I_{ij} = A_i + B_i \cos(f\ _i + d_j)$

A_i, B_i, f $_i$: data at each pixel

dj: phase shift

i: 1024x1024 pixels

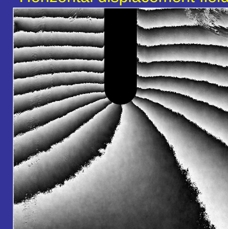
j: 1 to 5 phase shifts



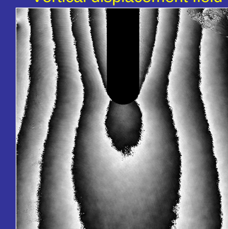
Examples of Moiré fringe patterns

at low load prior to onset of SIM transformation

Horizontal displacement field

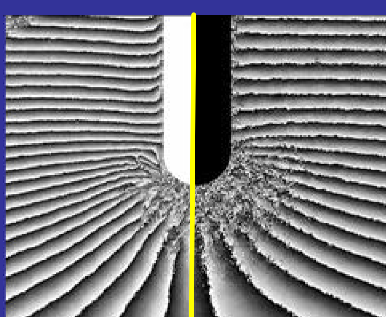


Vertical displacement field



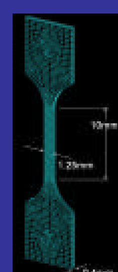
Effect of specimen grating thickness

elevated load, near end of plateau



Moiré with epoxy grating　Moiré with photoresist grating

Uniaxial tensile specimens

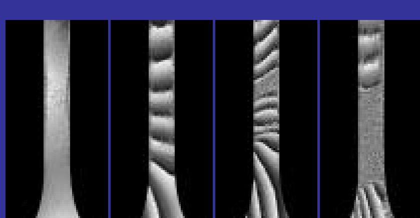


- Superelastic Nitinol
  - A_f = ~20 ^oC Material X
  - A_f = ~5 ^oC Material Y
- Two different processing histories
- Dimensions
  - Width 1.25 mm
  - Thickness 0.4 mm
  - Gage section 10mm

Moiré Interferometry Results

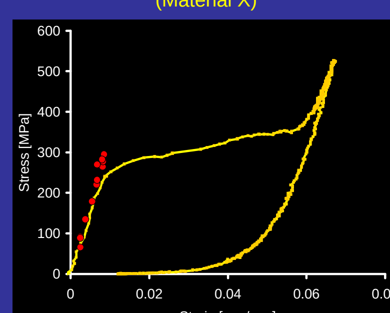
progressive loading of uniaxial tensile specimens

(Material X)



Comparison of Global Data and Local Moiré Strain Measurements

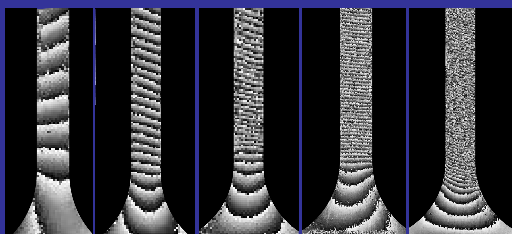
(Material X)



Moiré Interferometry Results

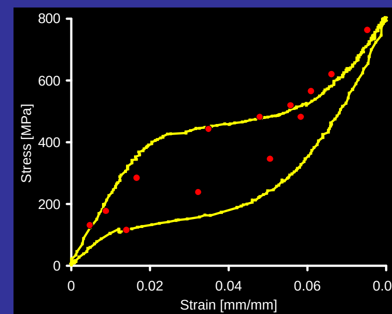
progressive loading of uniaxial tensile specimens

(Material Y)



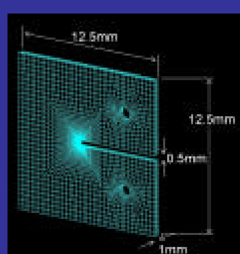
Comparison of Global Data and Local Moire Strain Measurements

(Material Y)



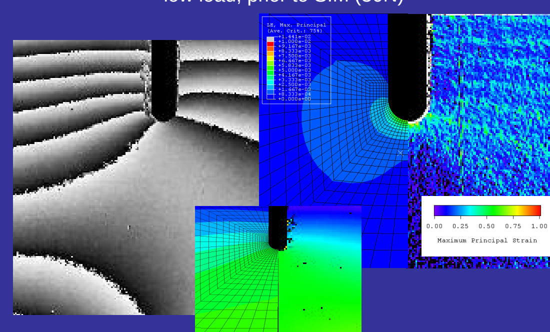
Compact tension specimens

Compact Tension Samples
- Superelastic Nitinol, A_f = 25 ºC
- Longitudinal and transverse orientations
- Dimensions
  - Notch size 500 µm
  - Thickness 0.6 mm
  - Width 12.54 mm



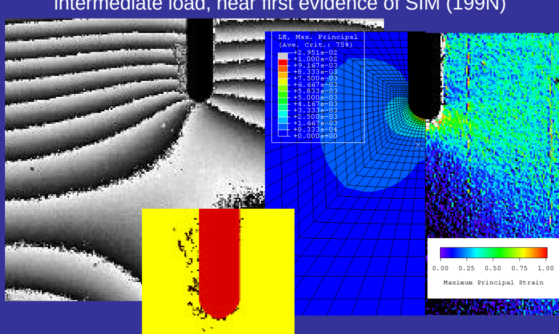
Moiré Interferometry Results

low load, prior to SIM (30N)



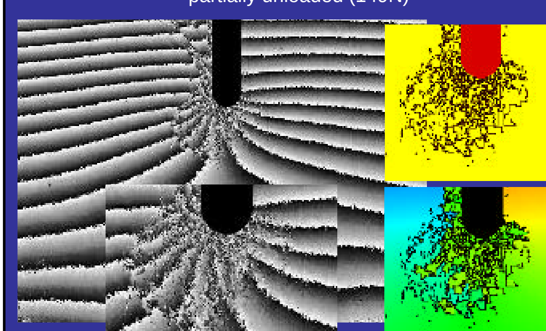
Moiré Interferometry Results

intermediate load, near first evidence of SIM (199N)



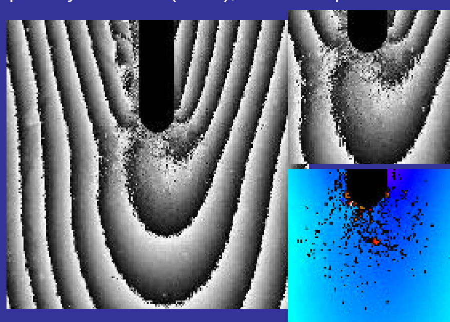
Moiré Interferometry Results

partially unloaded (149N)



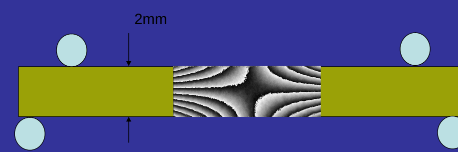
Moiré Interferometry Results

partially unloaded (149N), vertical displacement field

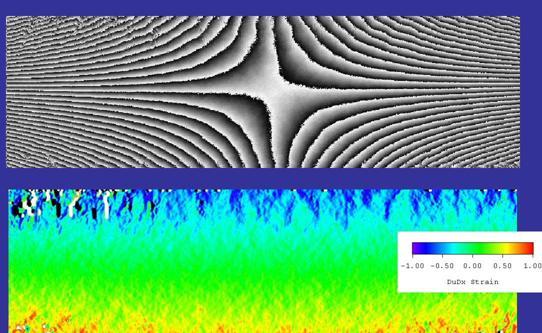


Moiré Interferometry Results

four point bend experiment



Moiré Interferometry Results



Summary

- Phase transformation in Nitinol is sub grain size (<10microns) and distributed
- Lüders-type localization was seen in some uniaxial specimens, different behavior in other specimens
- Transformation around stress concentrations follows repeatable, distributed patterns
- Volume fraction of SIM increases with increasing load, even beyond the end of the plateau
- Elastic strain decreases in the transformation zone during unloading and SIM persists until near complete unloading
- No evidence of a SIM toughening mechanism, perhaps stress shielding and redistribution effects

Conclusions

- Phase-shifted Moiré is an excellent technique for studying Nitinol and enables better engineering design and verification methods
- New material models should be developed which account for the observed distributed transformation behavior
- We still have more to learn