Internal Stresses in Tungsten Fiber Reinforced Bulk Metallic Glass Matrix Composites

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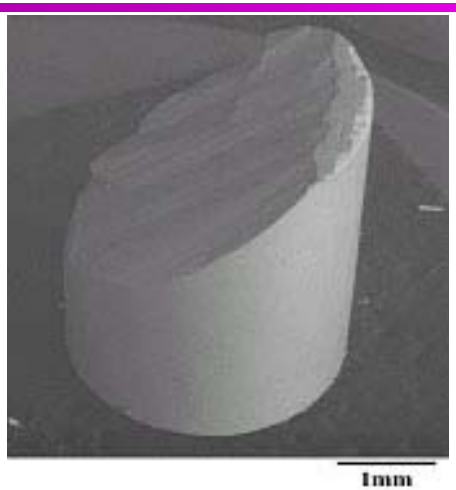
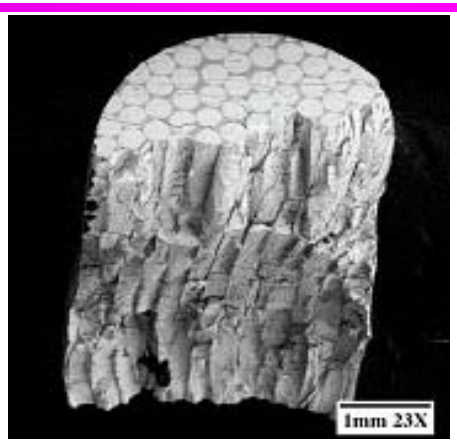
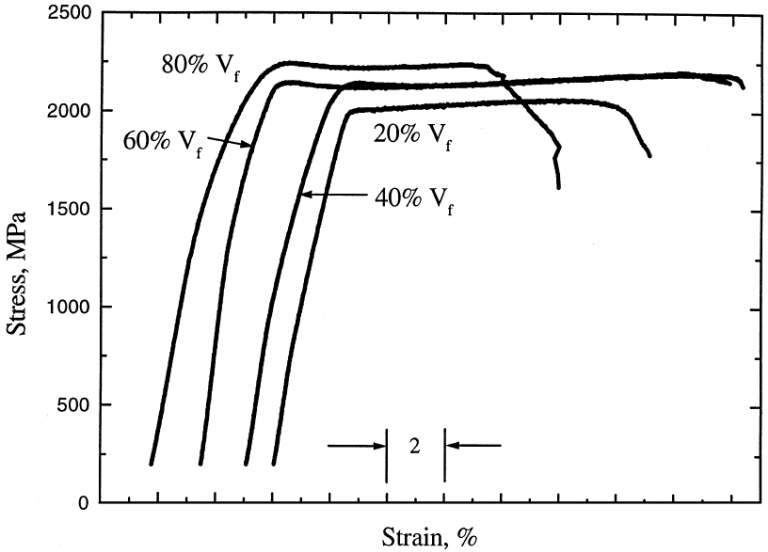
Outline

- BMG matrix tungsten fiber composites
- Neutron diffraction
- Finite element modeling
- Results
- Conclusion

BMG matrix tungsten fiber composites



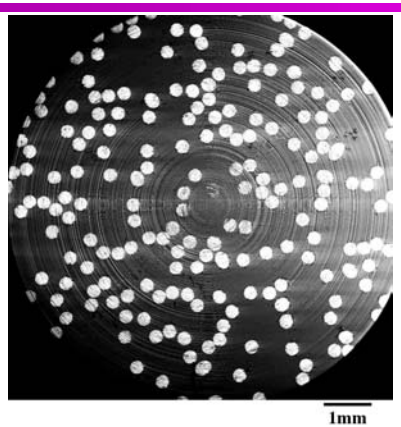




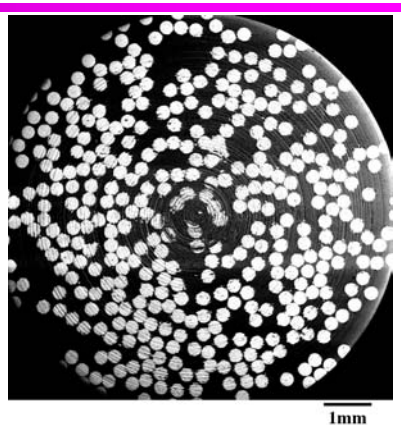
- Vit1: $Zr_{41.2}\ Ti_{13.8}\ Cu_{12.5}\ Ni_{10}\ Be_{22.5}$
- BMG/Tungsten fiber composites
  - Same ultimate stress as monolithic Vit1
  - Large increase in ductility
  - Knee in stress strain curve as tungsten fibers yield

R. D. Conner, R. B. Dandliker and W. L. Johnson, Acta Mater., vol. 46(17), pp. 6089-6102, 1998

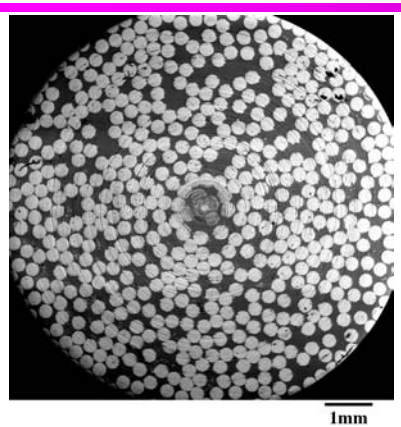
BMG matrix tungsten fiber composites



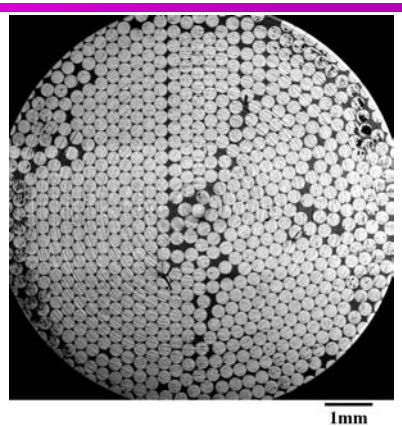
20% (21.0%)



40% (42.4%)



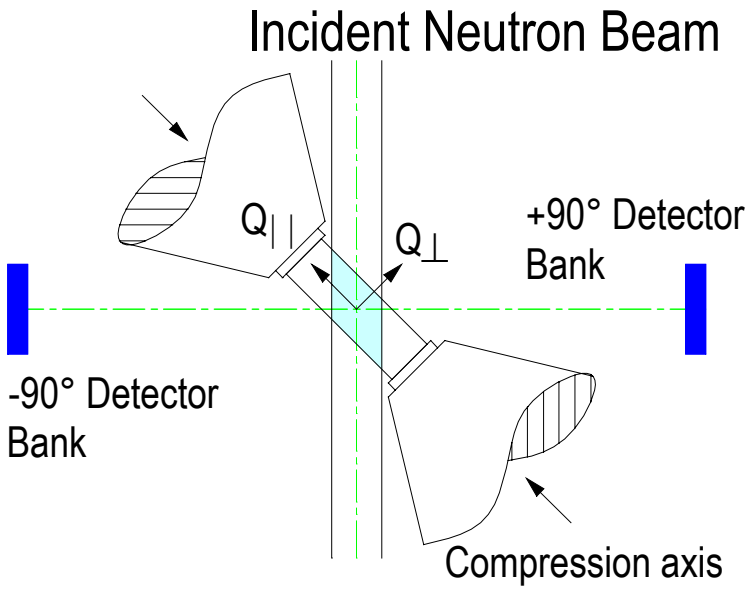
60% (61.9%)



80% (84.2%)

- Measured volume fractions deviates slightly compared to nominal volume fractions
- “Agglomeration” seen for all volume fractions
- “Stacking faults” seen for the 80% sample

Neutron diffraction

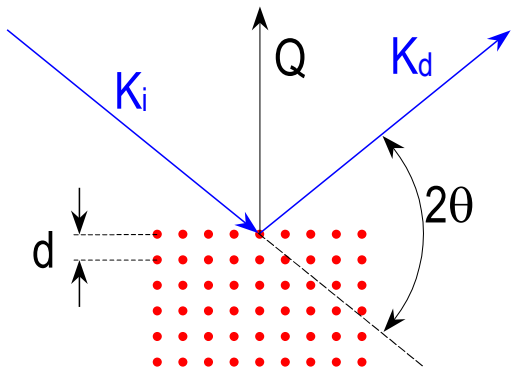


- Spectrometer for MAterials Research at Temperature and Stress (SMARTS)
- Schematic set-up for *in-situ* compression loading
- Measurement time is about 10-20 minutes per load level
- Measure elastic strains in two directions simultaneously
- Bulk measurement contrary to conventional X-ray measurements

Neutron diffraction

$$\lambda = 2d\sin\theta$$

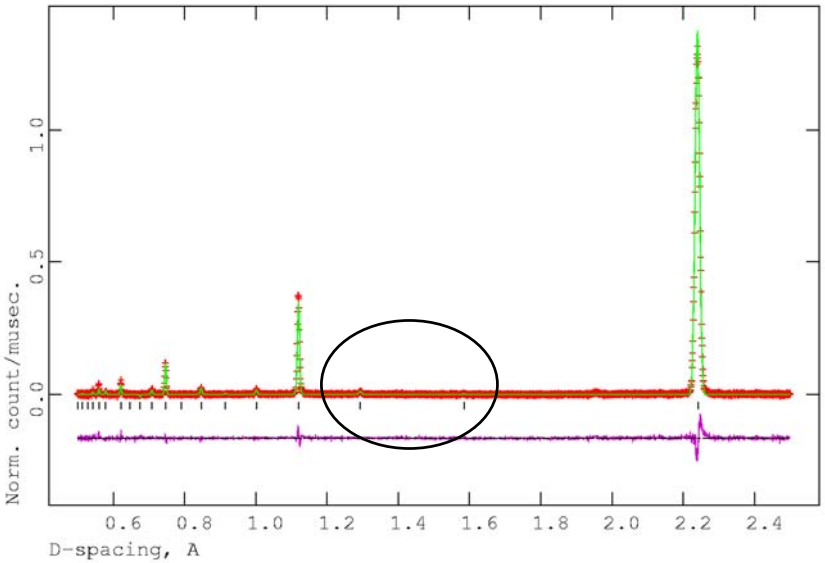
- Fixed λ; Reactor (steady state). Measure intensity as function of angle
- Fixed θ: TOF (spallation). Measure intensity as function of time-of-flight



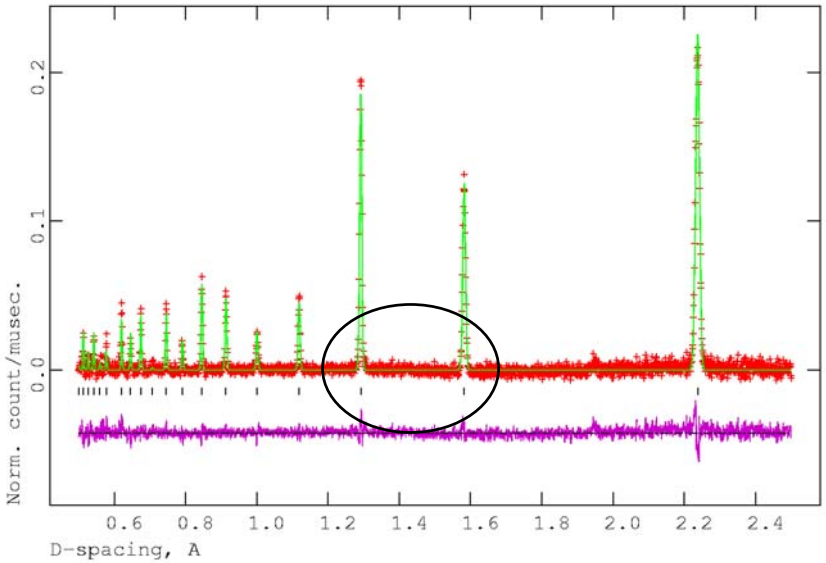
- Differences in lattice spacing => Only Elastic Lattice Strain of Crystalline Phase

$$\varepsilon_{hkl}^{el} = \frac{d_{hkl} - d_{hkl}^{0}}{d_{hkl}^{0}} = \frac{d_{hkl}}{d_{hkl}^{0}} - 1$$

Neutron diffraction



Parallel

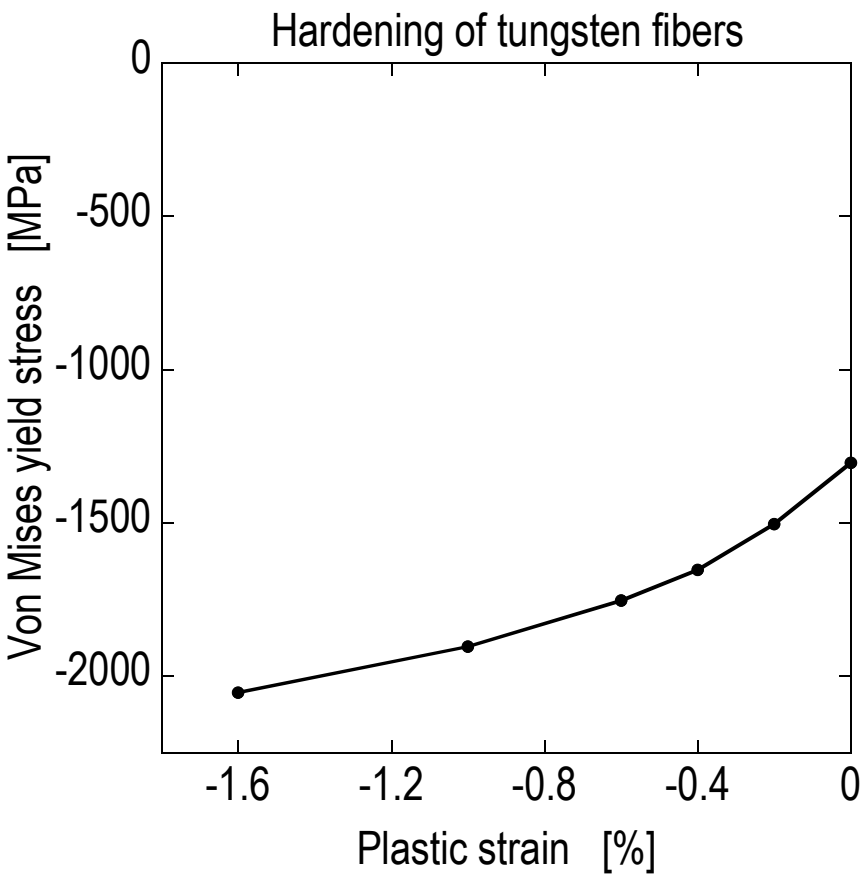


Perpendicular

- Diffraction patterns from BMG tungsten fiber composite sample (80%)
- Highly textured fibers; hh0 texture for wire drawn bcc metals
- Good statistics from short count times
  - $R_{wp} \approx$ 6-8%, strain error bar $\approx$ 15 $\mu\varepsilon$

Finite element model input

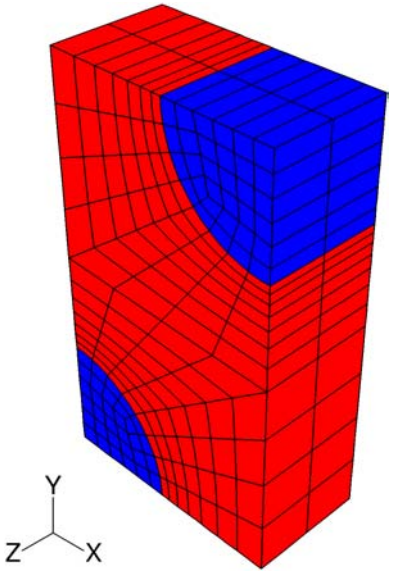
- BMG
  - Young's modulus: 96 GPa
  - Poisson's ratio: 0.36
  - Yield stress (Mohr-Coulomb): $\tau_c = 946 - 0.04\sigma_n$ [MPa]
  - No hardening
- Tungsten
  - Young's modulus: 410 GPa
  - Poisson's ratio: 0.28
  - Yield stress (Von Mises): $\sigma_y = 1305$ [MPa]
  - Hardening as shown in plot



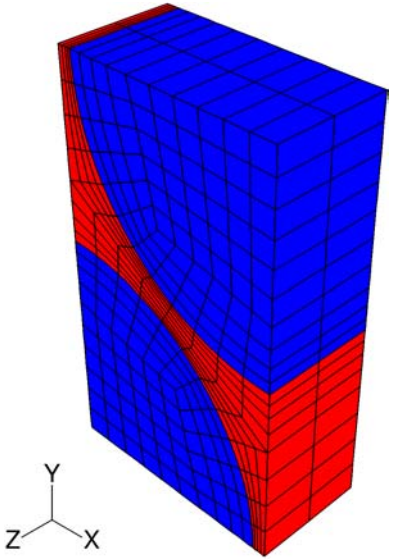
R. D. Conner, R. B. Dandliker and W. L. Johnson, Acta Mater., vol. 46(17), pp. 6089-6102, 1998
Lewandowski J. J. and Lowhaphandu P., Phil. Mag. A., in print
A. Saigal and G.G. Leisk, Mat. Sci & Eng. A, vol. 237, pp. 65-71, 1997

Finite element model

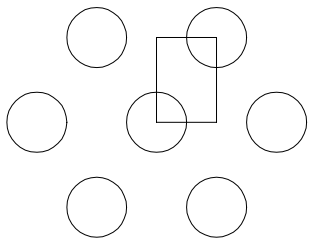
- Full 3D model due to loading along fibers
  - Unit cell model
  - Plane strain by keeping planes perpendicular to fibers plane
  - Brick 2nd order elements
- Hexagonal stacking in all models to accommodate high volume fractions
- Thermal cooling cycle
  - Same ΔT as previously found to give good comparison with measured thermal residual stresses (same for all volume fractions)



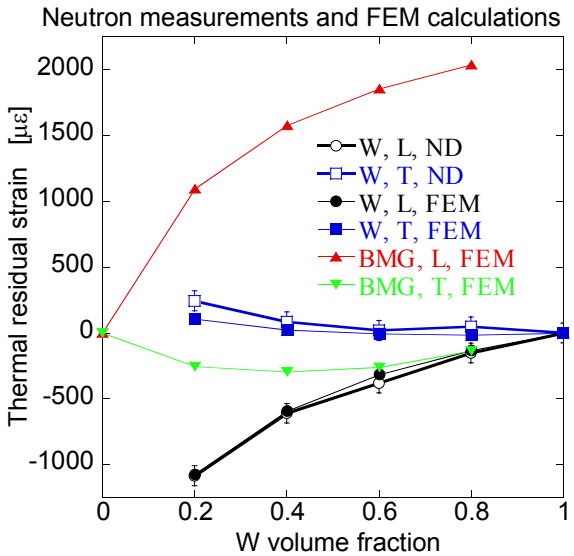
20% Mesh

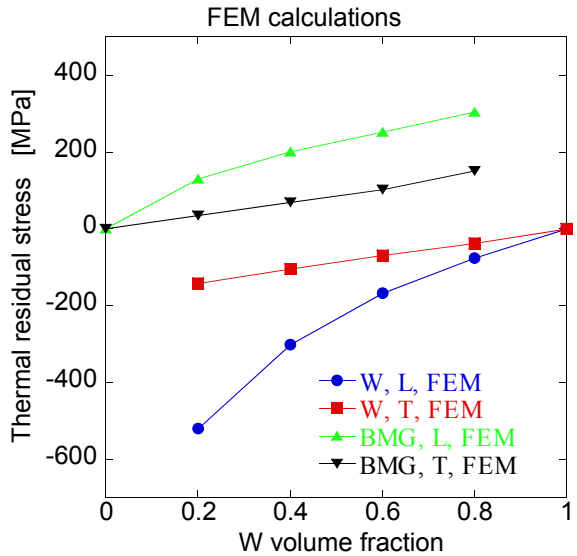


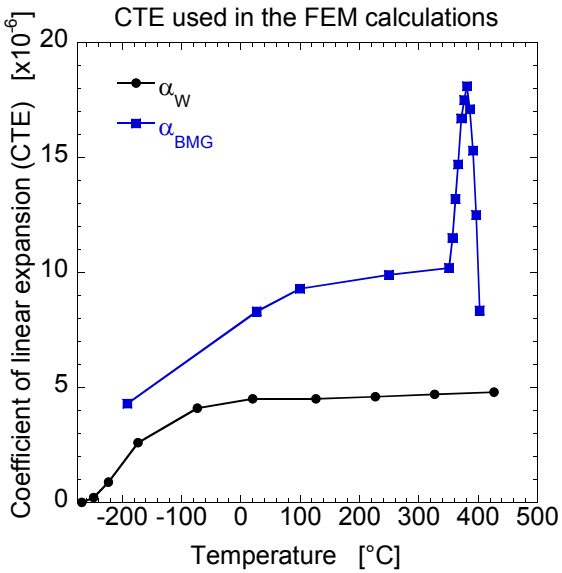
80% Mesh



Thermal residual strains



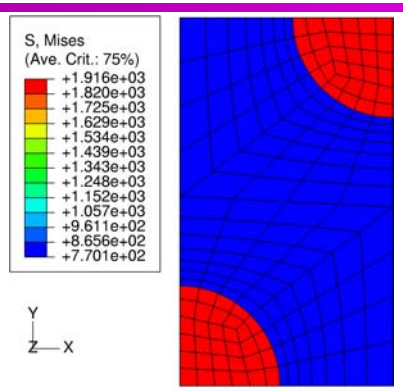




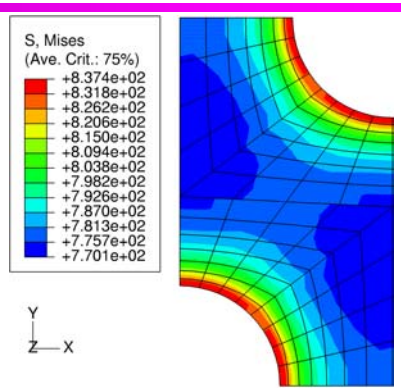
- Measured and calculated thermal residual stresses
  - Pure elasticity
  - Good agreement for the tungsten fibers
- Predict thermal residual *stresses* in both phases

D. Dragoi, E. Üstündag, B. Clausen and M. A. M. Bourke, Scripta Mater., vol. 45, pp. 245-252, 2001
Y. He, R. B. Schwarz and D. G. Mandrus, J. Mater. Res., vol. 11, p. 1836, 1996

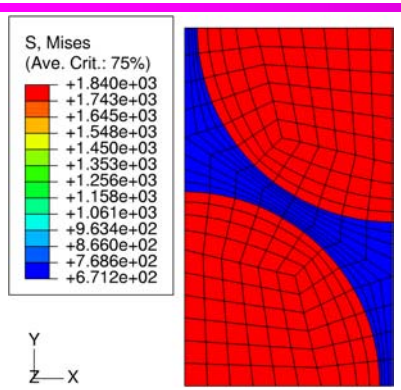
Finite element model



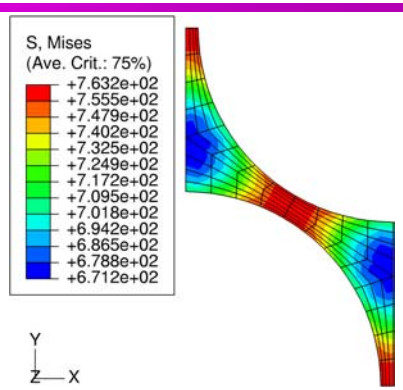
20% Von Mises



20% Von Mises
Matrix only



80% Von Mises

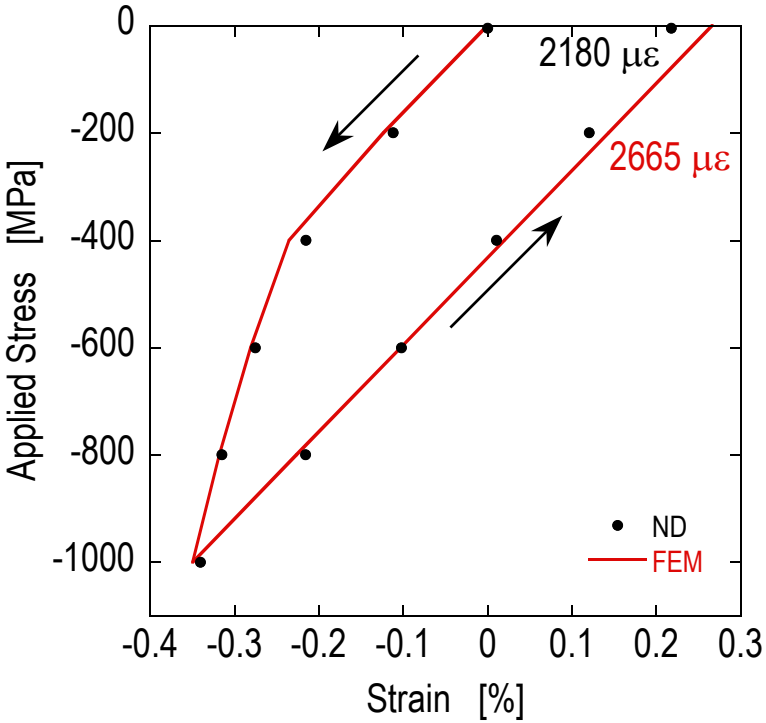


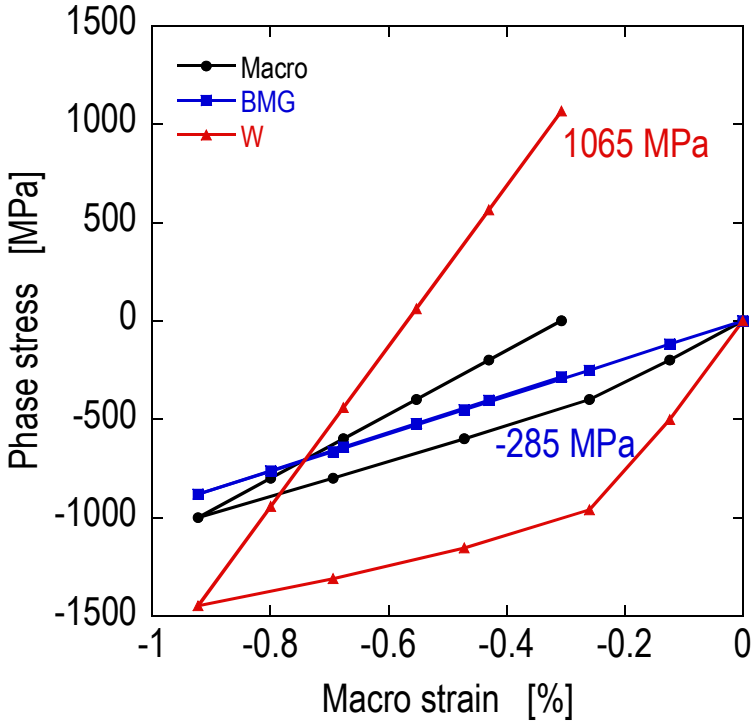
80% Von Mises
Matrix only

- Von Mises stresses at highest load level (1000MPa for 20, 1600MPa for 80%)
  - Stress concentration for the 80% - precursor for shear band formation
  - No appreciable variation of Von Mises stress in fibers

Measured lattice strains and predicted stresses, 20% sample

ND and FEM for W fiber ⇒ FEM, Load partitioning

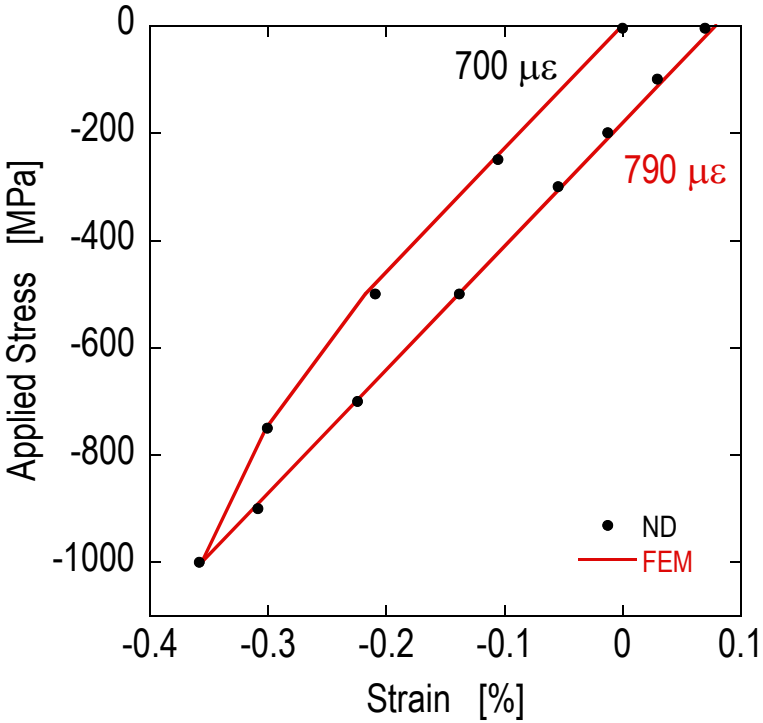


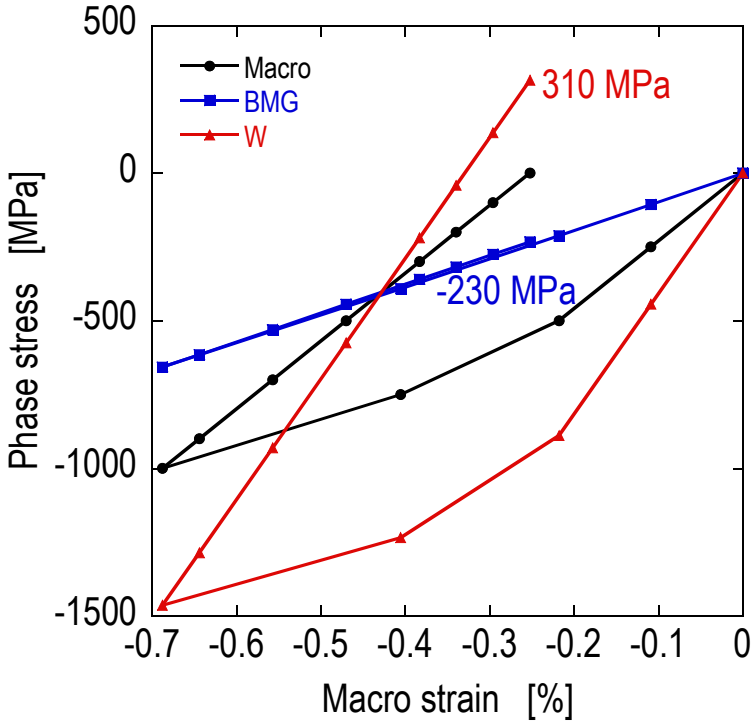


- Good agreement with loading data; Residual strain is overestimated
- Calculated loading and unloading slopes are slightly shallower than the measured slopes

Measured lattice strains and predicted stresses, 40% sample

ND and FEM for W fiber ⇒ FEM, Load partitioning

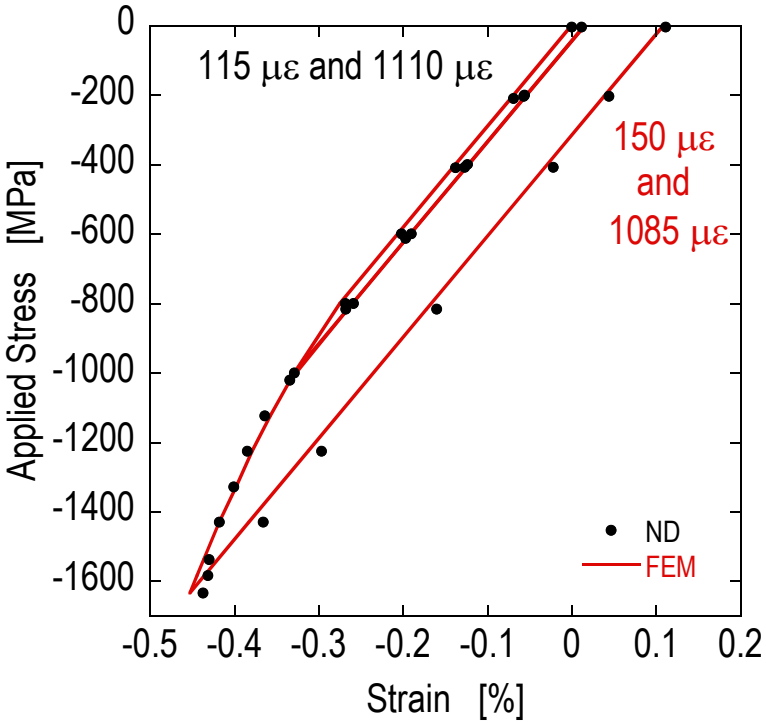


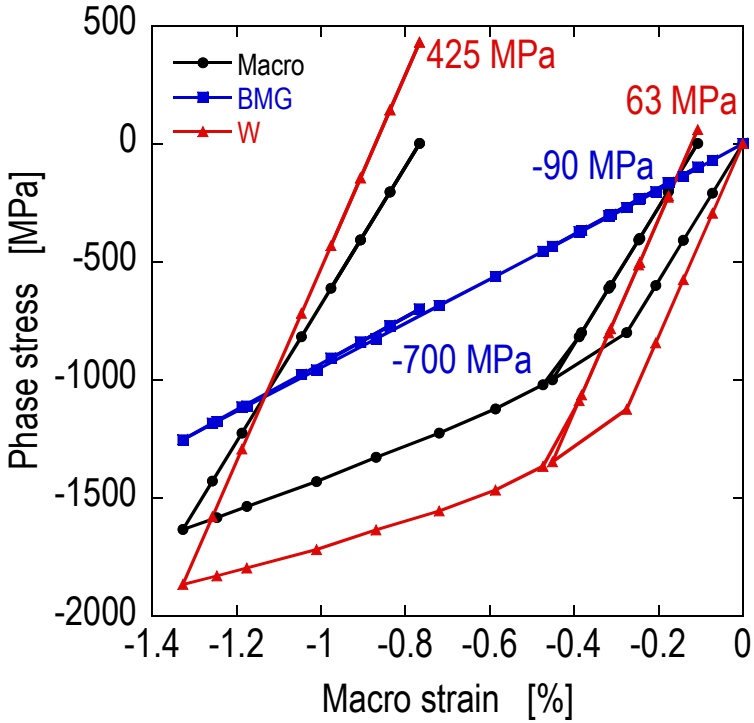


- Good agreement with loading data; Reasonable agreement with residual data
- Good agreement with measured slopes

Measured lattice strains and predicted stresses, 60% sample

ND and FEM for W fiber ⇒ FEM, Load partitioning

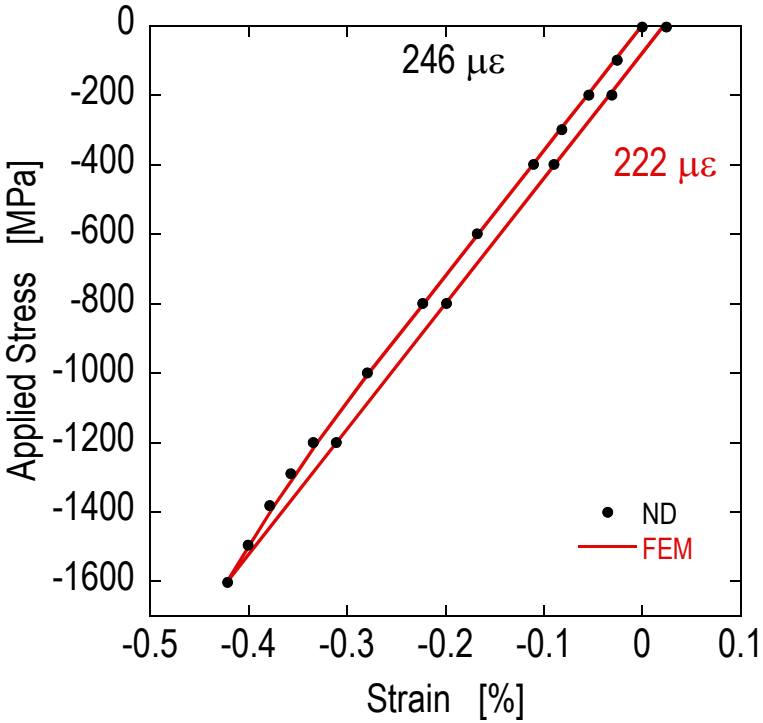


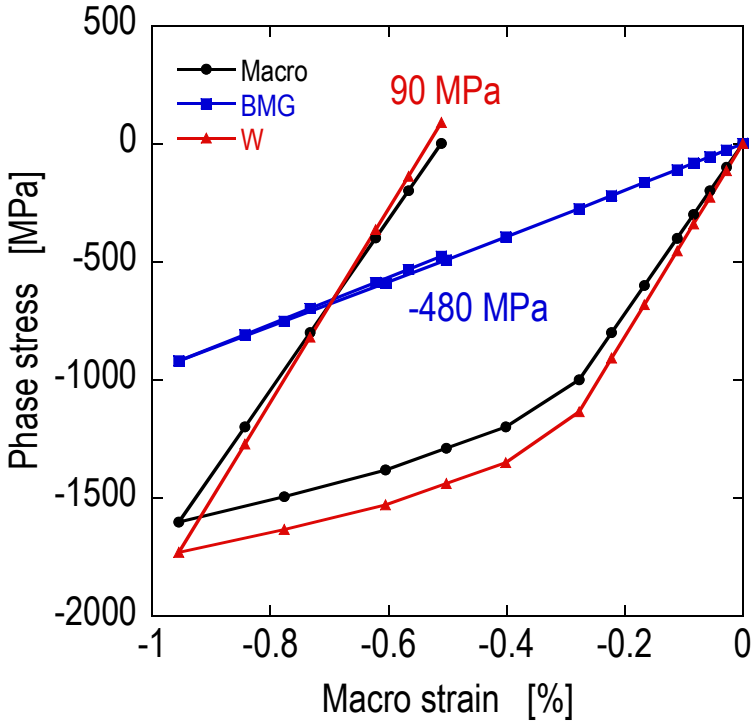


- Overestimates strains at high load; Good agreement for residual data
- Good agreement with measured slopes

Measured lattice strains and predicted stresses, 80% sample

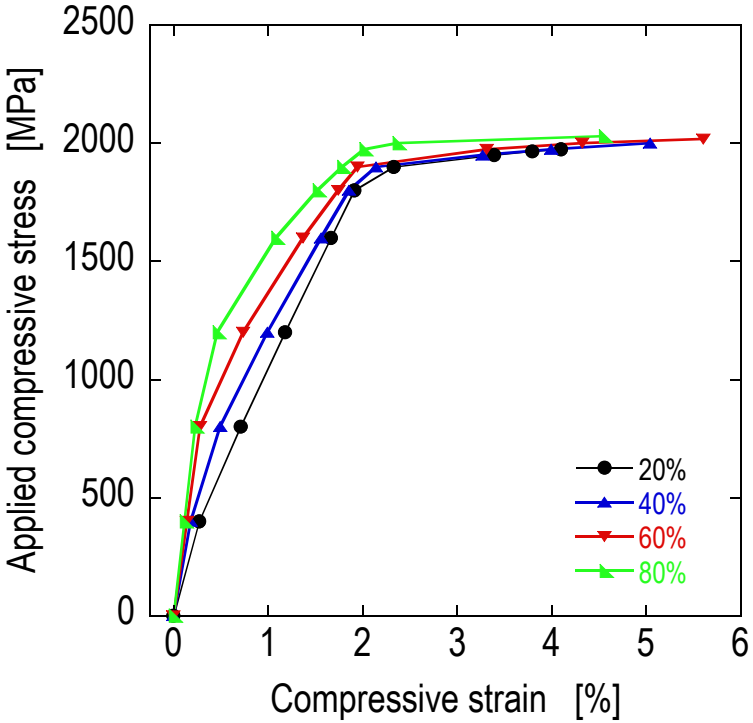
ND and FEM for W fiber ⇒ FEM, Load partitioning

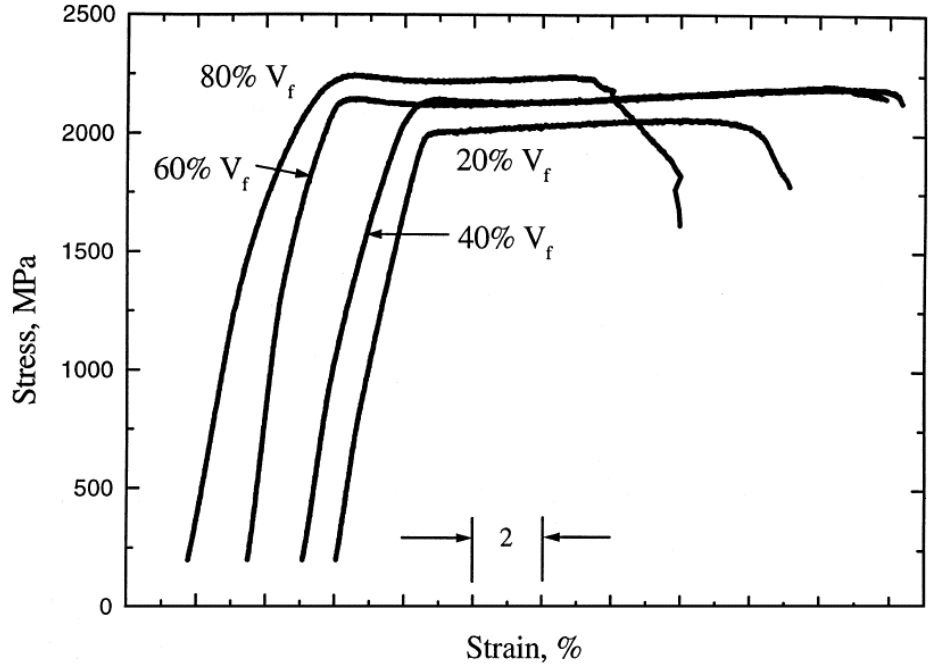




- Good agreement with both loading and residual data
- Good agreement with measured slopes

Yielding in BMG





- Predicted yield stress in the BMG using Mohr-Coulomb yield criteria
  - All samples predicted to have about the same ultimate stress
- Measured ultimate stress varies as a function of fiber volume fraction

Lewandowski J. J. and Lowhaphandu P., Phil. Mag. A., in print
R. D. Conner, R. B. Dandliker and W. L. Johnson, Acta Mater., vol. 46(17), pp. 6089-6102, 1998

Conclusions

- Neutron diffraction
  - 10-20 minutes count times gives adequate statistics
- Finite element modeling
  - Predictions of elastic strains in the tungsten fibers are in good agreement with the diffraction data

  ⇒ FEM provides phase stresses, residual stresses and load partitioning
  - The Von Mises yield stress used in FEM is the same for all volume fractions and there is good agreement with the onset of non-linearity in the diffraction data for all volume fractions

  ⇒ In-situ Von Mises yield stress of fibers seems to be unaffected by volume fraction