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Solid Oxide Fuel Cell Seal Glass-BN Nanotubes Composites

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Solid oxide fuel cell seal glass G18 composites reinforced with ~4 weight percent of BN nanotubes were fabricated via hot pressing. Room temperature strength and fracture toughness of the composite were determined by four-point flexure and single edge V-notch beam methods, respectively. The strength and fracture toughness of the composite were higher by as much as 90 % and 35 %, respectively, than those of the glass G18. Microscopic examination of the composite fracture surfaces using SEM and TEM showed pullout of the BN nanotubes, similar in feature to fiber-reinforced ceramic matrix composites with weak interfaces. Other mechanical and physical properties of the composite will also be presented.

SOFC Seal Glass - Boron Nitride Nanotubes Composites

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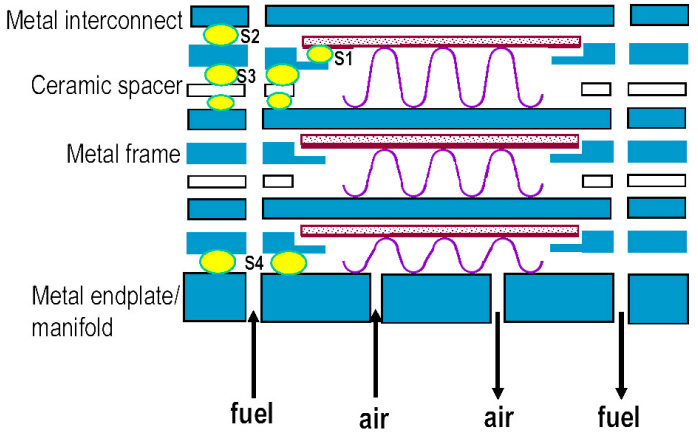
Planar Solid Oxide Fuel Cell (SOFC) Seals

Seal Requirements

- Hermetic to separate and contain fuel and oxidant within the cell and to bond cell components together
- Chemically and mechanically compatible with various SOFC oxide and metallic components and electrical insulator



S1: PEN to Frame
Ceramic to Metal Seal
S2: Interconnect to Frame
Metal to Metal Seal
S3: Frame to Spacer
Metal to Ceramic Seal
S4: Frame to Endplate
Metal to Metal Seal

SOFC Seal Glass

- Composition (mol %): 35BaO-15CaO-5Al_2O_3-10B_2O_3-35SiO_2 (BCAS)
- Low mechanical reliability due to low strength (50 MPa) and low fracture toughness (K_{Ic}<1 MPa.$\sqrt{m}$) -- resulting in limited seal life

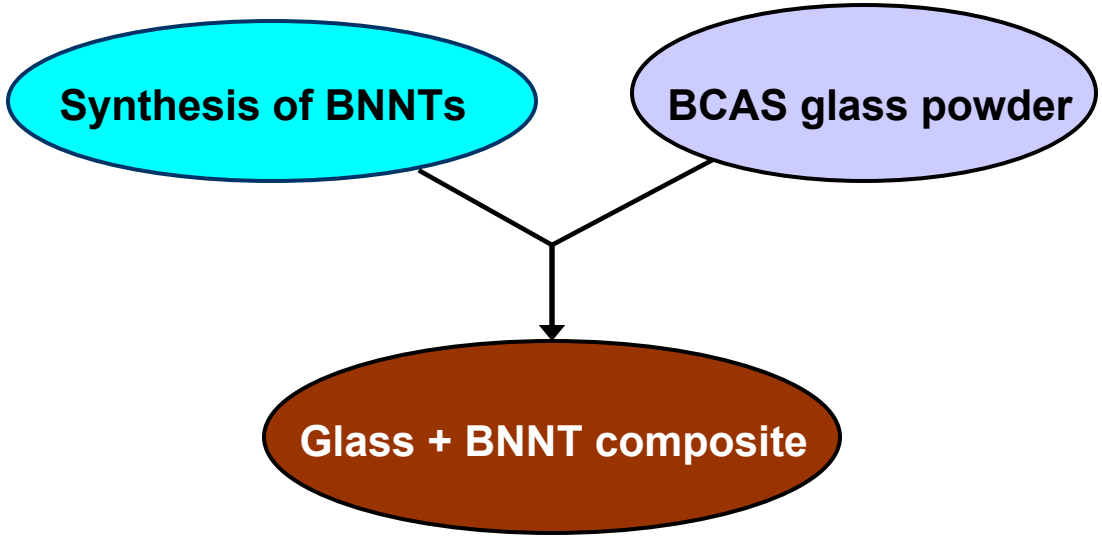
Objective

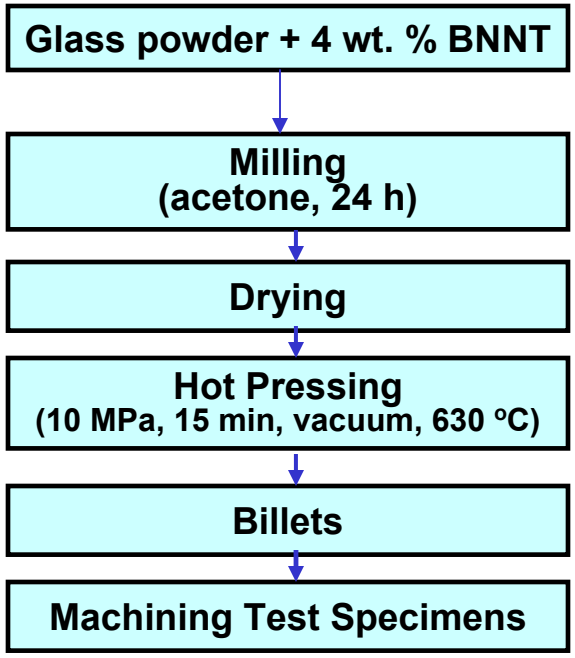
- Improve strength and fracture toughness of SOFC seal glass (BCAS)

Approach

- Reinforce BCAS glass with BN nanotubes (BNNTs)
- Characterize glass-BNNT composite by SEM/TEM
- Measure mechanical properties of composite
- Fractography of composite fracture surfaces

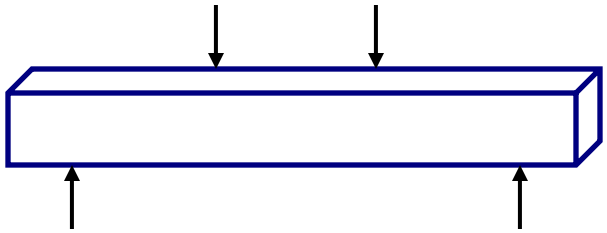
Fabrication of BCAS glass-BNNT Composite





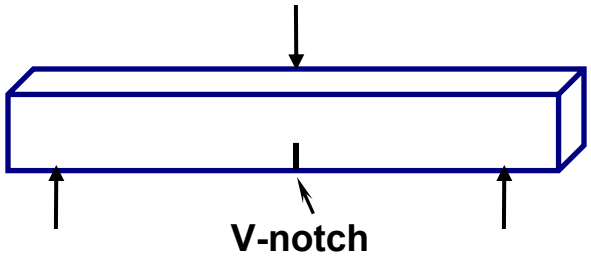
Mechanical Properties Evaluation

Strength



- Test bars: 2 mm x 3 mm x 25 mm
- Test rate: 50 MPa/s
- Test temperature/environment: RT/air
- No. of test specimens: 10
- Test method: ASTM C 1611 (4-point Bend)

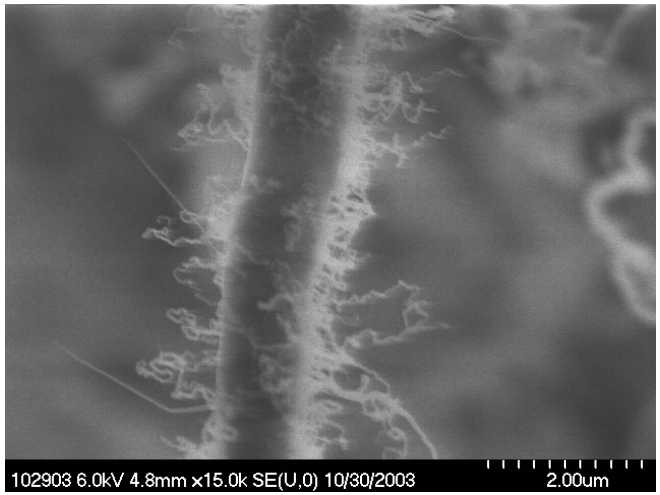
Fracture toughness



- Test bars: 2 mm x 3 mm x 25 mm
- Test rate: 0.5 mm/min
- Test temp/environment: RT/air
- No. of test specimens: 3
- Test method: single edge V-notched beam (SEVNB)

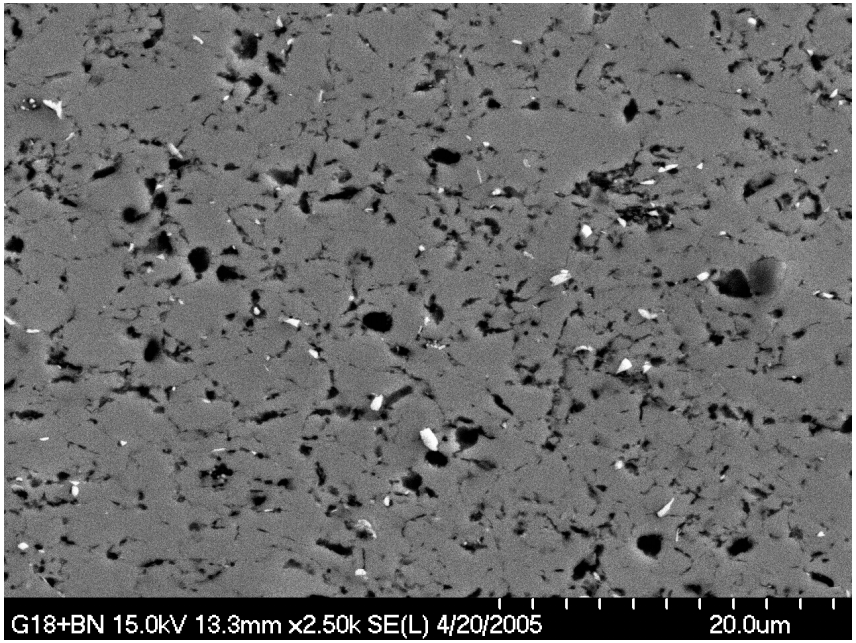
- Elastic modulus (impulse excitation, ASTM C1259)
- Vickers hardness (ASTM C1327)
- Density (mass/volume)

FESEM Microstructures of BNNTs

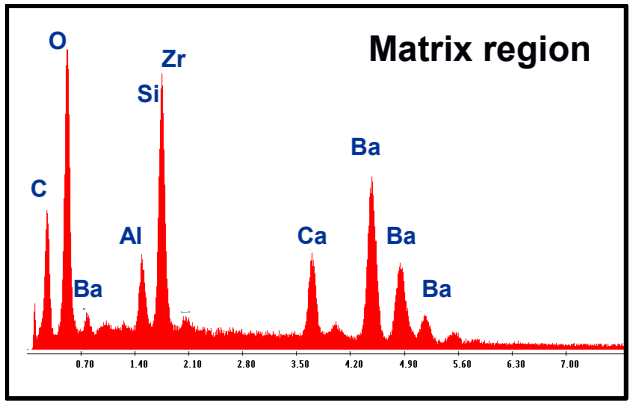


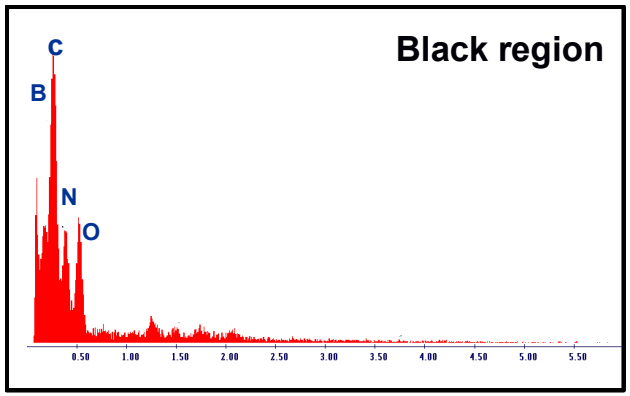
- **Diameter: tens to hundreds of nanometers**
- **Length: tens of micrometers**

SEM/EDS of Glass-BNNT Composite

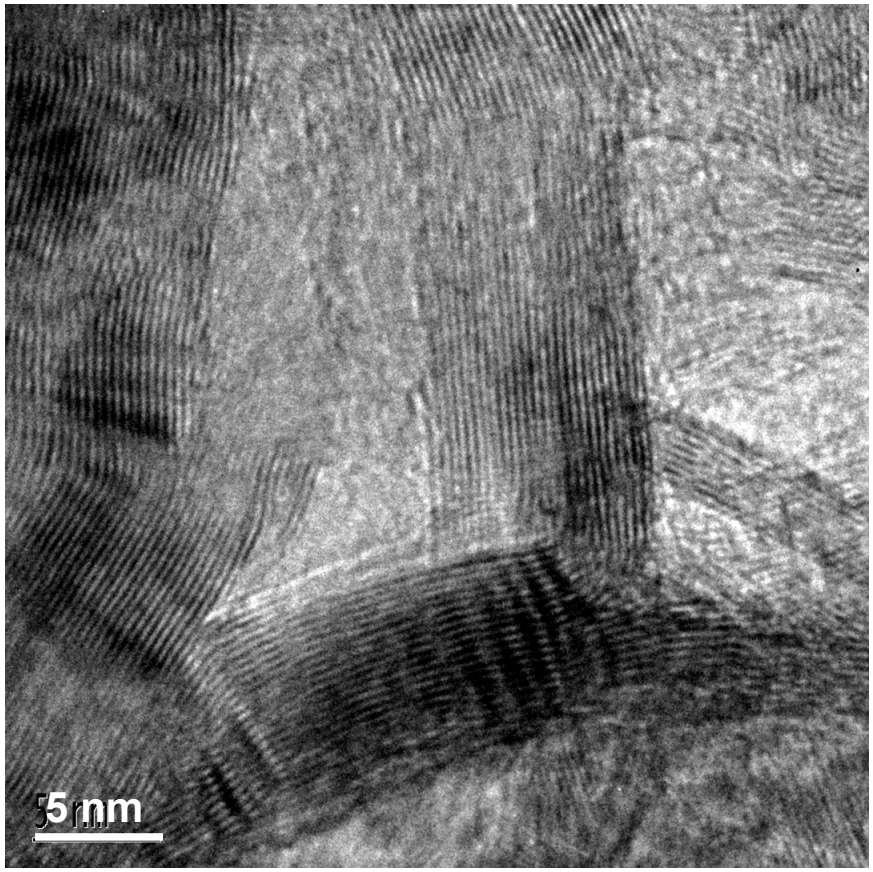


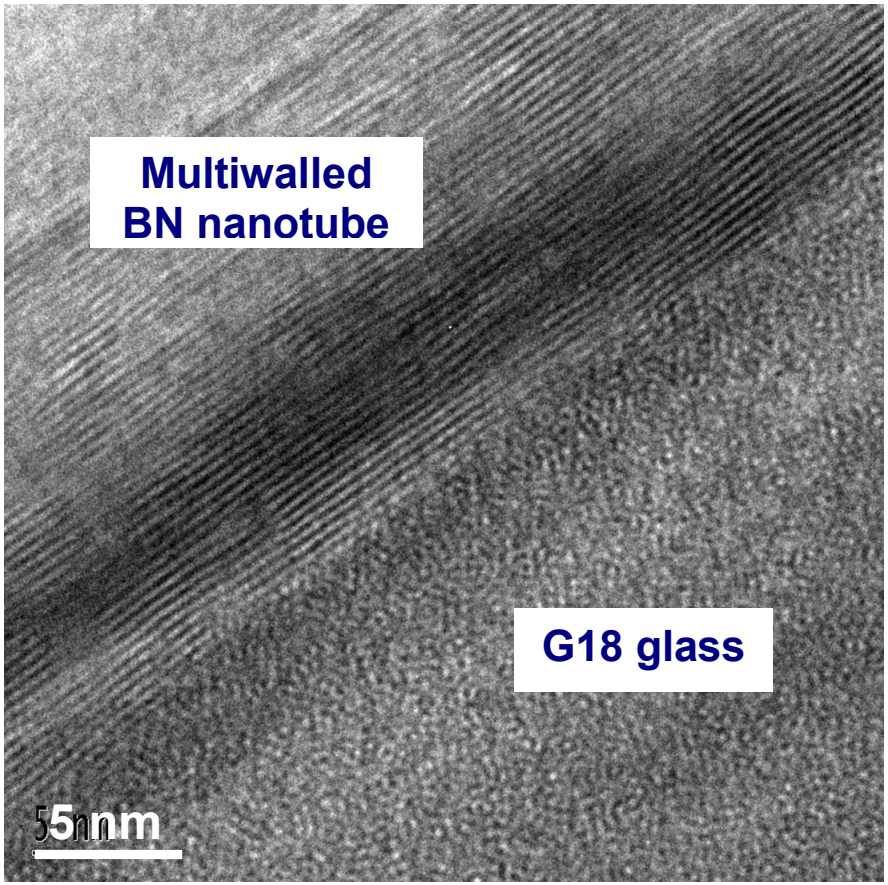
Black regions: BNNT clusters





TEM of Glass-BNNT Composite

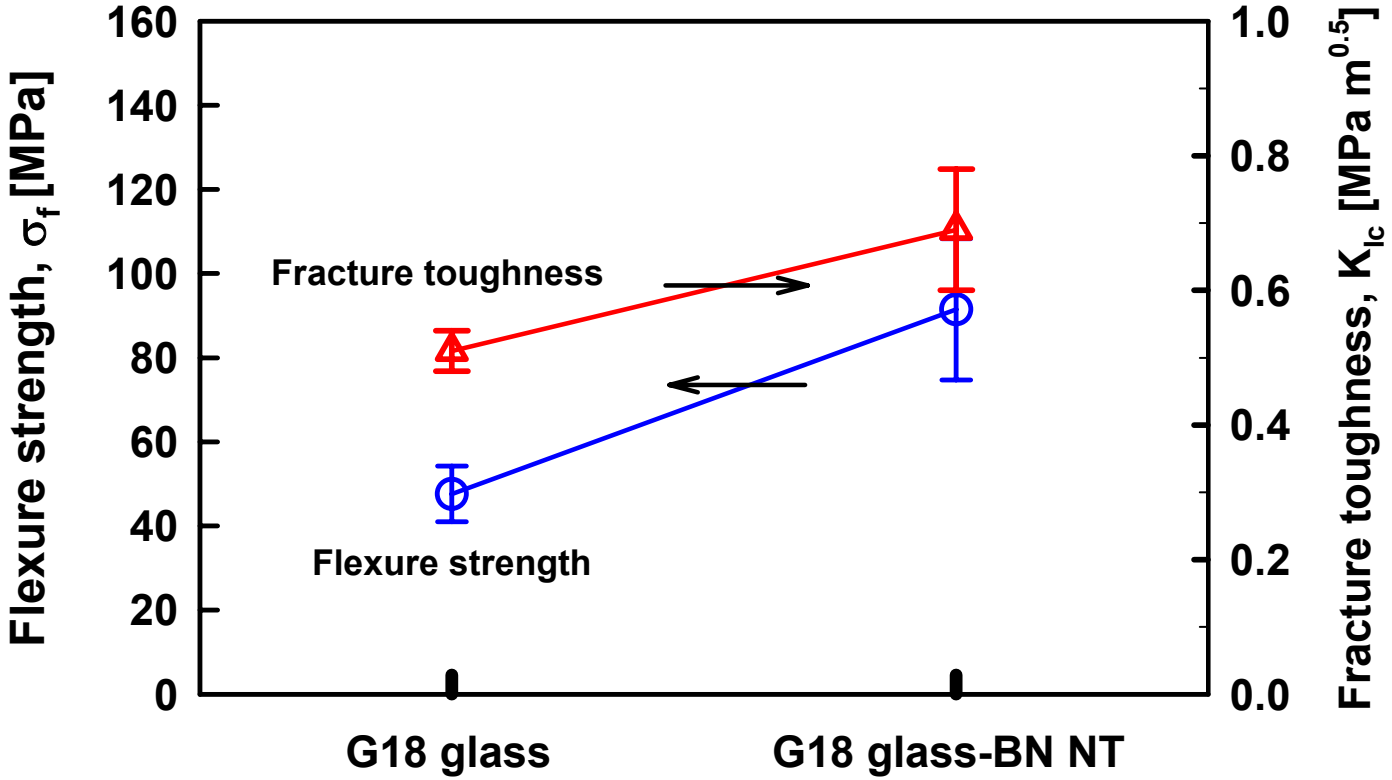




Lattice structure and clusters of mutiwalled BNNTs in composite

BNNT/glass interface in the composite

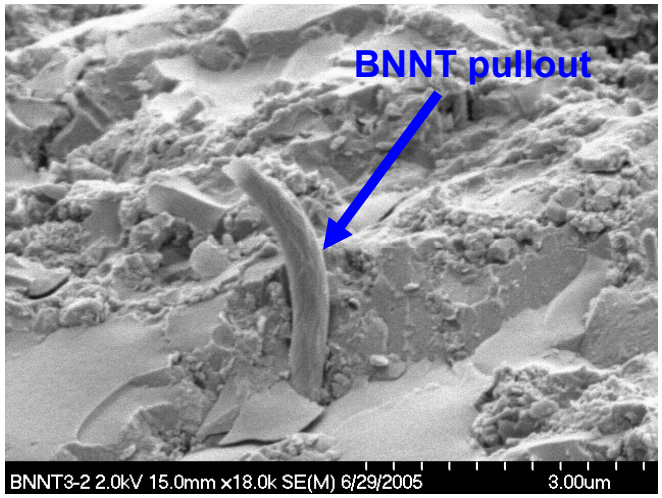
Strength and Fracture Toughness

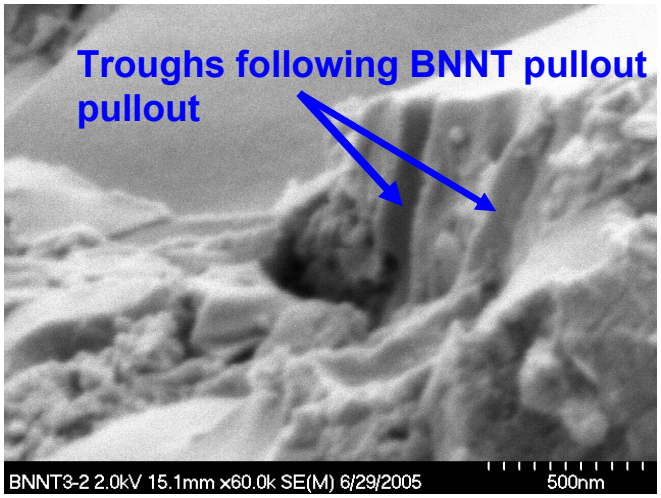


- Significant strength increase (90%): from 48 ± 7 MPa for glass to 92 ± 17 MPa for composite
- Flaws: mostly volume (pores) associated
- Fracture toughness increased (35%): from 0.51 ± 0.037 MPa√m for glass to 0.70 ± 0.09 MPa√m for composite

SEM of Fracture Surfaces

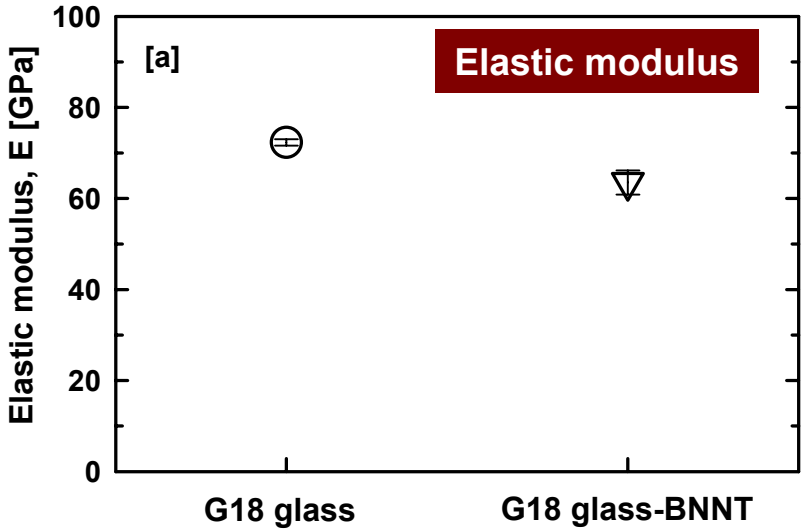
Glass-BNNT Composite

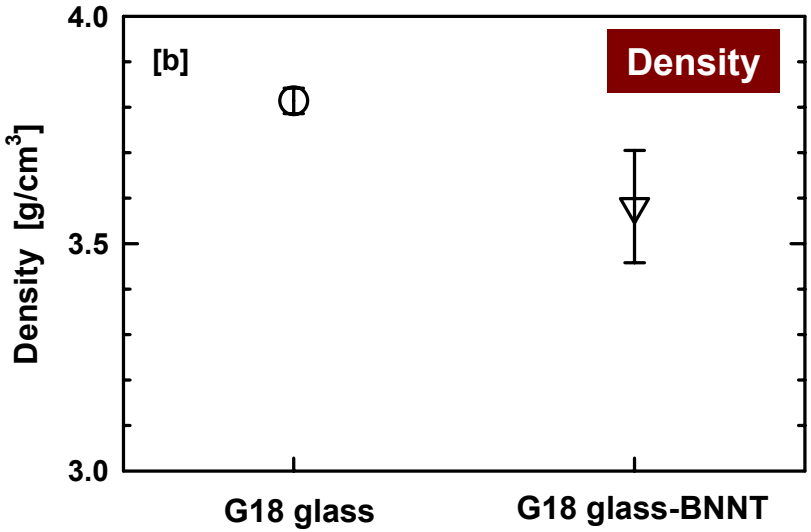


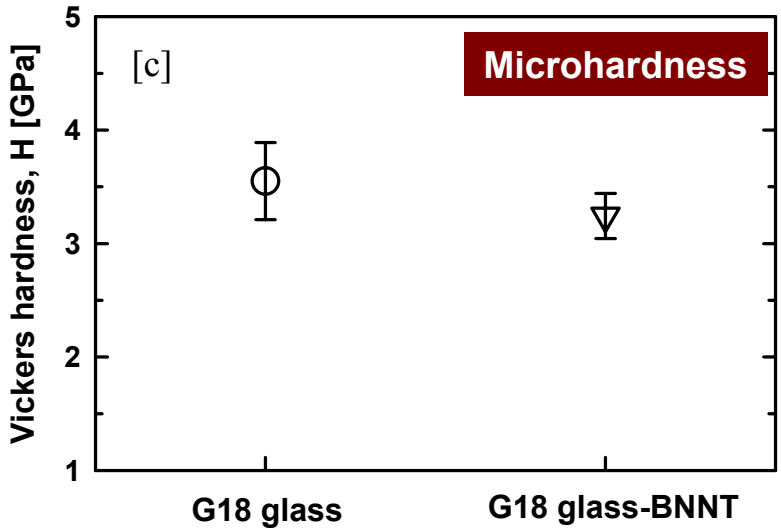


- Fracture surfaces showing pullout of BNNTs and resulting troughs
- Bridging may be a major contributing factor for reinforcement

Elastic Modulus, Density, & Hardness







Rule of mixture not-applicable to elastic modulus and density (Density: glass = 3.814; BN = 2.2; Composite = 3.582 g/cm^3)

Summary and Conclusions

- BCAS glass composites reinforced with 4 wt % BNNTs fabricated (1st time ever)
- Reinforcement of BCAS glass with 4 wt % BNNTs results in:
  - Significant increase (90 %) in flexure strength
  - Moderate increase (35 %) in fracture toughness
  - Lower elastic modulus, density and hardness
- Rule of mixture not-applicable to modulus and density
- BNNT pullout is the toughening mechanism
- Addition of 4 wt% BNNTs will have little effect on viscosity of BCAS glass and its sealing behavior at SOFC operating temperatures

Acknowledgements

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