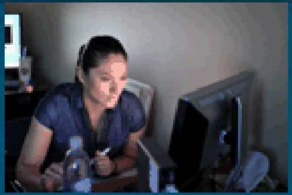
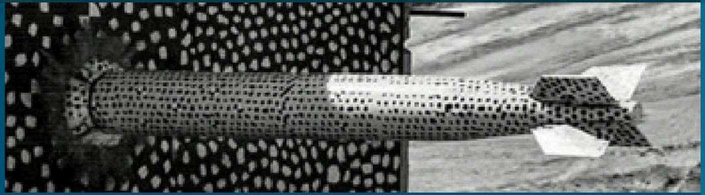
SAND2018-11791C

Dynamic Confinement Response of Unfilled and GMB-Filled Epon 828 and Temperature Effect





PRESENTED BY

Bo Song, Brett Sanborn, Aisha Haynes, Christopher Macrae

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89th Shock and Vibration Symposium, November 4-8, 2018, Dallas, Texas

Potting

*In electronics, **potting** is a process of filling a complete electronic assembly with a solid or gelatinous compound for resistance to shock and vibration, and for exclusion of moisture and corrosive agents. Thermosetting plastics or silicone rubber gels are often used. Many sites recommend using silicone or epoxy to protect from impact and loose wires.*

Potting material design and associated properties are critical to the performance against shock/vibration.

Environments for Potting Materials

- Shock/impact → **Dynamic**
- Containment → **Confinement** Properties at
- Temperature → **High/Low Temperatures**

Material focus in this study –

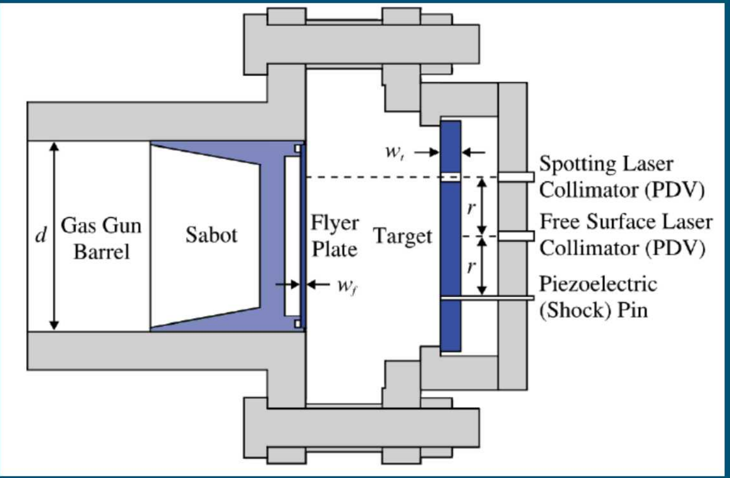
Unfilled Epon 828 and filled Epon 828 with glass micron balloons

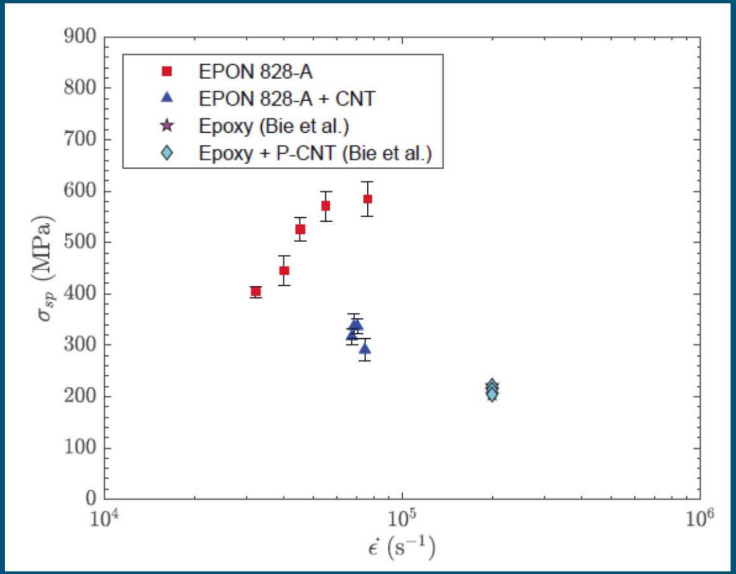
Literature Search for Epon 828

Very limited information about dynamic compressive response of Epon 828.

- **Plate impact tests**
  - Pepper et al., (2018) International Journal of Impact Engineering – **Epon 828/Epikure 3223**
  - Pepper et al., (2018) AIP Conference Proceedings - **Epon 828/Epikure 3223 and carbon nanotube composite**
  - Lang et al., (2018) AIP Conference Proceedings – **Epon 828/T403**

- **Ballistic tests**
  - Pol and Liaghat (2016) Polymer Composites – **Epon 828/D400/Nanoclay**
  - Pol et al., (2012) Journal of Composite Materials – **Epon 828/D400/Nanoclay**

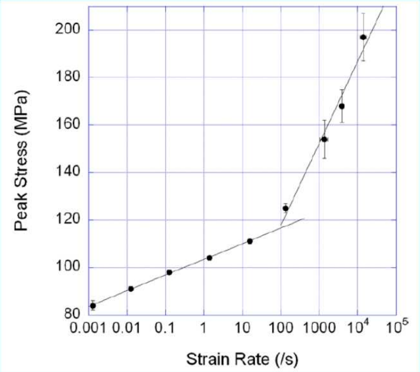


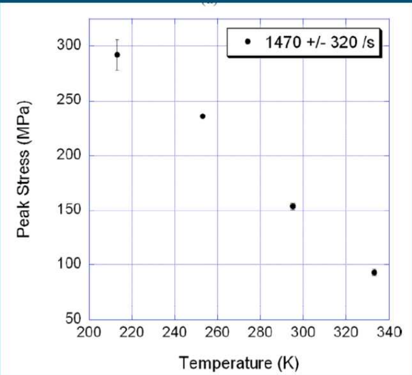


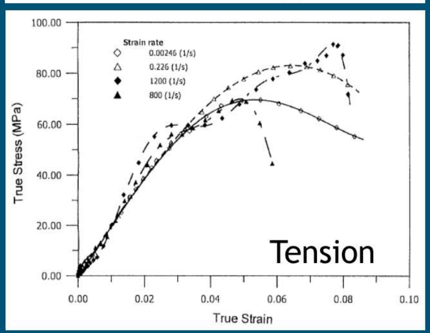
Literature Search for Epon 828

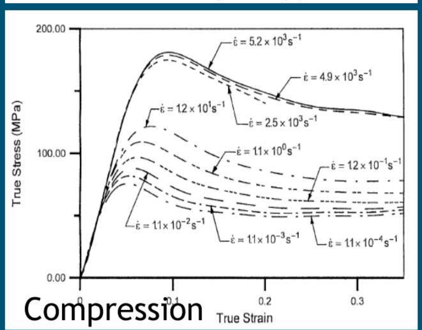
- **Split Hopkinson Bar/Kolsky Bar Tests**
  - Jordan et al., (2008) Mechanics of Time-Dependent Materials – **Epon 826/DEA**
    - ✓ Uniaxial compression (unconfined)
    - ✓ Strain-rate and temperature effects
  - Chen et al., (2002), Polymer Testing – **Epon 828/T403**
    - ✓ Uniaxial compression and tension (unconfined), room temperature
    - ✓ Strain rate effect
  - Chen and Zhang, (1997) Journal of Engineering Materials and Technology – **Epon 828/T403**
    - ✓ Uniaxial compression at different temperatures
    - ✓ ***Multiaxial room-temperature compression (confined) at only one strain rate, without any information about confining pressure***

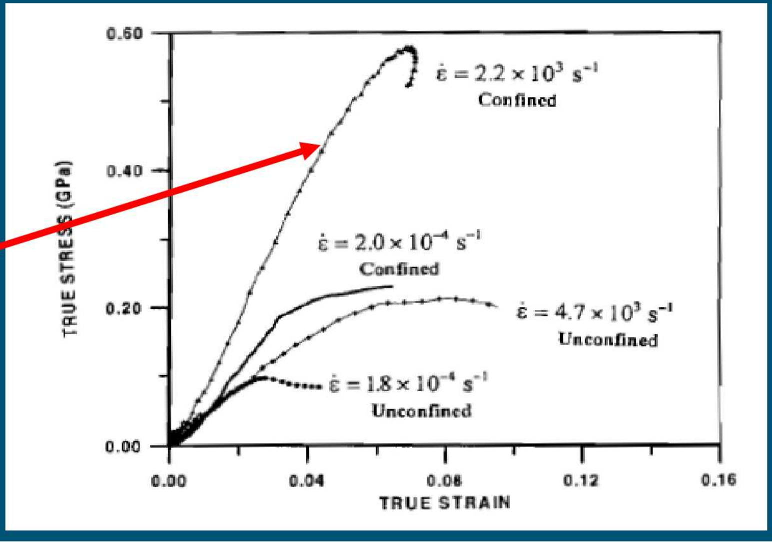
As of today, we have only *1* dynamic compressive stress-strain curve of Epon 828 under confinement.











Design of Dynamic Compression Tests with Lateral Confinement at Different Temperatures

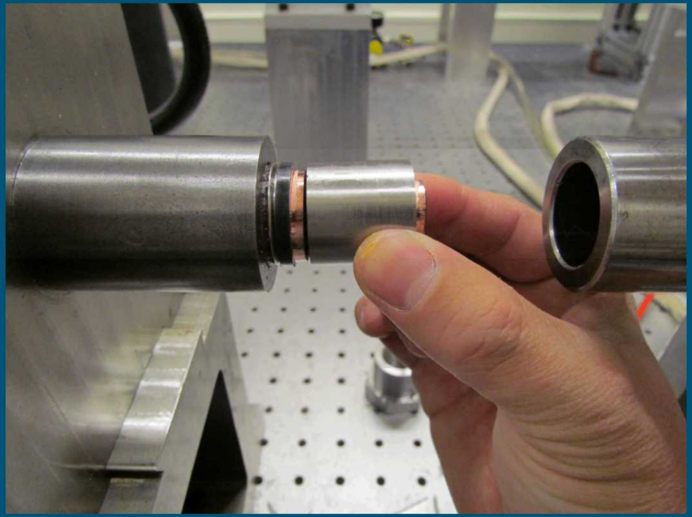
Goal:

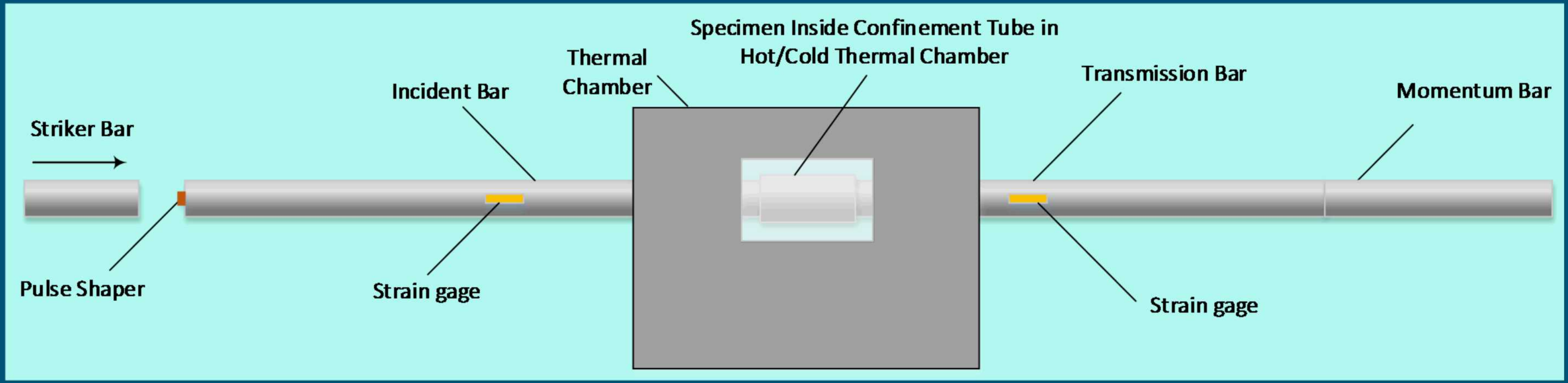
- Better simulate actual mechanical environments subjected to the potting materials
  - Dynamic (high-strain-rate) loading at different impact velocities
  - Compression tests
  - Passive confinement
  - Temperature effect
- Provide quantitatively information to analysts/modelers as much as possible for material model calibration/validation.
  - Compressive stress-strain curves of laterally confined material at different strain rates and temperatures
    - Challenge: pulse shaping design for constant strain rate tests
  - *In-situ* measurement of confining pressure to the potting material
    - Challenge: novel experimental technique to measure confining pressure during dynamic loading

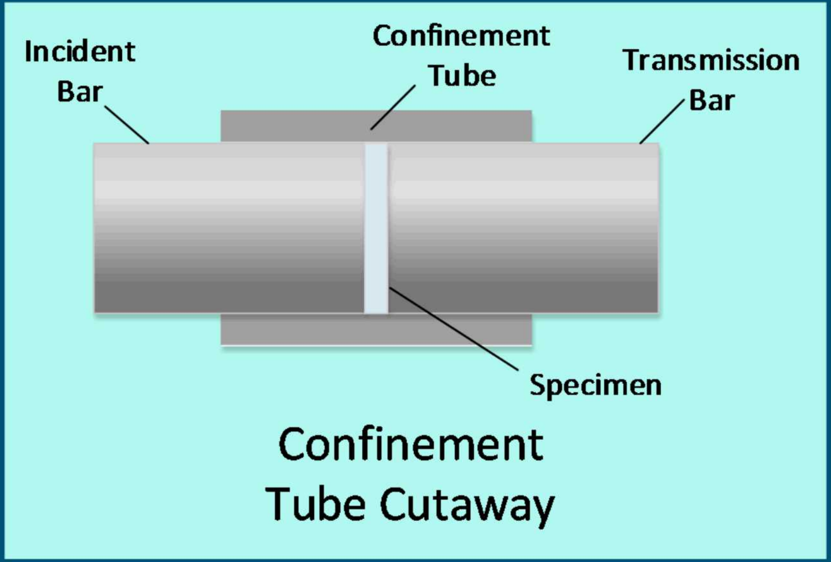
Solution:

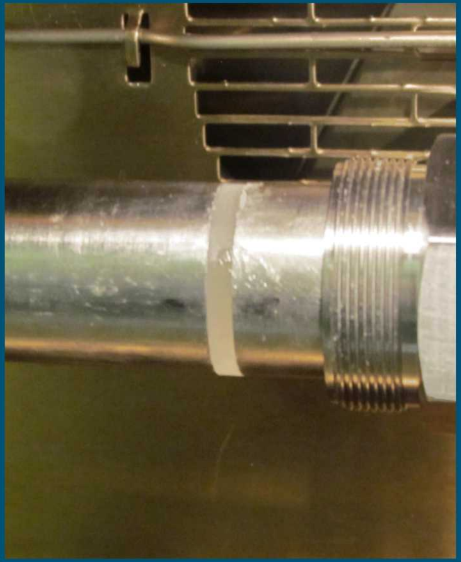
- ✓ Split Hopkinson pressure bar (or Kolsky compression bar) tests with
  - ✓ Thermal chamber
  - ✓ Unique design of confining tube
  - ✓ Novel confining pressure measurement with PVDF thin film force transducer

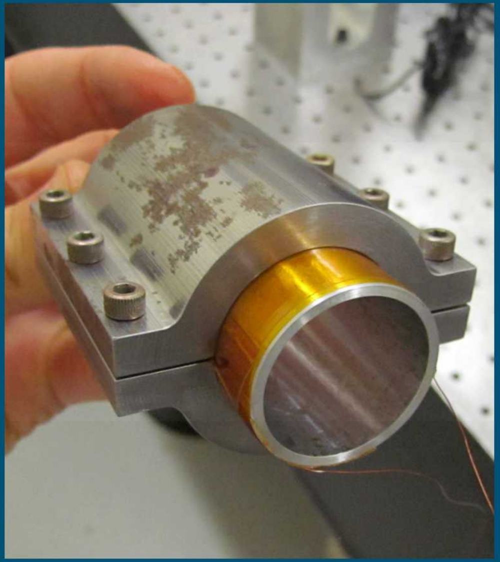
Split Hopkinson Pressure Bar (Kolsky Compression Bar)

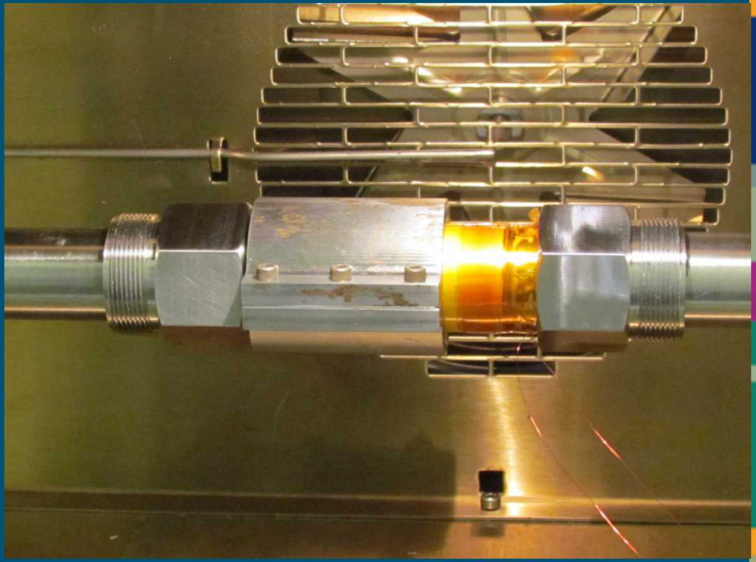








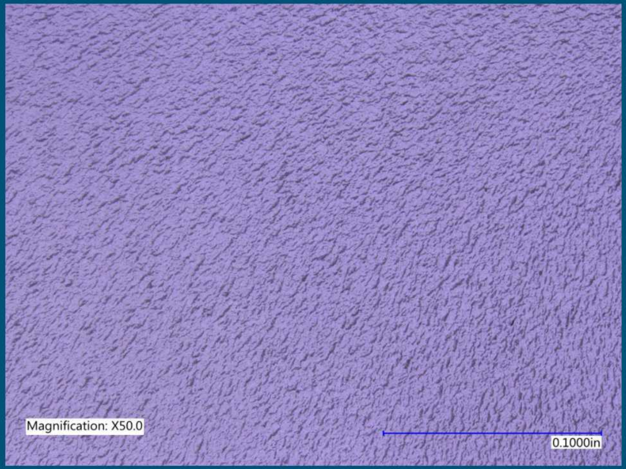


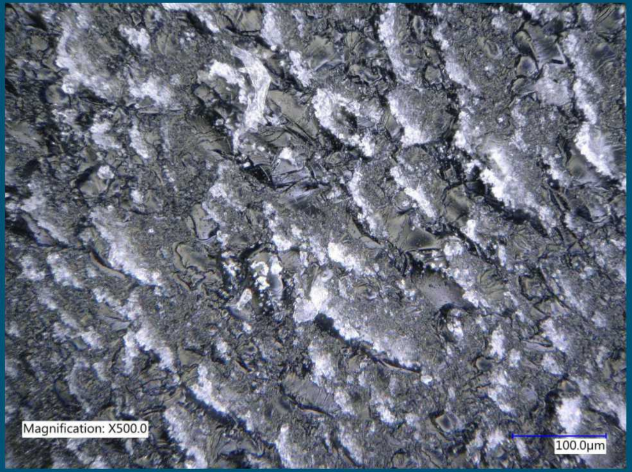


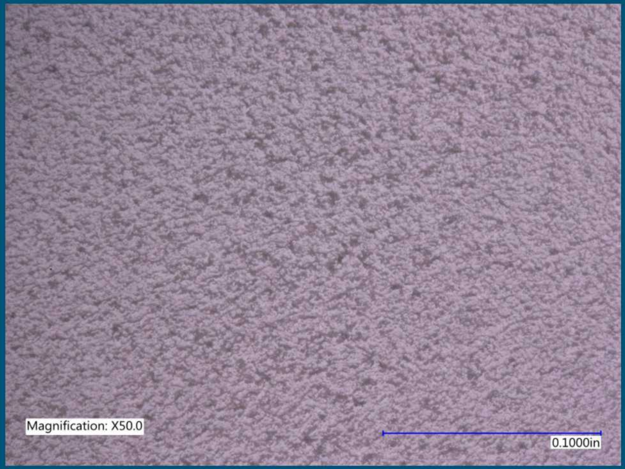
Materials, Specimen, and Testing Conditions

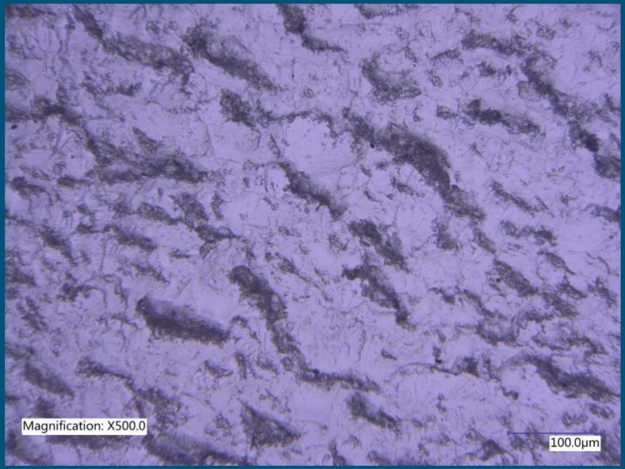
Unfilled Epon 828/DEA
- 25.4 mm diameter; 2.2 mm thick
- Density: 1128 ± 2 kg/m^3

GMB filled Epon 828/DEA
- 25.4 mm diameter; 2.0 mm thick
- Density: 1044 ± 7 kg/m^3







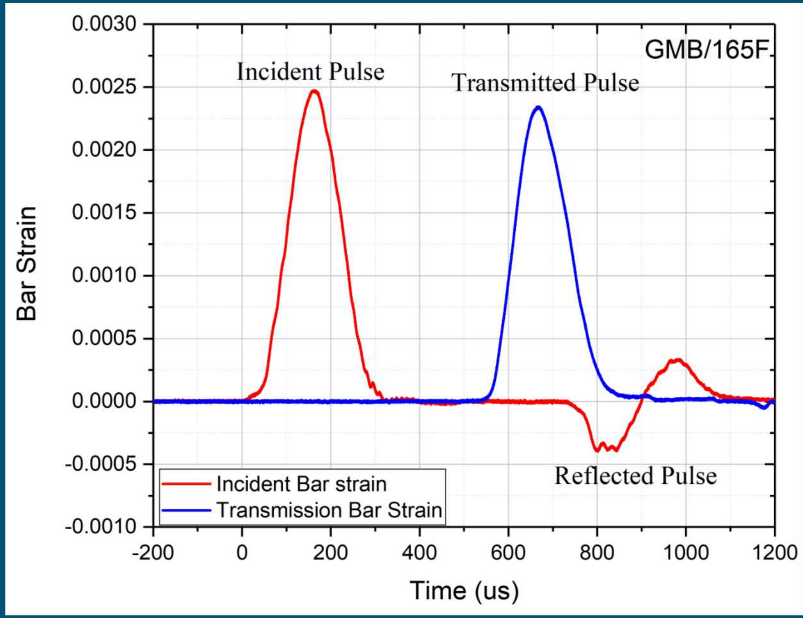


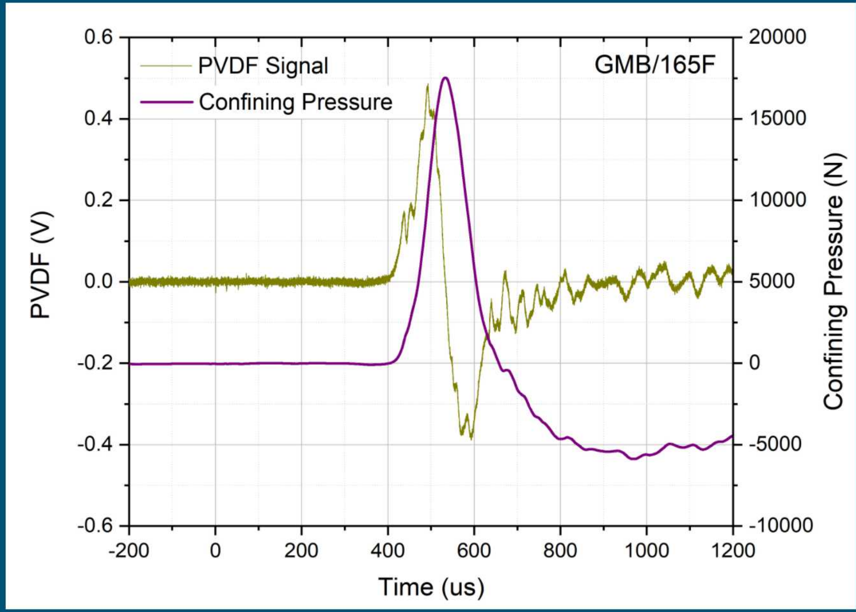
Test Conditions
(still in progress)

- 3 Different Strain Rates – 200, 1000, and 3000 s^{-1}
- 3 Different Temperatures – R.T., 165 F, -50F

Product	Particle Size (microns, by volume) (3M QCM 193.2)			
	Distribution			Effective Top Size
	10th%	50th%	90th%	95th%
A16/500	30	60	95	115
A20/1000	25	60	90	105
H20/1000	25	60	90	105
D32/4500	20	40	65	80
H50/10,000 EPX	15	35	60	70

Typical Oscilloscope Records





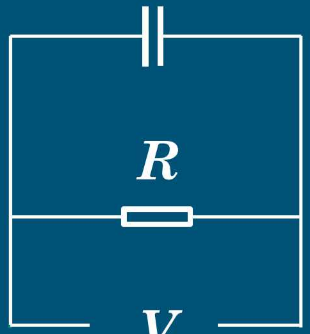
Strain rate, strain, and stress

$$\dot{\varepsilon} = \frac{C_0}{l_s}\left(\varepsilon_i - \varepsilon_r - \varepsilon_t\right) = -2\frac{C_0}{l_s}\varepsilon_r$$

$$\varepsilon = \int_0^t \dot{\varepsilon}(\tau)\,d\tau$$

$$\sigma = \frac{E_0 A_0}{2A_s}\left(\varepsilon_i + \varepsilon_r + \varepsilon_t\right) = \frac{A_0}{A_s}E_0\varepsilon_t$$

PVDF

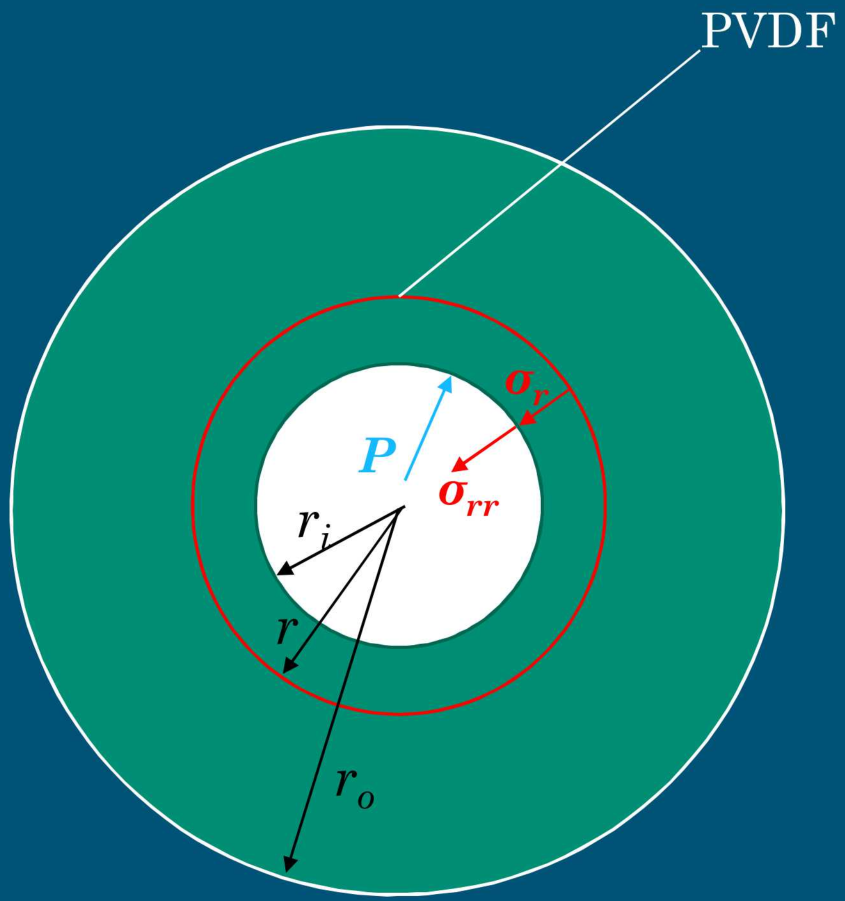


$$F = \frac{1}{k}\cdot\int_0^t \frac{V(t)}{R}dt$$

$$\sigma_r = \frac{F}{A} = \frac{F}{\pi \cdot d \cdot l(t)}$$

$$l(t) = l_s(1-\varepsilon)$$

Confining Pressure



Confining Pressure

$$\sigma_{rr} = -P$$

Stress Analysis in a Thick Walled Cylinder

Vullo, V., (2014) Circular Cylinders and Pressure Vessels, Springer.

$$\sigma_r = \frac{P \cdot r_i^2}{r_o^2 - r_i^2} \cdot \left(1 - \frac{r_o^2}{r^2}\right)$$

$$r_i = 1/2"$$

$$r = 9/16"$$

$$r_o = 13/16"$$

$$\sigma_{rr} = \frac{r_o^2 - r_i^2}{r_o^2 - r^2} \cdot \frac{r^2}{r_i^2} \cdot \sigma_r = \frac{r_o^2 - r_i^2}{r_o^2 - r^2} \cdot \frac{r^2}{r_i^2} \cdot \frac{1}{2\pi \cdot r_i \cdot l_s \cdot (1-\varepsilon)} \cdot \frac{1}{k} \cdot \int_0^t \frac{V(t)}{R} dt$$

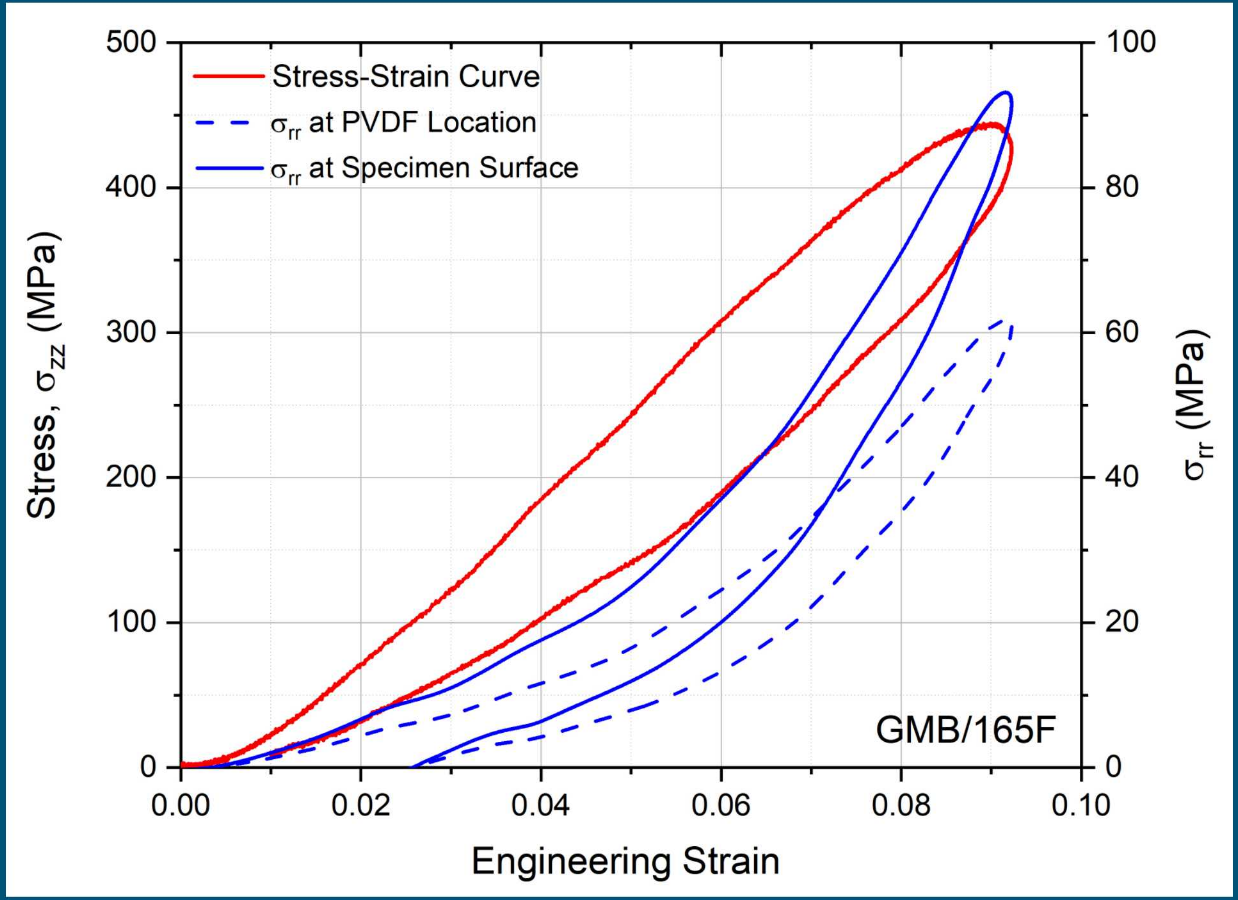
Dynamic Compressive Stress-Strain Curve of GMB Filled Epon 828 at 165F

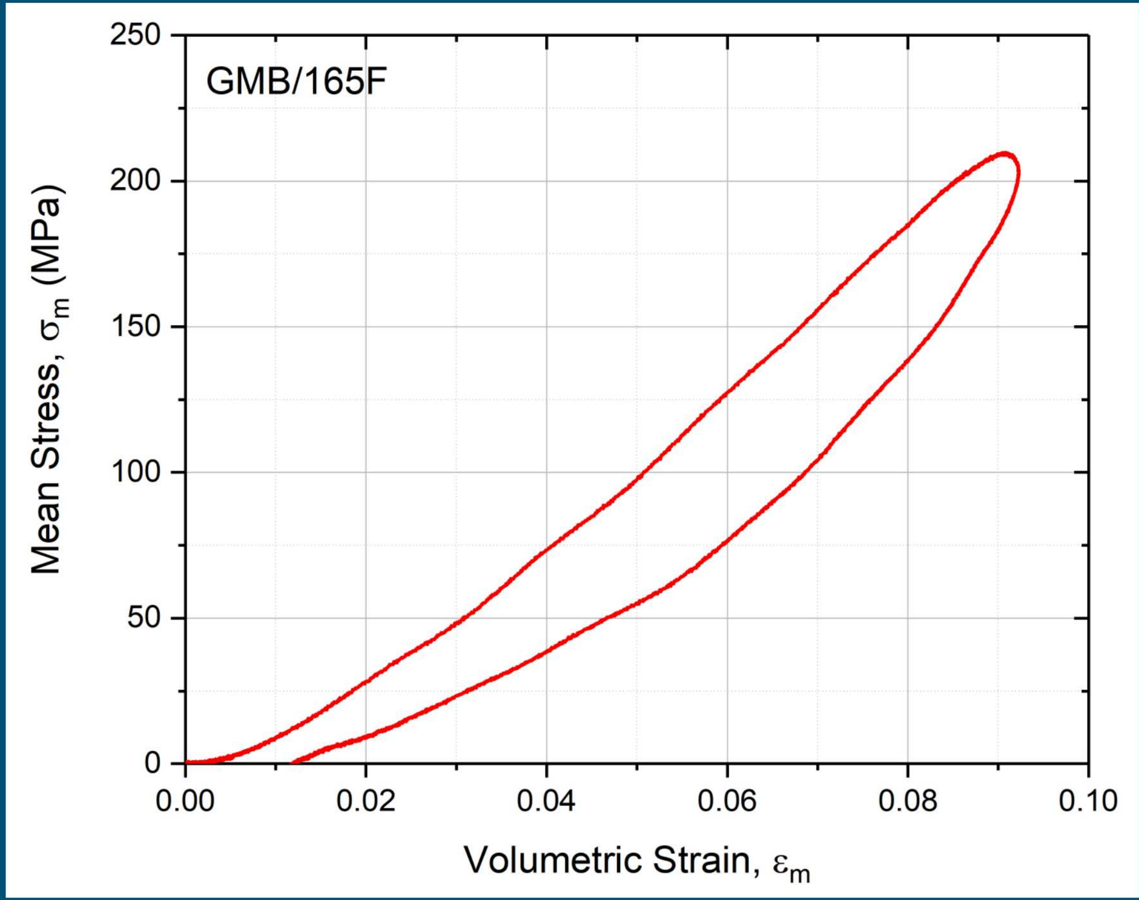
- *Ravi-Chandar, K., and Ma, Z., (2000) "Inelastic Deformation in Polymers under Multiaxial Compression," Mechanics of Time-Dependent Materials, 4:333-357.*
- *Luo, H., Cooper, W. L., and Lu, H., (2014) "Effects of Particle Size and Moisture on the Compressive Behavior of Dense Eglin Sand under Confinement at High Strain Rates," International Journal of Impact Engineering, 65:40-55.*

$$\sigma_m = \frac{1}{3}\left(\sigma_{zz} + 2\sigma_{rr}\right)$$

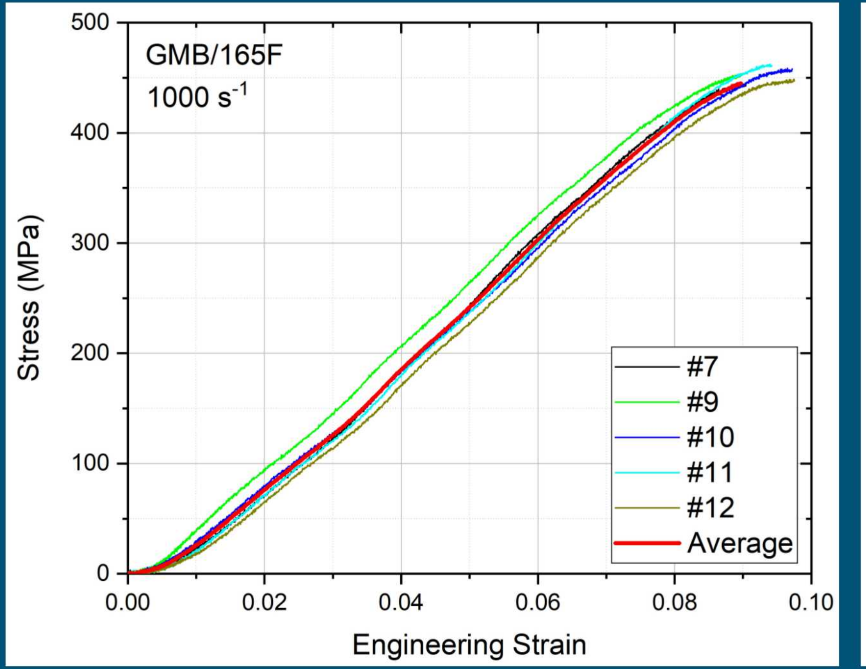
$$\varepsilon_m = \varepsilon_{zz} + 2\varepsilon_{rr}$$

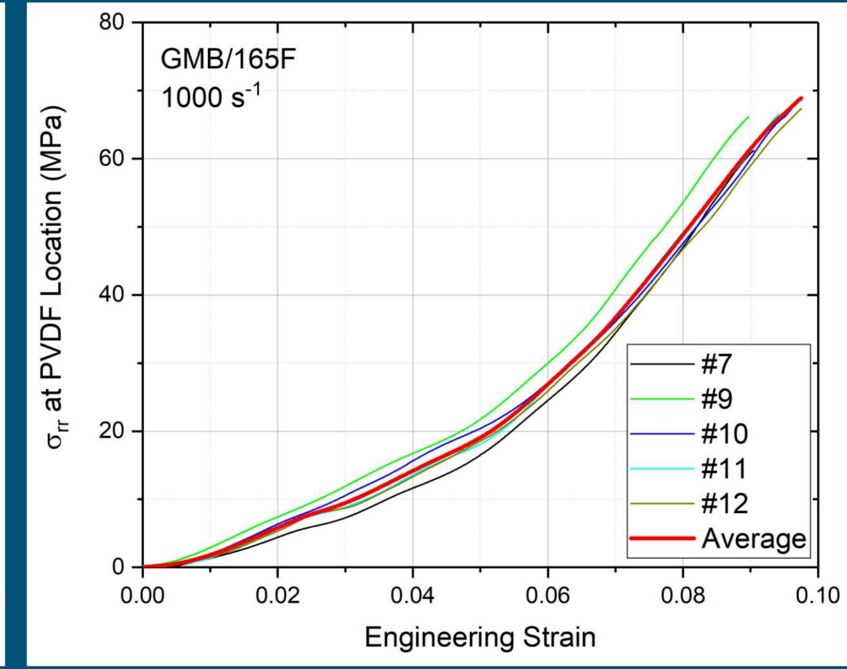
$$\varepsilon_{rr} << \varepsilon_{zz}$$

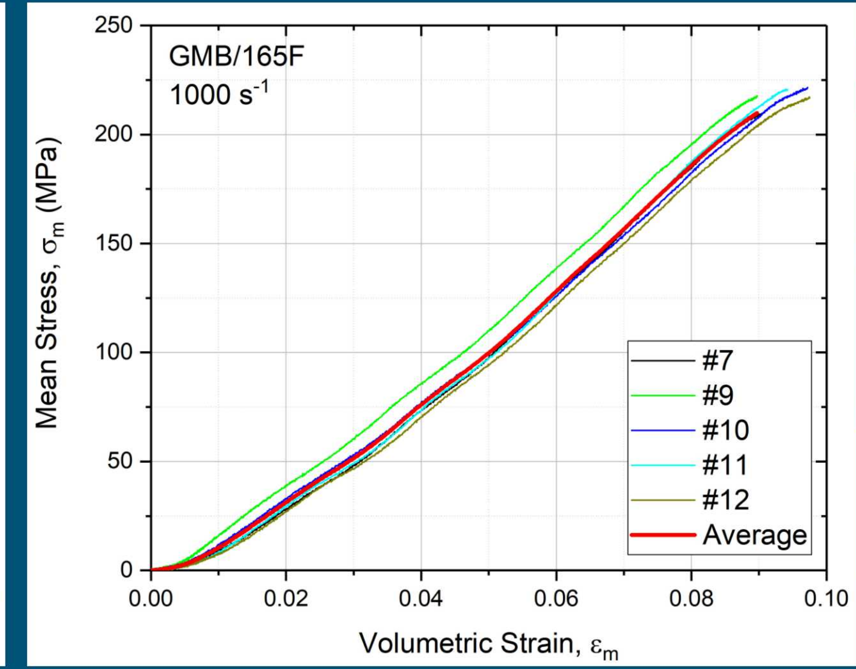




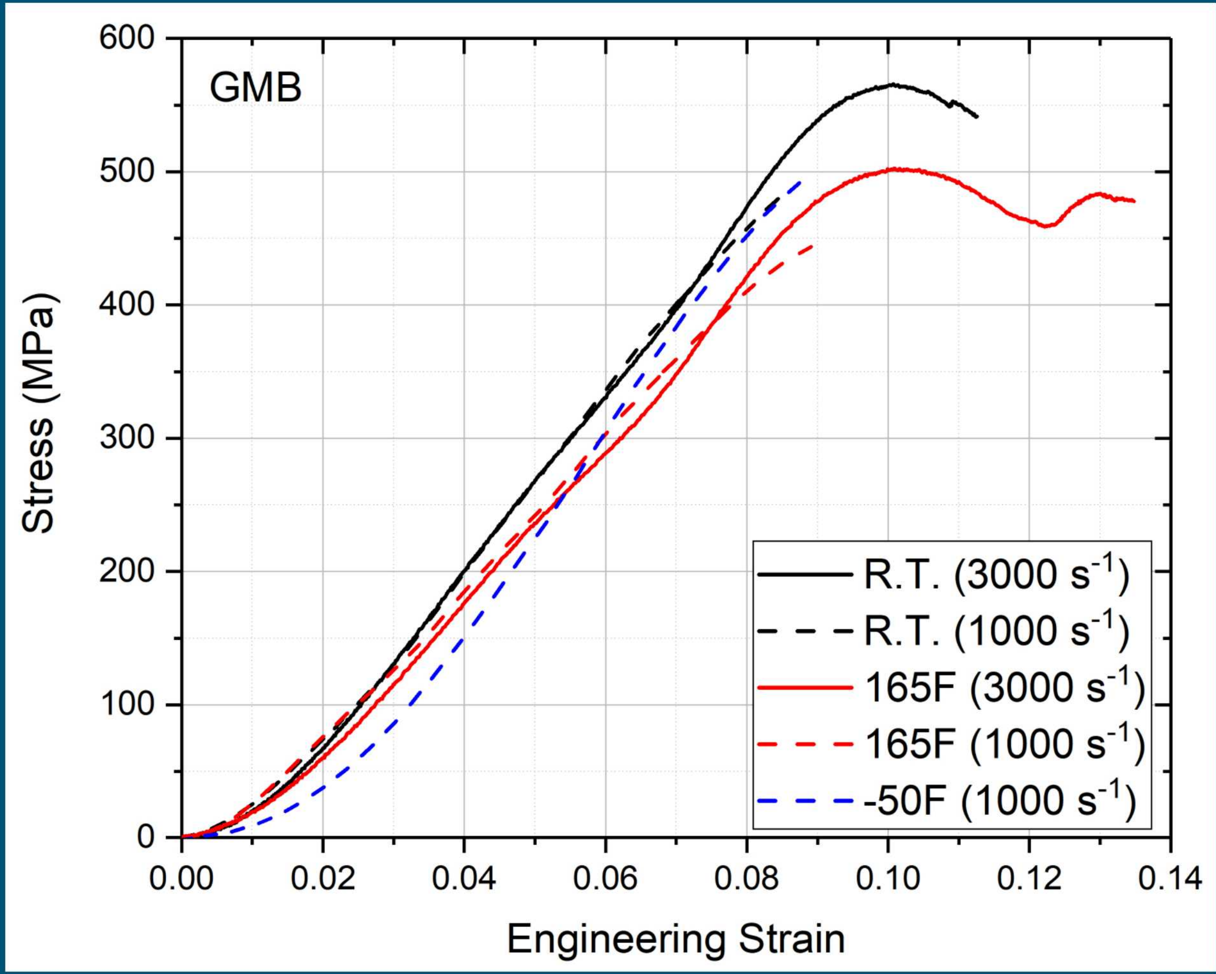
Repeatability Check

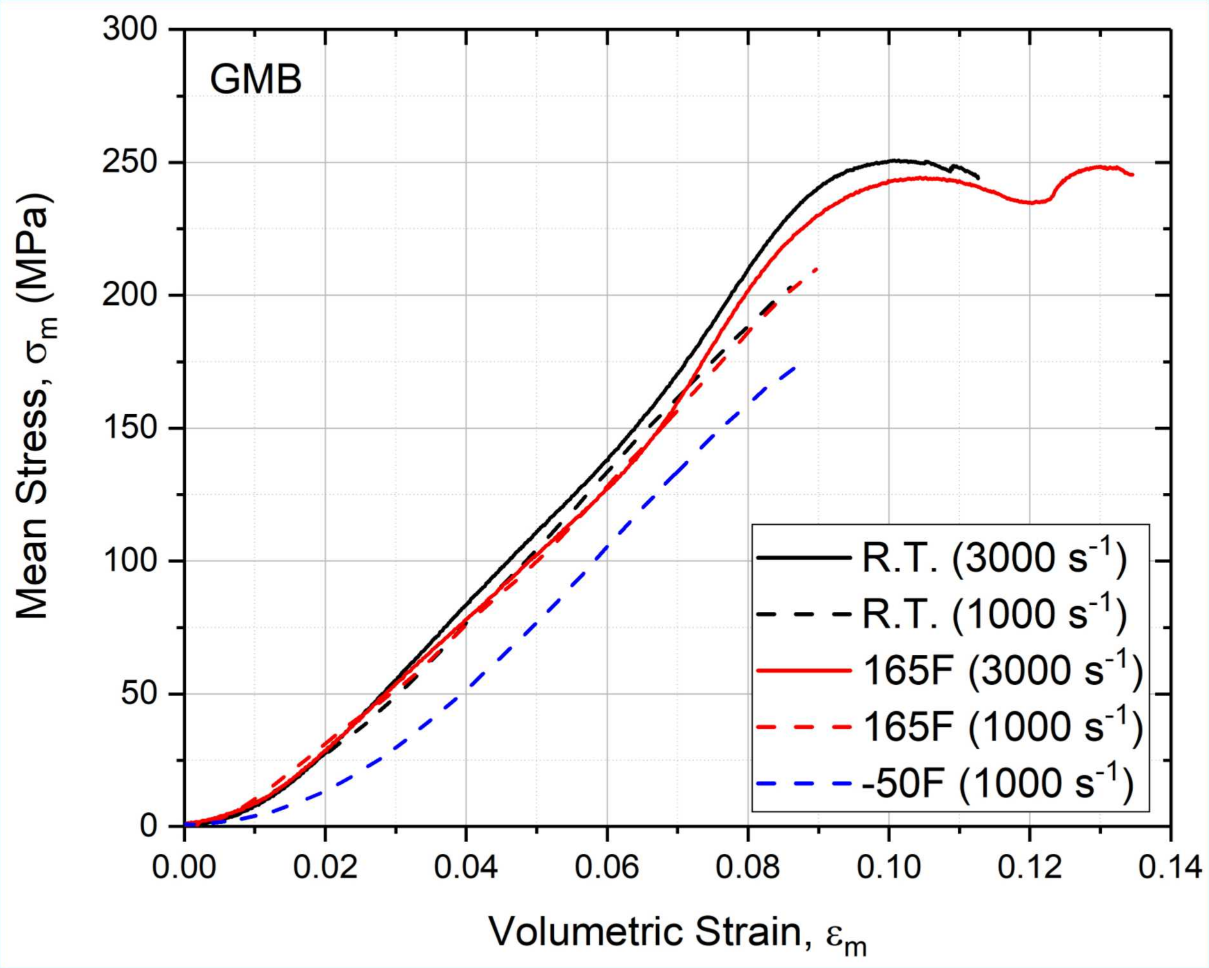




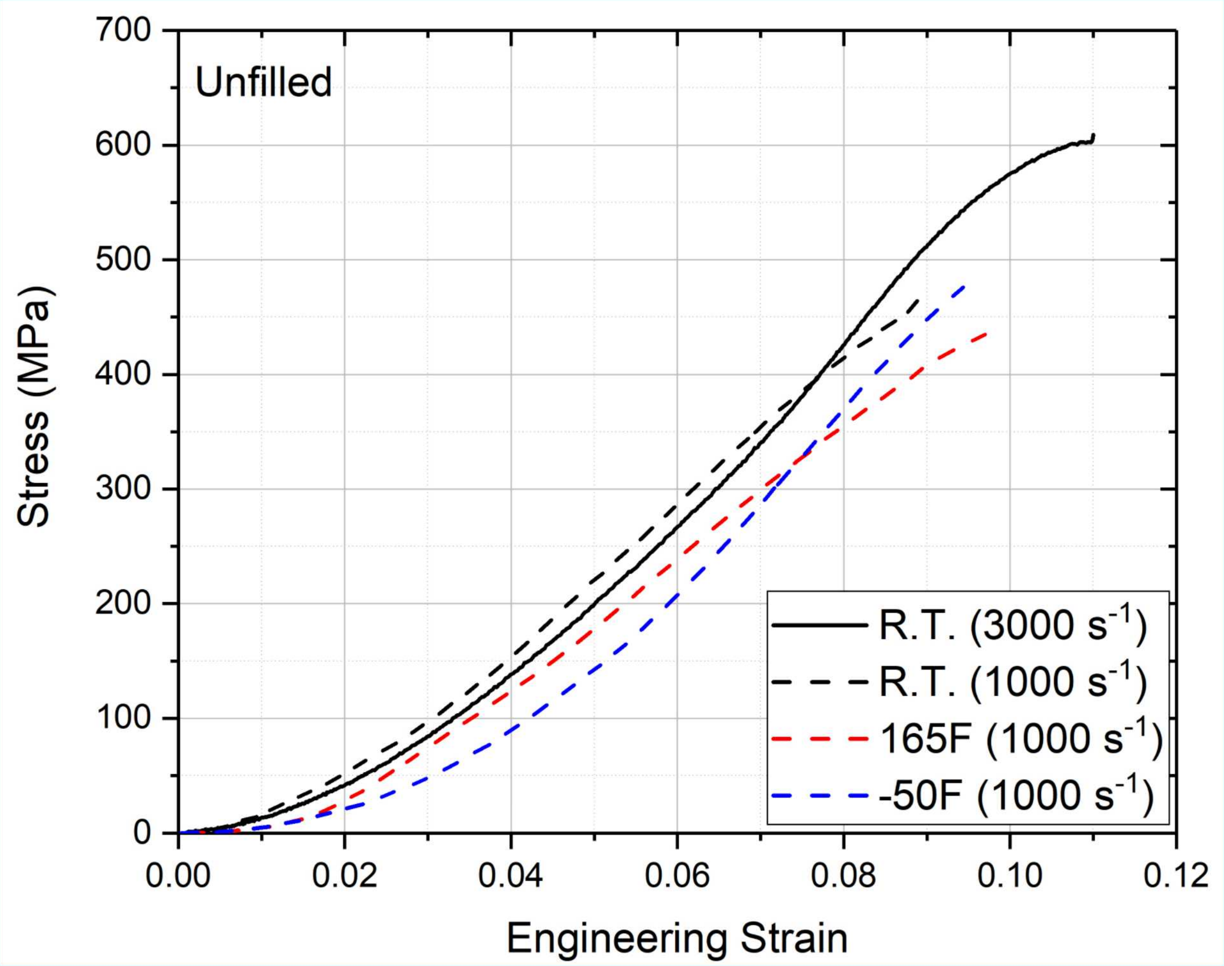


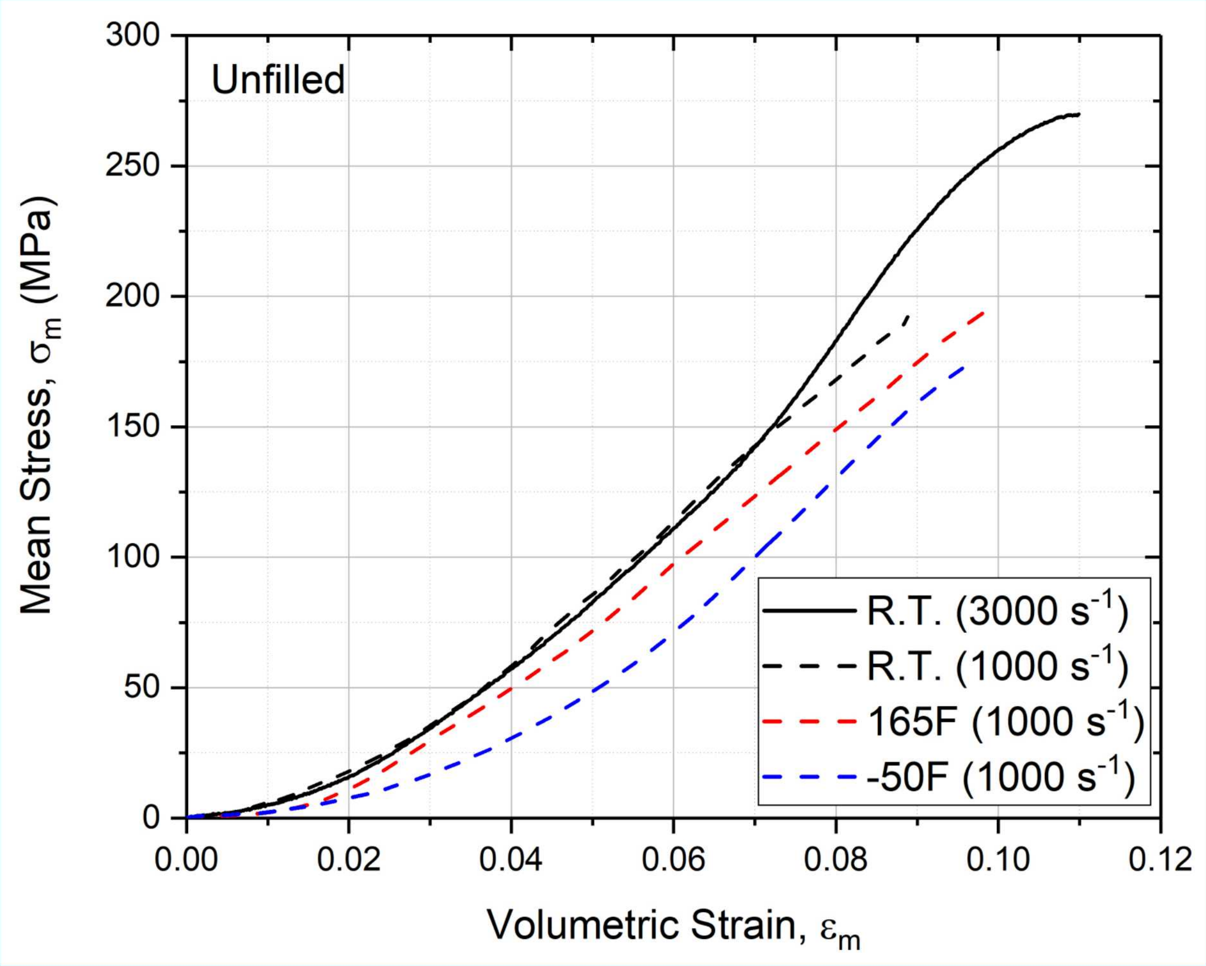
Strain-rate and Temperature Effects on Dynamic Compressive Stress-Strain Curves of Confined GMB-filled Epon 828



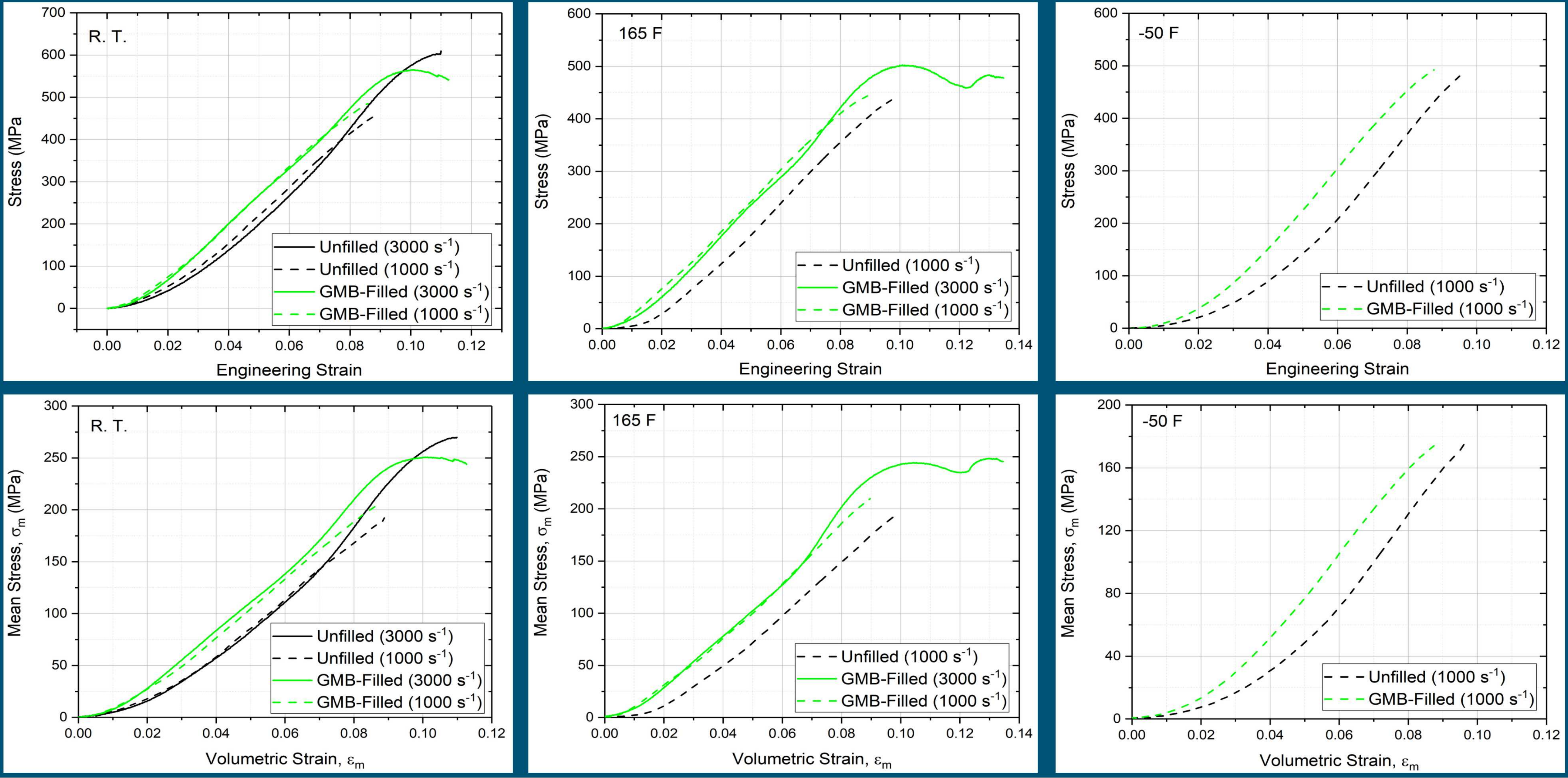


Strain-rate and Temperature Effects on Dynamic Compressive Stress-Strain Curves of Confined Unfilled Epon 828

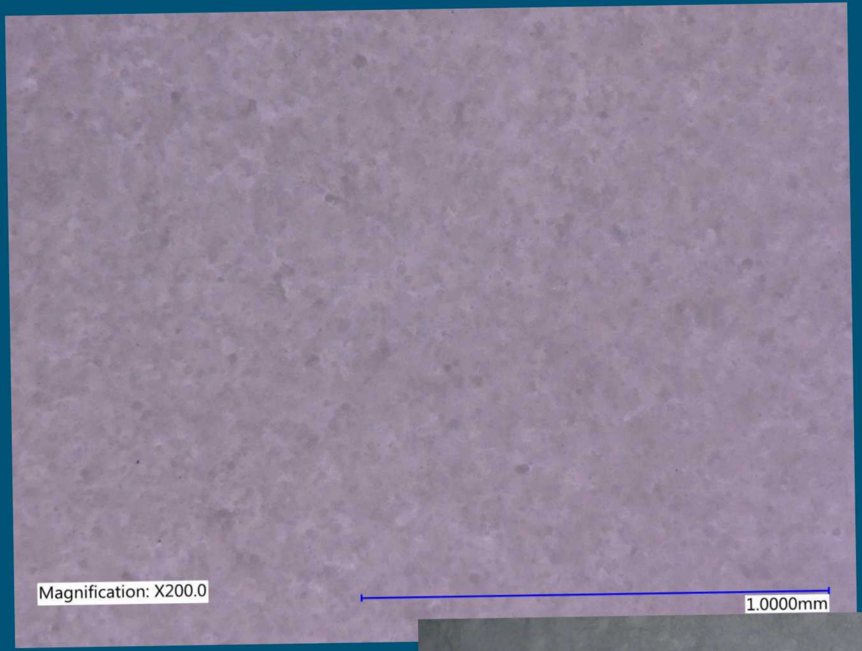


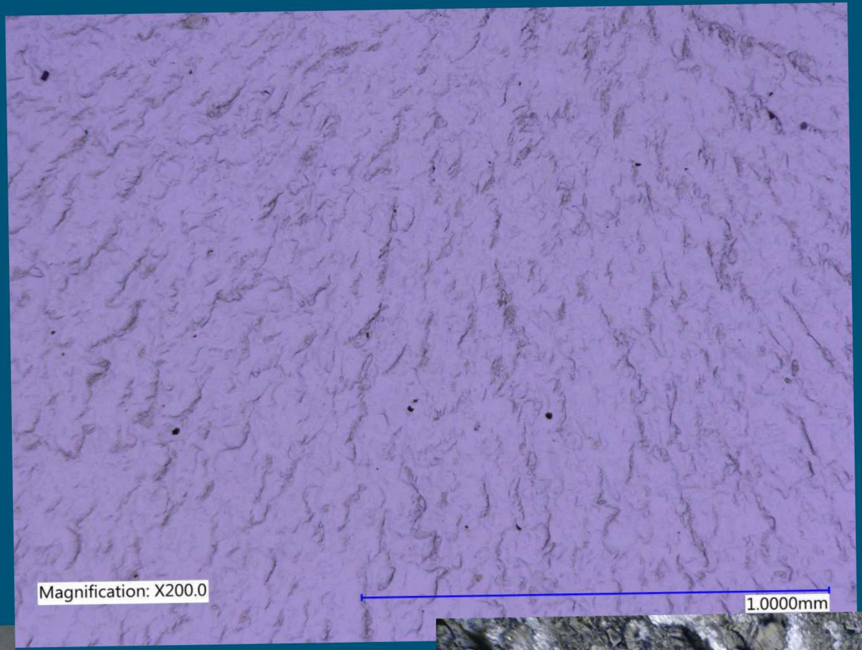


GMB-Filled VS Unfilled Epon 828



Post-Test GMB-Filled VS Unfilled Epon 828 Specimens



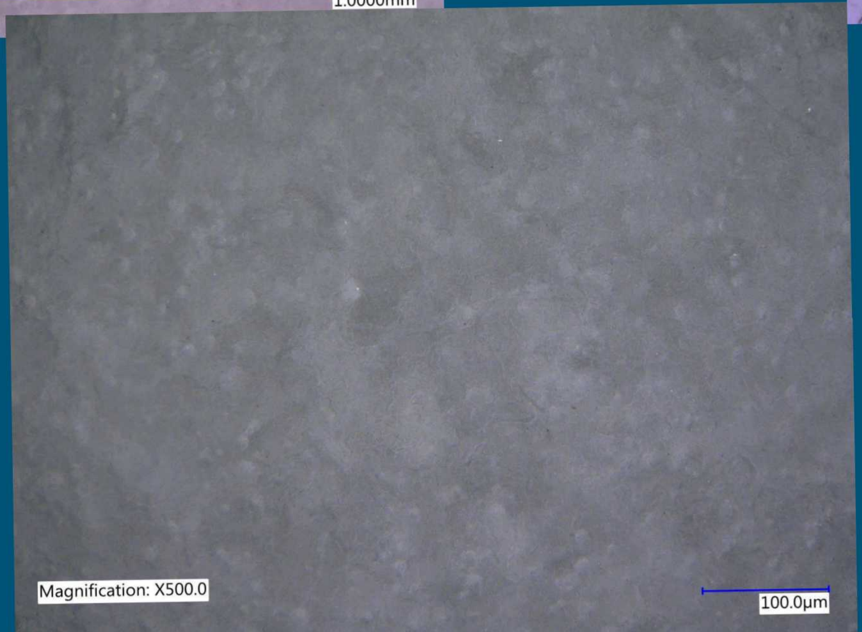


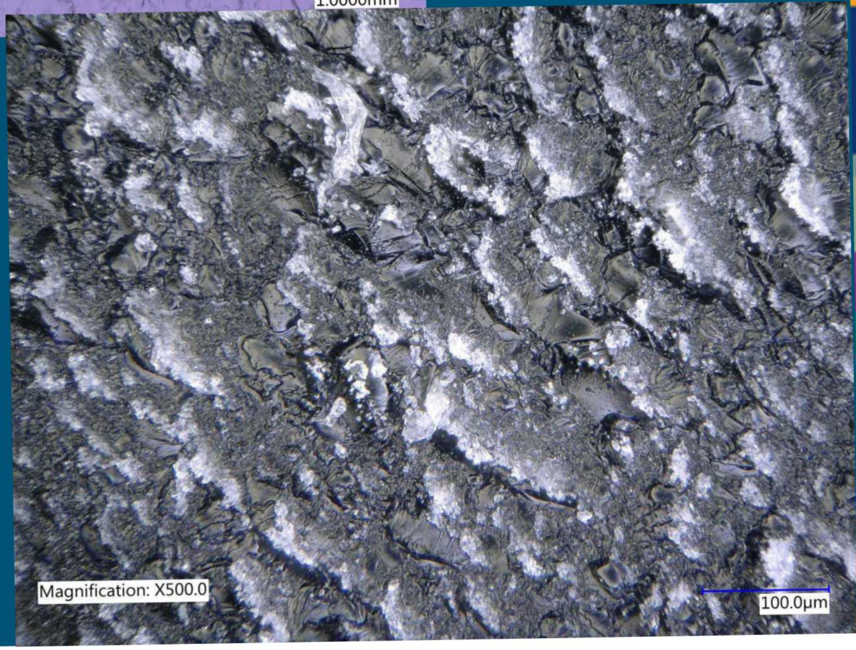
Unfilled:

1000/s
165F

GMB Filled:

1000/s
165F





Conclusions and Path Forward

- Unfilled Epon 828 and GMB-filled Epon 828 epoxy were dynamically characterized with a Kolsky compression bar under lateral confinement at different strain rate and temperatures

- Lateral confinement pressure during dynamic loading was measured with PVDF implemented in the confining tube
  - With lateral confinement pressure, more information including mean stress-strain curve, shear stress-strain curve can be obtained

- Dynamic compressive stress-strain responses of unfilled Epon 828 and GMB-filled Epon 828 were obtained at nearly uniaxial strain condition
  - Insignificant strain-rate and temperature effects were observed for both materials within the range investigated in this study
  - GMB-filled Epon 828 had a lower density but slightly higher strength than unfilled Epon 828

- **Path forward**

  - PVDF calibration for verification of lateral confining pressure
  - Complete all other tests, including the tests at lower strain rate, ~200 s^{-1}, and determine strain-rate and temperature effects