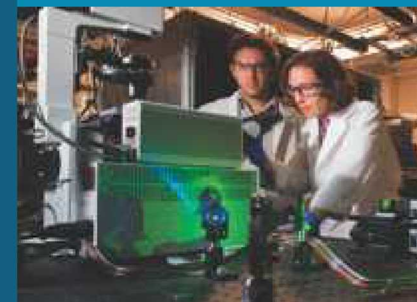
SAND2019-12993C

Dynamic Confinement Characterization of Potting Materials Under Extreme Environments



PRESENTED BY

Brett Sanborn[1], Bo Song[1], Aisha Haynes[2], Christopher Macrae[2]

[1] Sandia National Laboratories

[2] US Army CCDC Armaments Center

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Striving for accuracy in constitutive models: confined or unconfined response?

- **Electronics potting:** mechanical, electrical, and environmental protection of components
- **In a real application**: Case is filled with polymer resin => Cap/cover is installed => **Potting material is triaxially confined**
  - Simulation teams need to use the **confined response** for *Constitutive model calibration and Validation*
  - What's the difference?

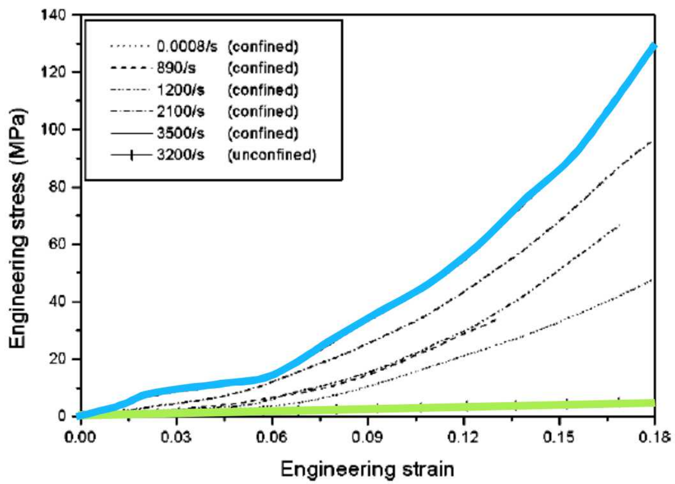


Fig. 4 Axial dynamic compressive stress-strain curves of EPDM rubber at various strain rates under nearly uniaxial strain conditions

B. Song, W. Chen. (2004) Dynamic Compressive Behavior of EPDM Rubber Under Nearly Uniaxial Strain Conditions. Journal of Engineering Materials and Technology. 126: 213-217

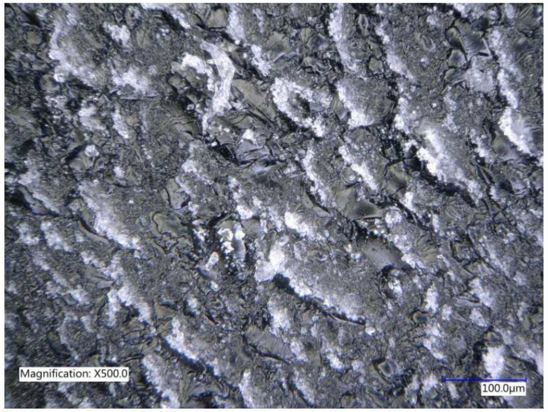
Potting material response is critical for system design

Environments for Potting Materials	Testing Conditions
➢ Shock/impact	High rate Kolsky Bar
➢ Encapsulated	Confined
➢ Temperature	High, Ambient, and Low Temperature

Materials, Specimens, and Testing Conditions

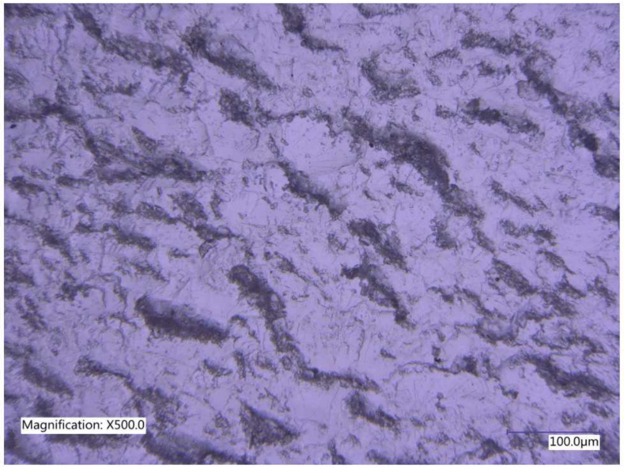
Unfilled EPON 828/D230

- 25.4 mm diameter; 3.9 mm thick
- Density: 1128 ± 2 kg/m^3



GMB filled EPON 828/D230

- 25.4 mm diameter; 3.8 mm thick
- Density: 1044 ± 7 kg/m^3



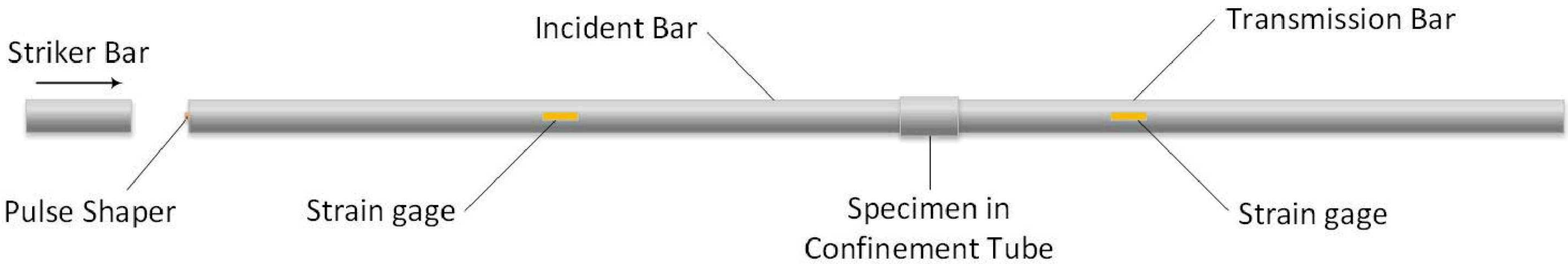
Test Conditions

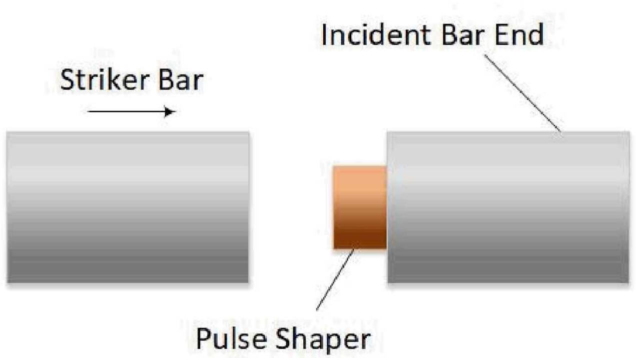
- 3 Different Strain Rates – 200, 1000, and 3000 s^{-1}
- 3 Different Temperatures – R.T., 165° F (74° C), -50° F (-45° C)
- 5 repeated tests at each condition
- 90 total tests

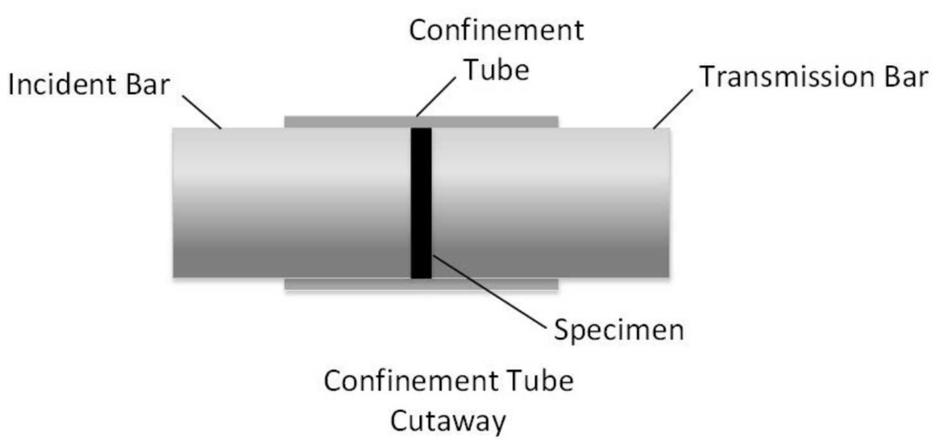
Product	Particle Size (microns, by volume) (3M QCM 193.2)			
	Distribution			Effective Top Size
	10th%	50th%	90th%	95th%
A16/500	30	60	95	115
A20/1000	25	60	90	105
H20/1000	25	60	90	105
D32/4500	20	40	65	80
H50/10,000 EPX	15	35	60	70

High Rate Experimental Methods

Common confined configuration:







Traditional Confining Tube

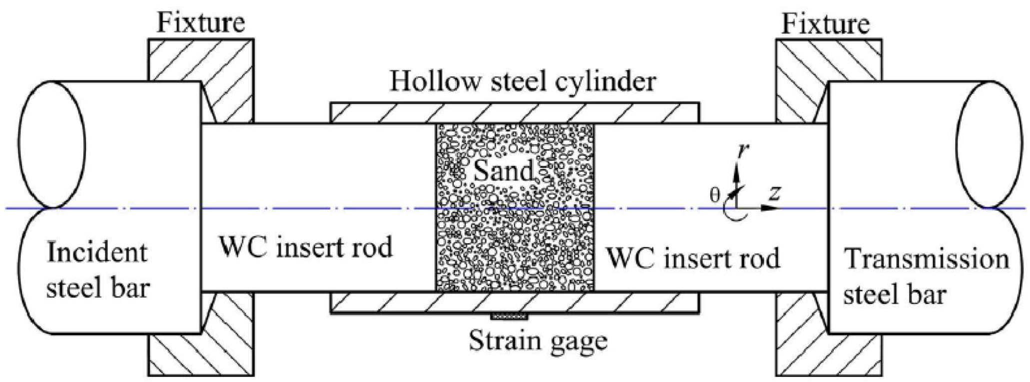


Fig. 1. Schematic SHPB setup for dynamic compression of a sand specimen under confinement. (a). SHPB schematic; (b). Test section for the sand specimen

Circumferential pressure:

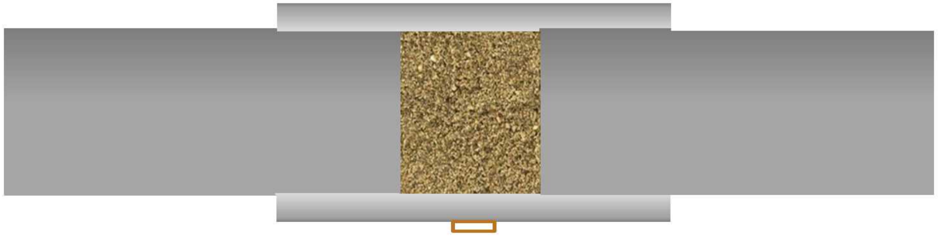
$$\sigma_{rr}(t) = \sigma_{\theta\theta}(t) = 0.5\left(\alpha^2 - 1\right)E_c\varepsilon_h(t) \text{ and } \varepsilon_{rr}(t) = \varepsilon_{\theta\theta}(t)$$
$$= \varepsilon_h\left[(1 - \nu_c) + (1 + \nu_c)\alpha^2\right]/2$$

Hydrostatic pressure (mean stress) and volumetric strain:

$$\sigma_m(t) = (\sigma_{zz}(t) + 2\sigma_{rr}(t))/3 \text{ and } \varepsilon_m(t) = \varepsilon_{zz}(t) + 2\varepsilon_{rr}(t)$$

Luo H, Cooper WL, Lu H. 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 (2014) 40-55

Confining Tubes with Specimens of Varying Length

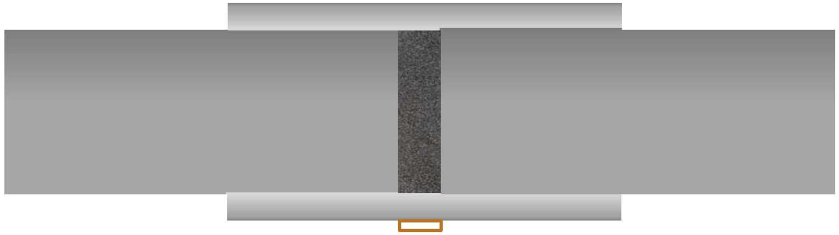


(Sand Specimen)

Case 1:

Strain gage is thinner than specimen (hoop direction)

Provides an average measurement



(Potting Material)

Case 2:

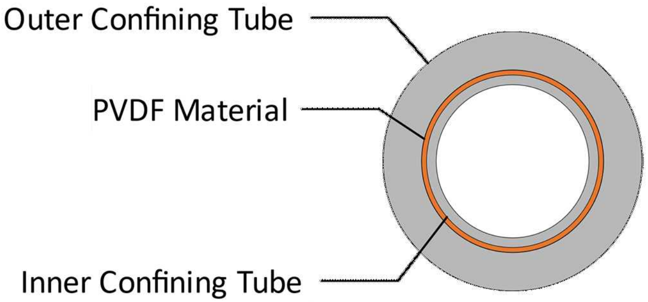
Strain gage has similar length as specimen

Exact positioning is crucial

Slight changes in position may make strain measurement inaccurate

New Method to Measure Radial Force using PVDF

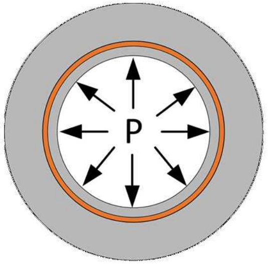
Goal: direct force measurement that does not depend on positioning

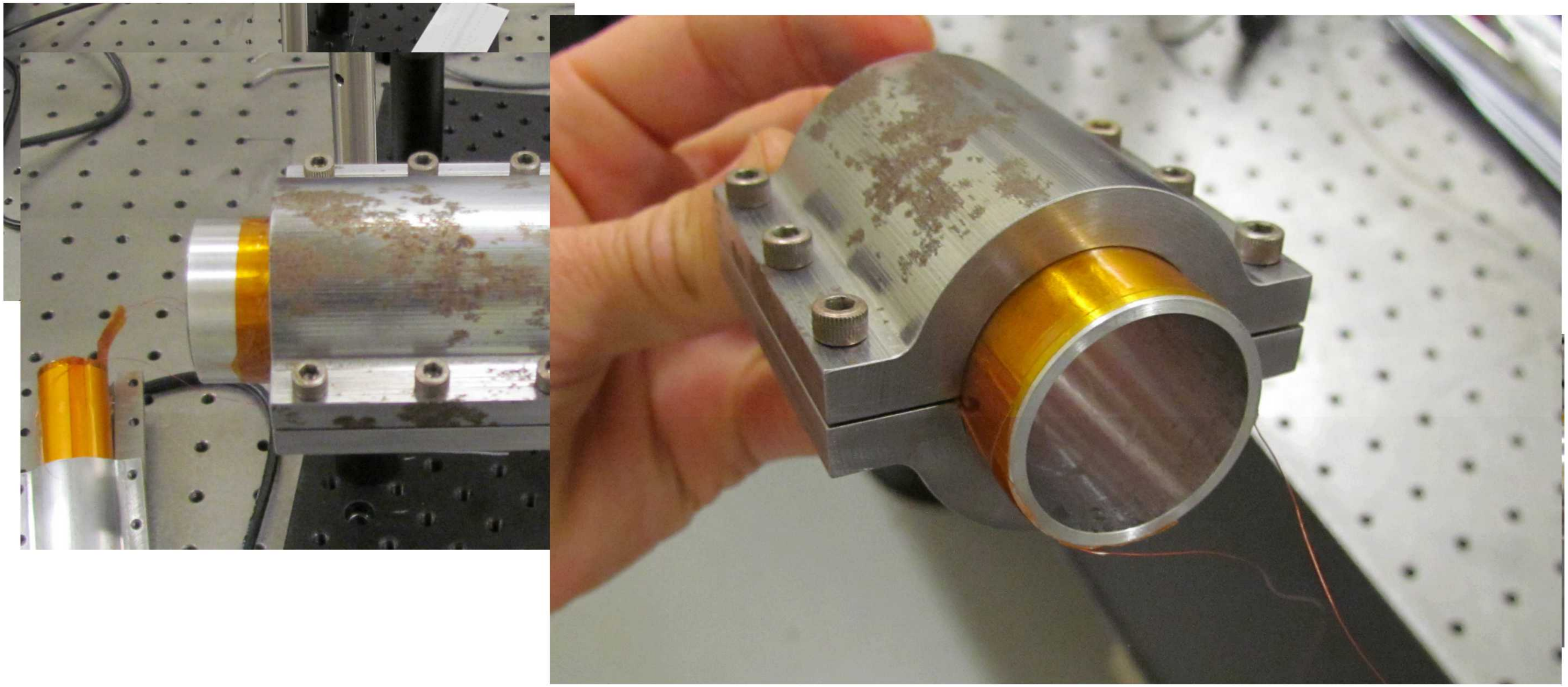


Axial Compression

PVDF compressed in Z direction

Voltage signal



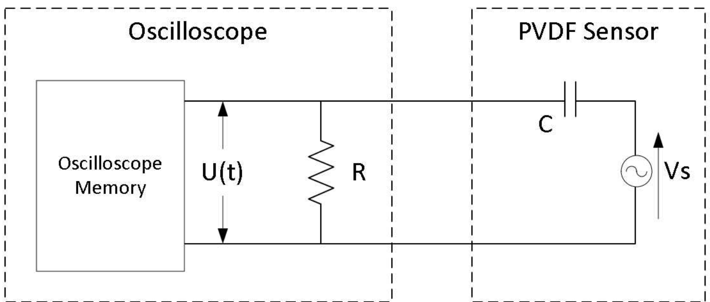


New Method to Measure Radial Force using PVDF

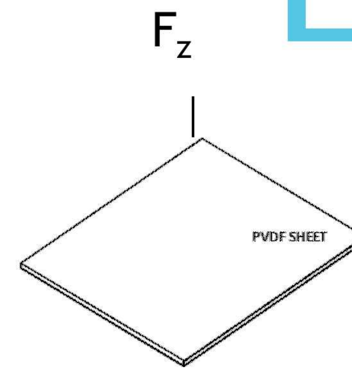
Polyvinylidene Difluoride (PVDF)

- Large piezoelectric constant
- Produced in thin sheets
- Used to measure forces in tight locations

Equivalent Circuit:



$$q(t) = \frac{Q(t)}{A} = \int_o^t \frac{U(t)}{A\,R}\,dt$$

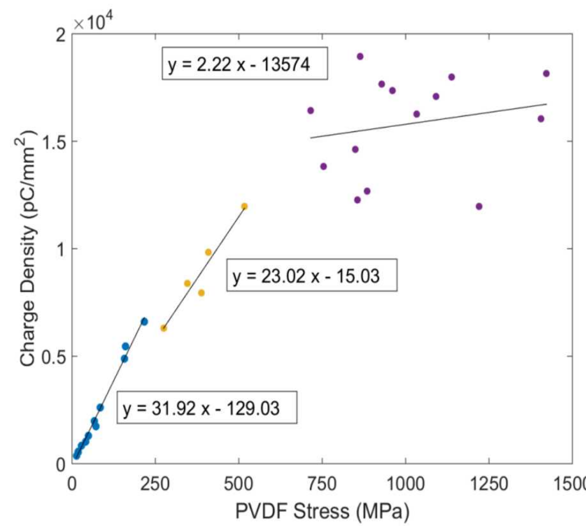


$$q(t) = \frac{kF(t)}{A} = k\sigma(t)$$

$$F(t) = \int_o^t \frac{U(t)}{kR}\,dt$$

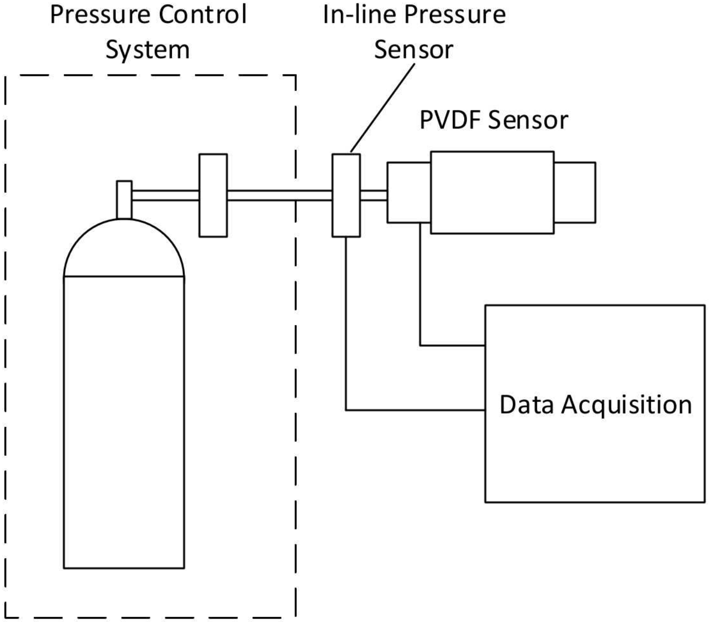
Q: charge
U: output voltage
A: PVDF area
R: discharge resistor
k: piezo constant

- Requires assumption that the PVDF is loaded perfectly in the Z-direction
- This does not capture any structural response of the tube and sensor stackup



PVDF Sensor Calibration

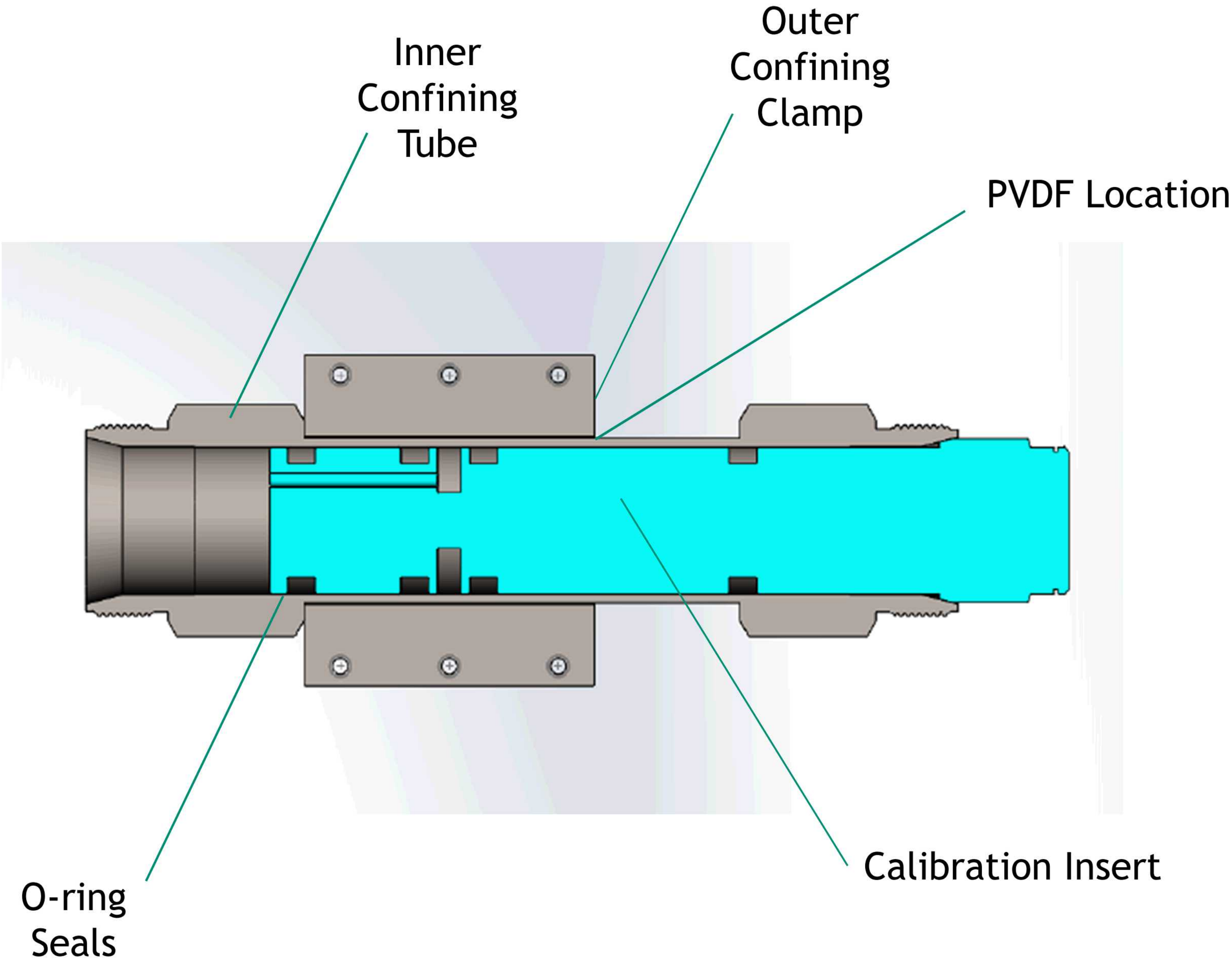
Although we have a nominal calibration value for the PVDF material, the sensor output must be calibrated *in situ*



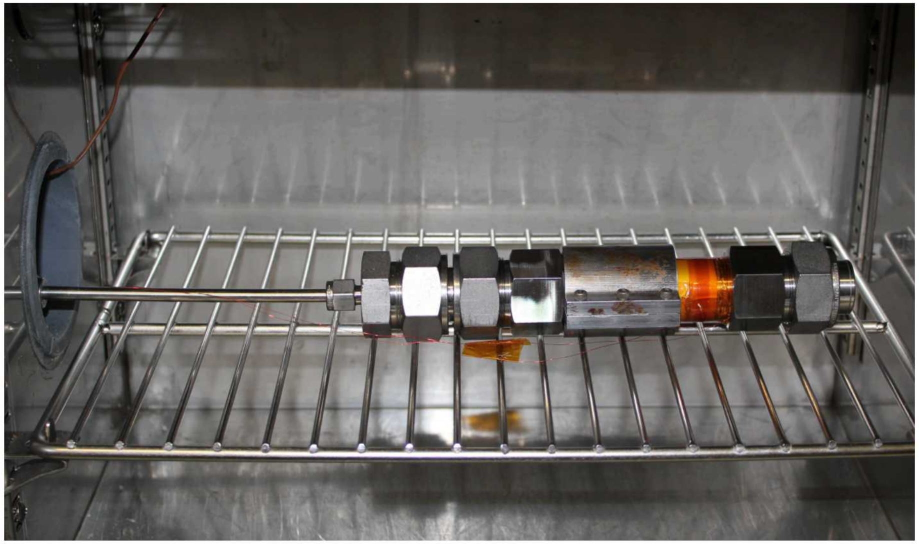
Calibration Process:

- Applied pneumatic pressure to sensor
- Measured output of a calibrated sensor and the PVDF sensor
- Varied the maximum applied pressure (1000, 2000, and 3000 psi)
- Varied the environmental temperature using a thermal chamber (-50°, ambient, and 165° F)

PVDF Sensor Calibration

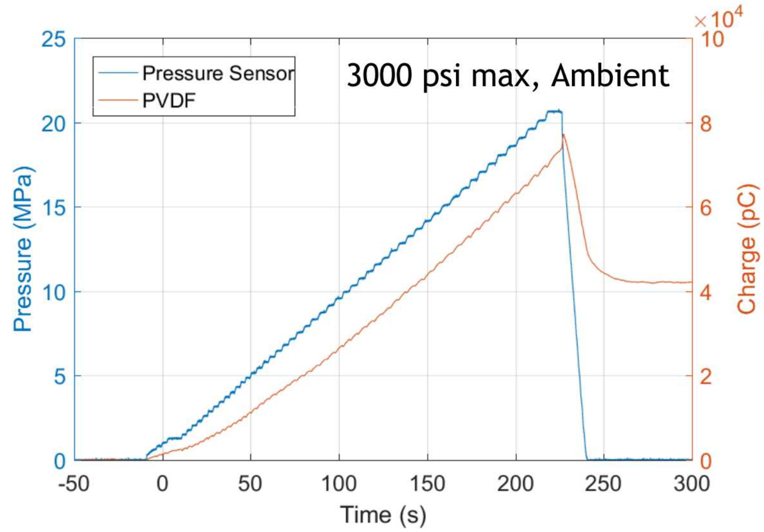


Calibration



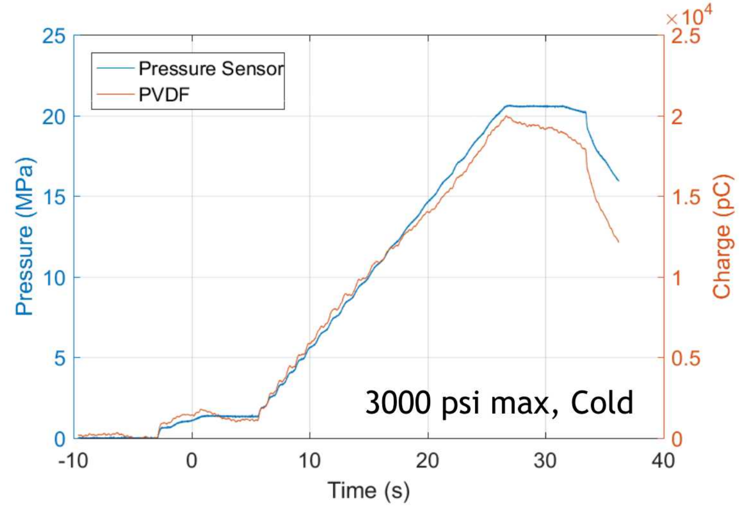
PVDF Sensor Calibration

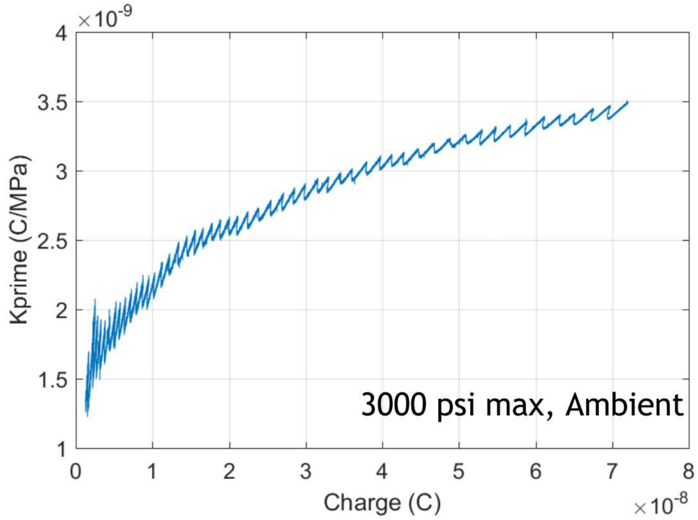
- PVDF Sensor output closely matches pressure sensor
- PVDF may not capture flat plateaus and unloading at this temperature
- Output at ambient and hot temperatures showed similar qualitative behavior
- The PVDF captured the pressure plateau and unloading more closely at cold temperature



- The charge-pressure calibration factor k' is defined as:

$$k' = \frac{PVDF\ output}{Pressure\ Sensor\ output}$$

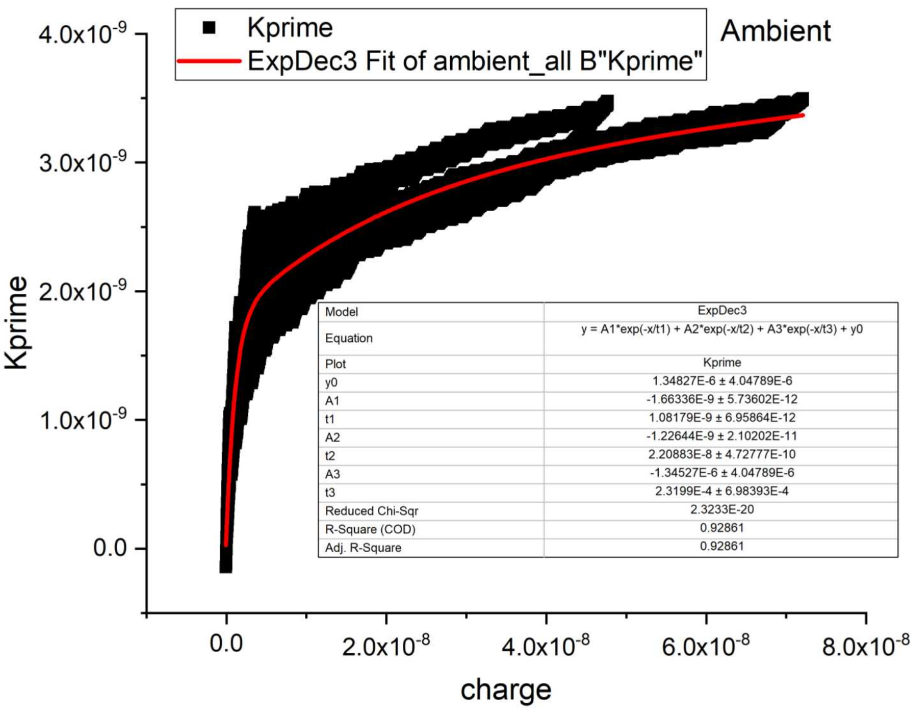




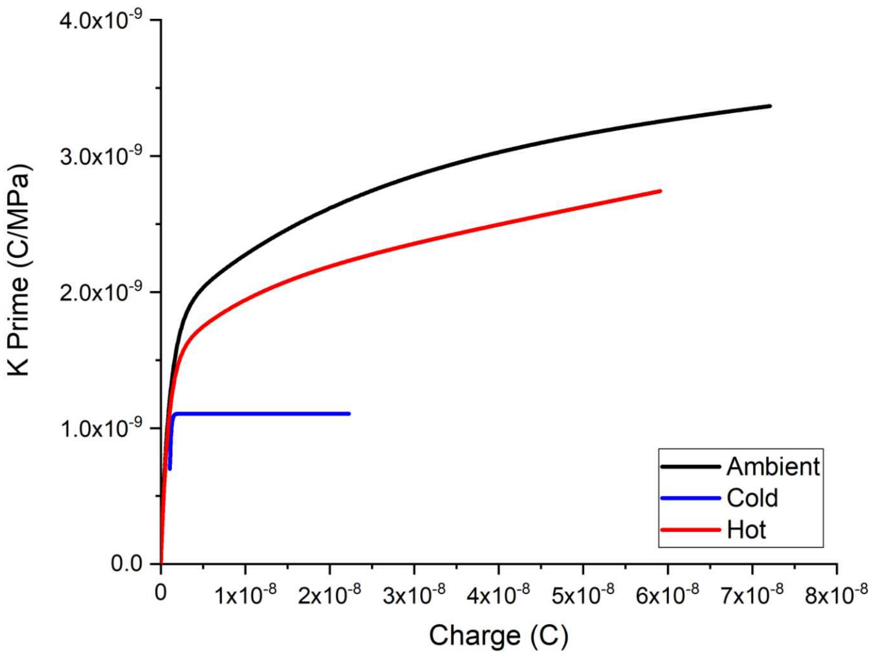
Includes PVDF output + structural response of the tube and clamp arrangement

PVDF Sensor Calibration

- For each temperature, all data at different pressures was pooled
- Exponential functions were fit to obtain a charge-pressure relationship for each temperature condition
- The k' gage factor was different at different temperatures

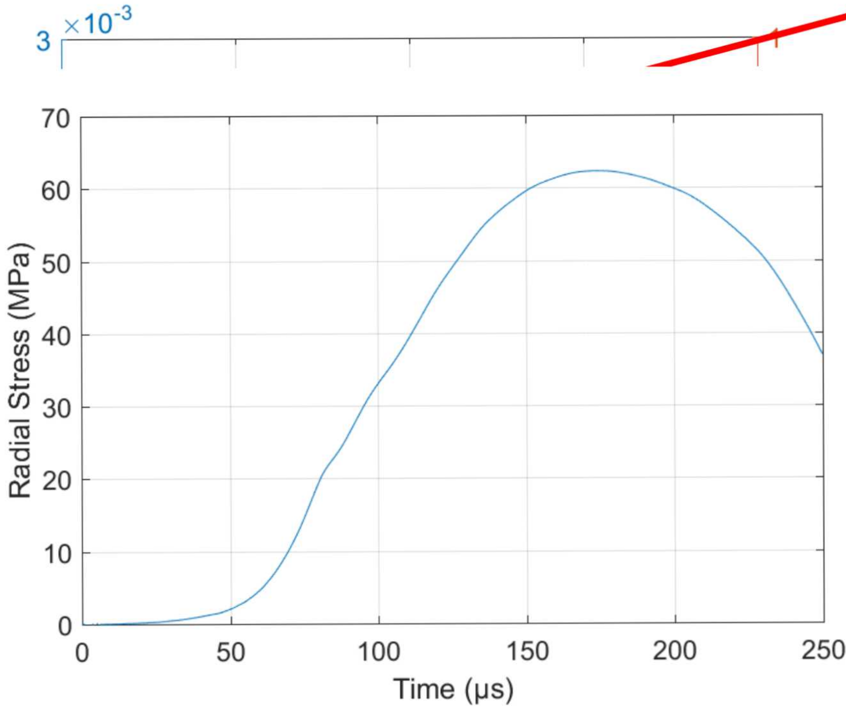


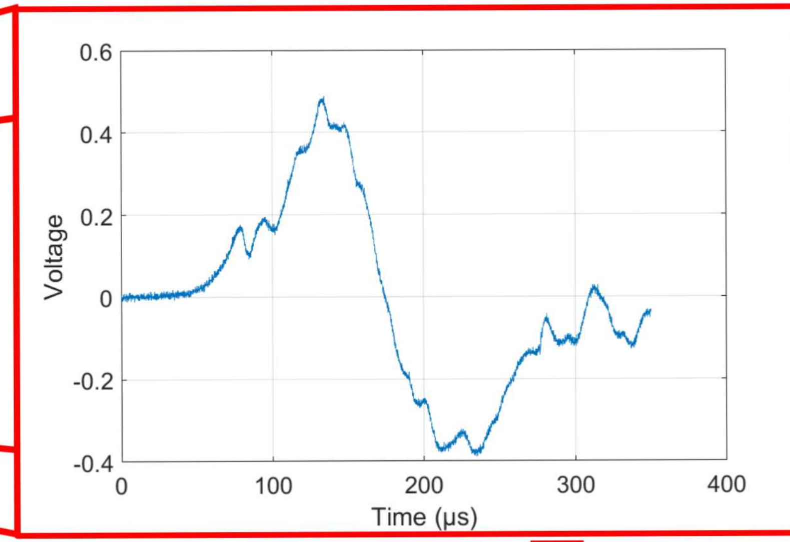
Model	ExpDec3
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + A3*exp(-x/t3) + y0
Plot	Kprime
y0	1.34827E-6 ± 4.04789E-6
A1	-1.66336E-9 ± 5.73602E-12
t1	1.08179E-9 ± 6.95864E-12
A2	-1.22644E-9 ± 2.10202E-11
t2	2.20883E-8 ± 4.72777E-10
A3	-1.34527E-6 ± 4.04789E-6
t3	2.3199E-4 ± 6.98393E-4
Reduced Chi-Sqr	2.3233E-20
R-Square (COD)	0.92861
Adj. R-Square	0.92861



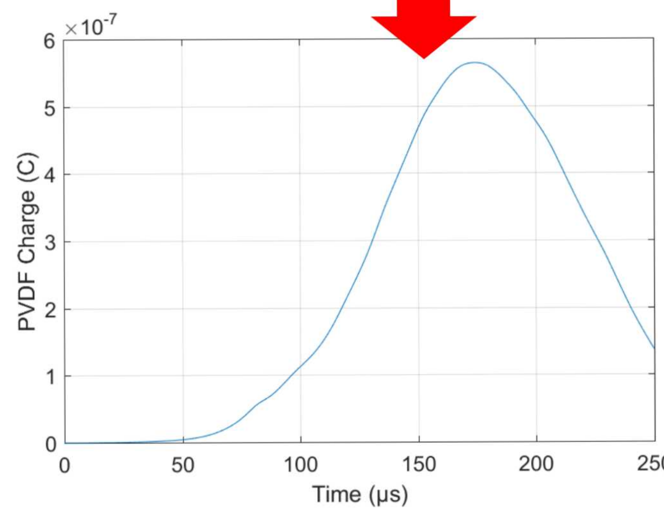
- These fits were applied to obtain the internal pressure for the Kolsky bar experiments using the instrumented confining tube

Output from PVDF/Dynamic Test

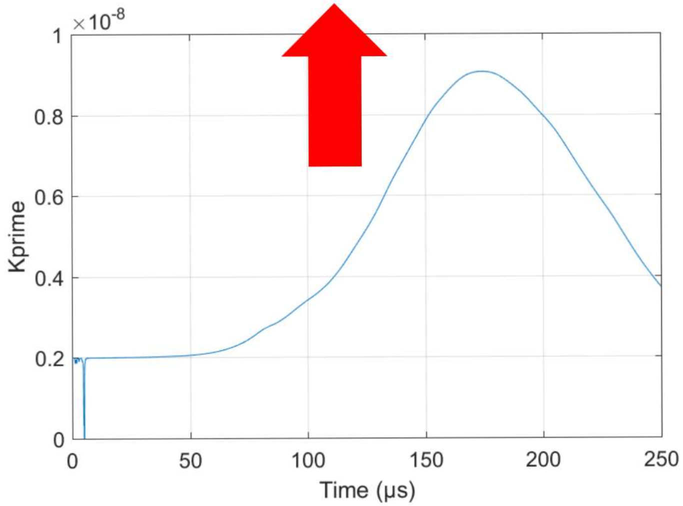




$$C(t) = \int_0^t \frac{V(t)}{R} dt$$



Exponential k' function



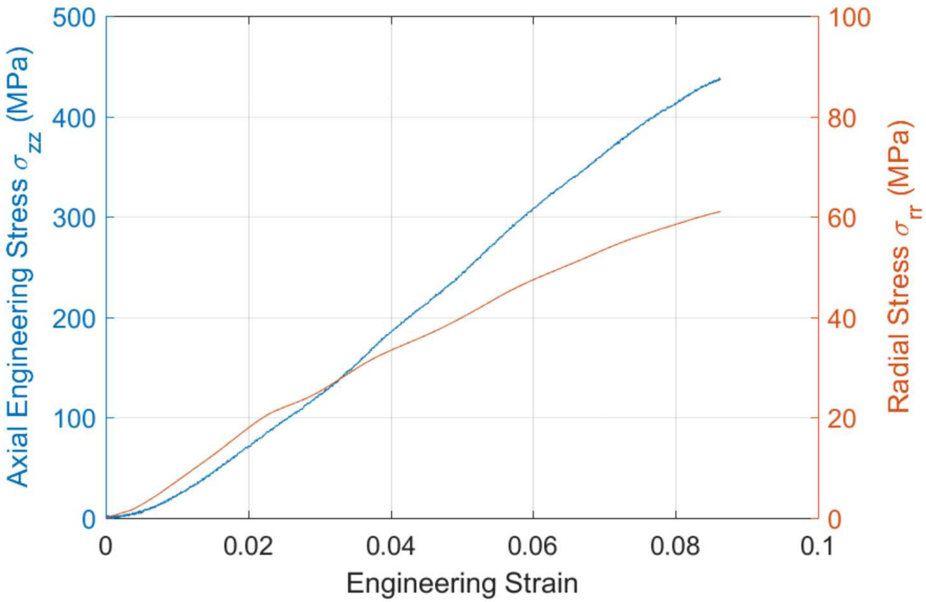
Dynamic Compressive Stress-Strain Curve of GMB Filled EPON 828 at 165F at 1000 s^{-1}

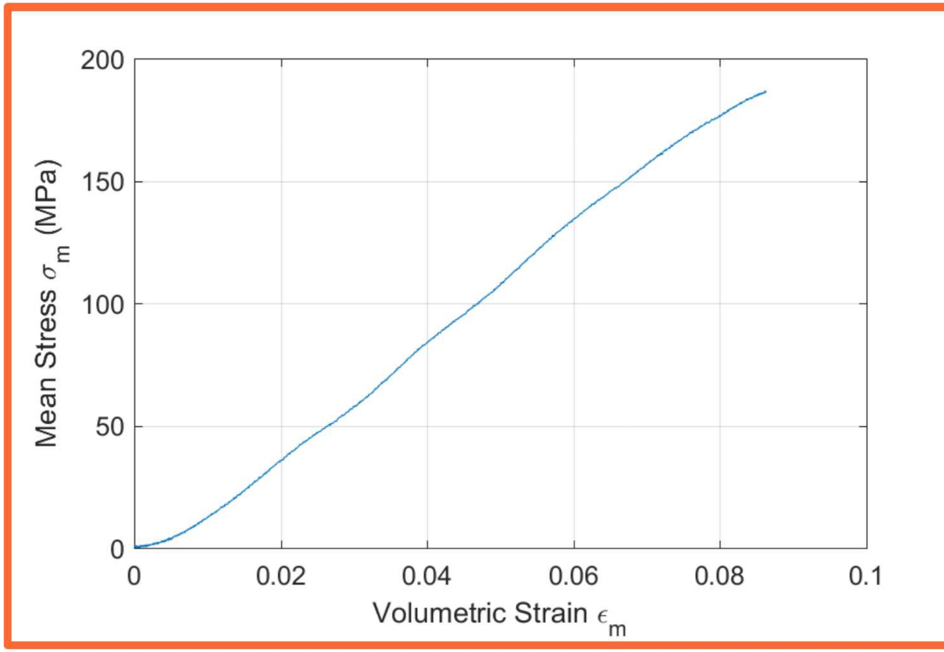
- *Ravi-Chandar, K., and Ma, Z., (2000) "Inelastic Deformation in Polymers under Multiaxial Compression," Mechanics of Time-Dependent Materials, 4:333-357.*
- *Luo, H., Cooper, W. L., and Lu, H., (2014) "Effects of Particle Size and Moisture on the Compressive Behavior of Dense Eglin Sand under Confinement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

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

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

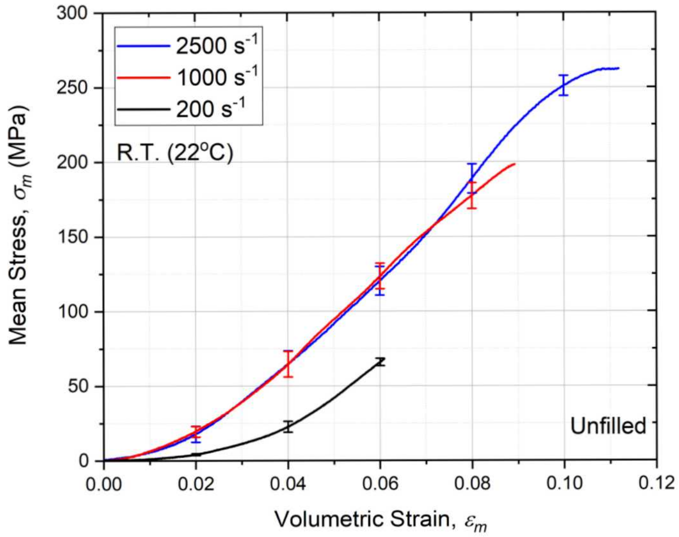
$$\varepsilon_{rr} << \varepsilon_{zz}$$



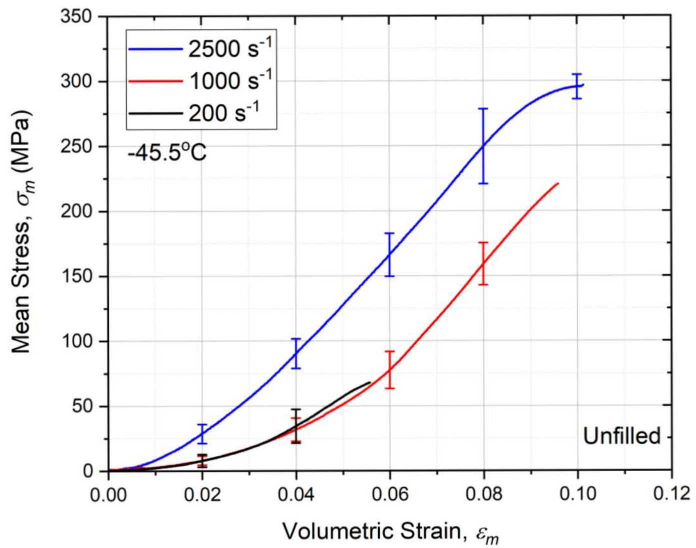


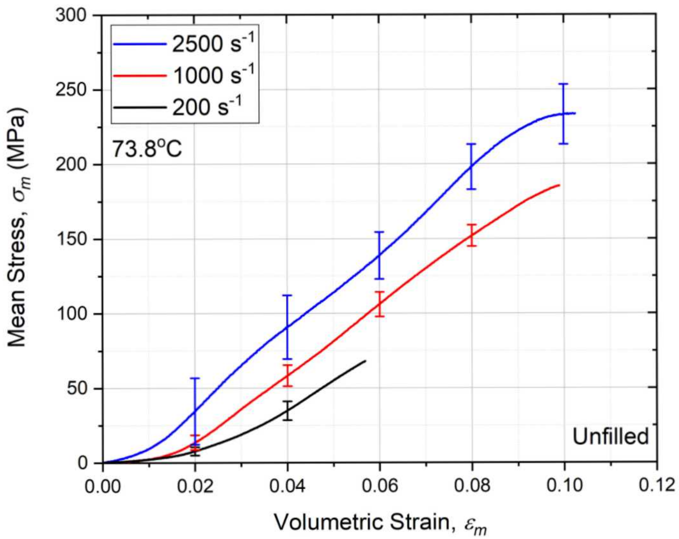
Confined Stress-Strain Response at Different Rates and Temperatures

Strain Rate Effect - Unfilled EPON 828/D230

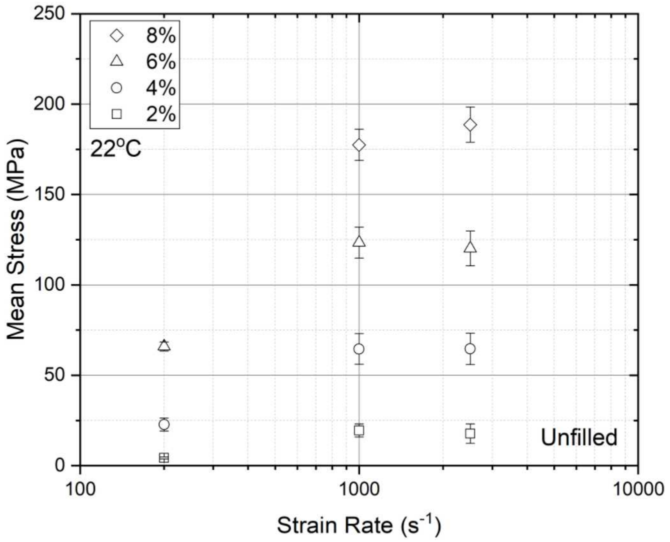


- Unfilled EPON
- Flow stress at 200 s^{-1} was generally lower than other rates (except cold temperature)

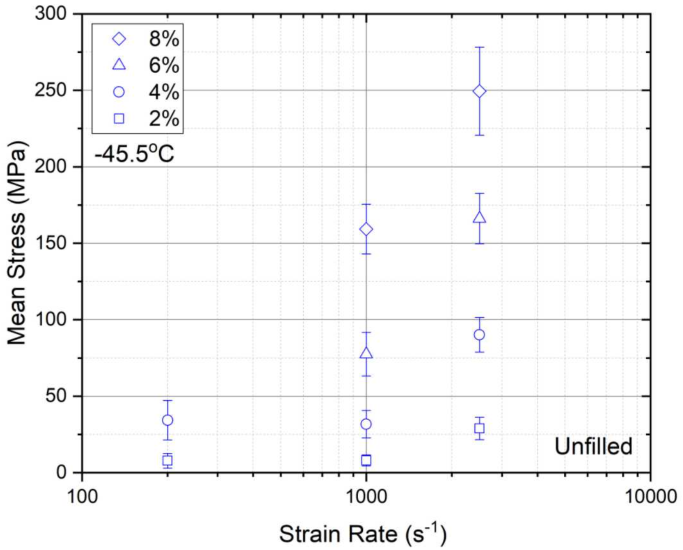


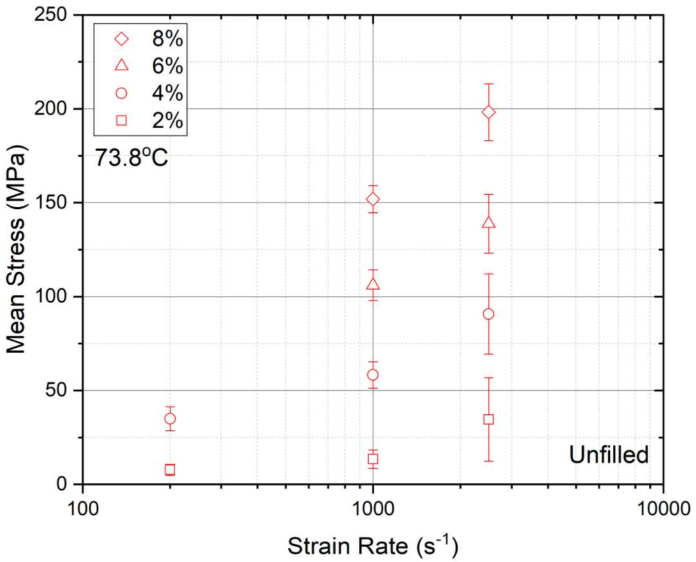


Strain Rate Effect - Unfilled EPON 828/D230

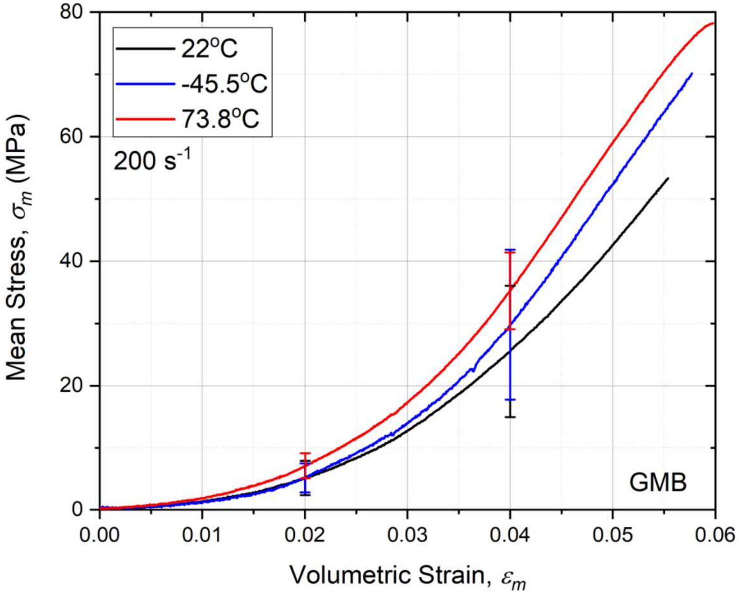


- Unfilled
- Rate effects at each temperature
- Flow stress behavior at different rates

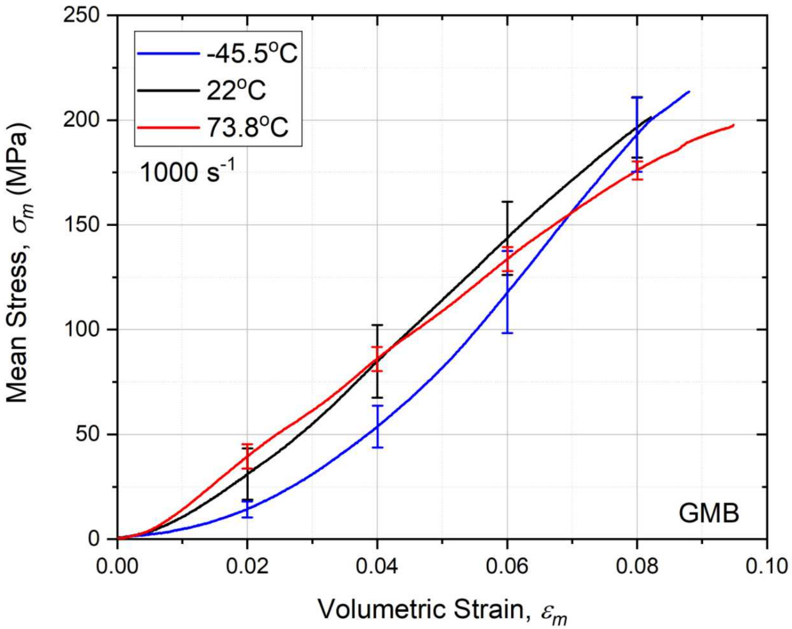


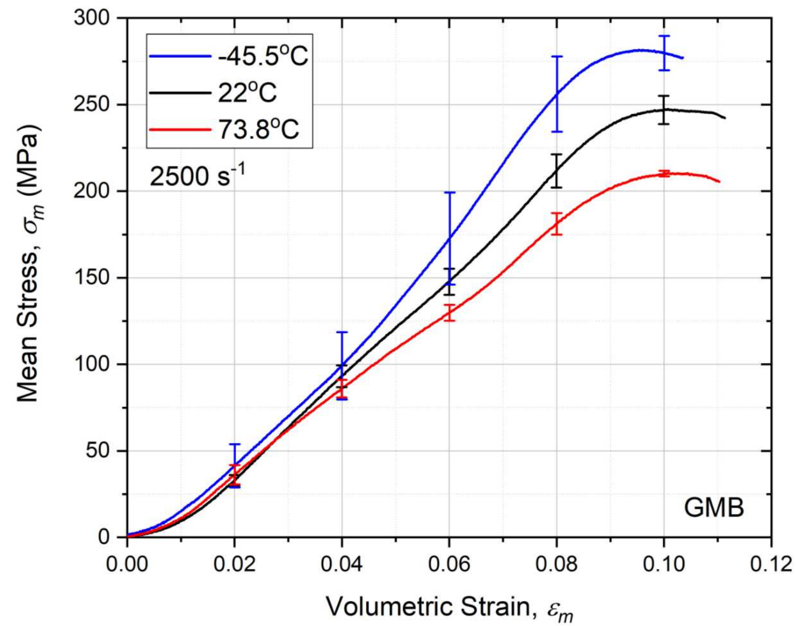


Temperature Effect – GMB Filled EPON 828/D230

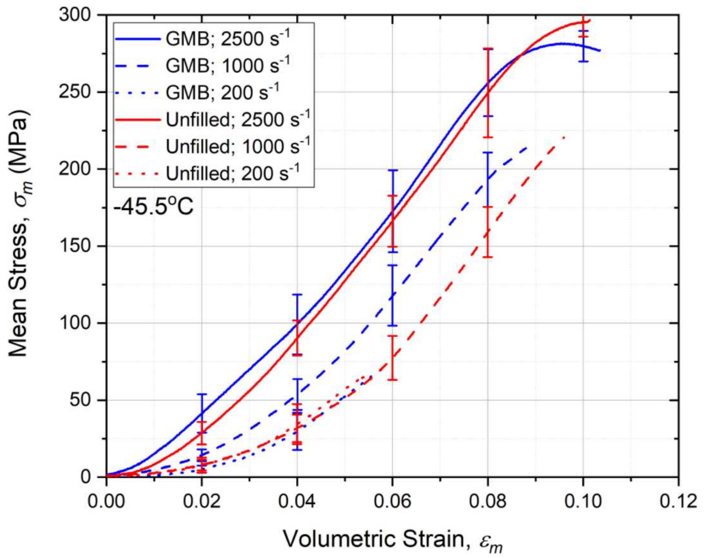


- Filled
- Higher ultimate stress was reached at cold temperature at 2500 s^{-1}
- The stress-strain response at different temperatures overlapped until divergence at 4% strain (at 2500 s^{-1})

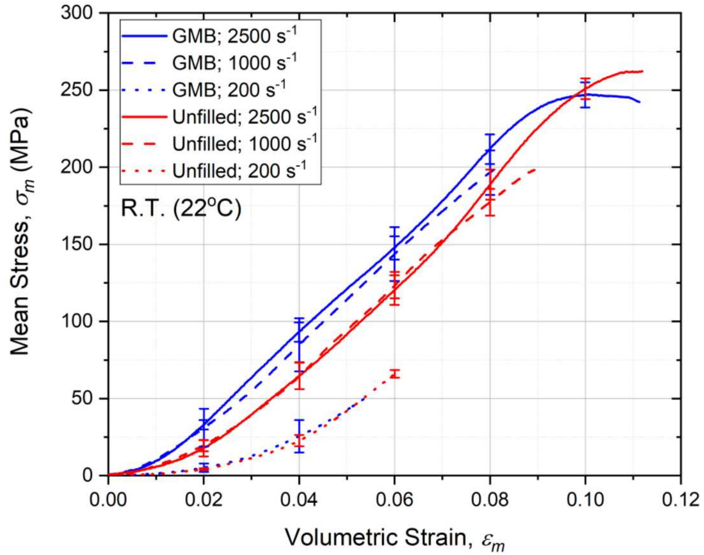


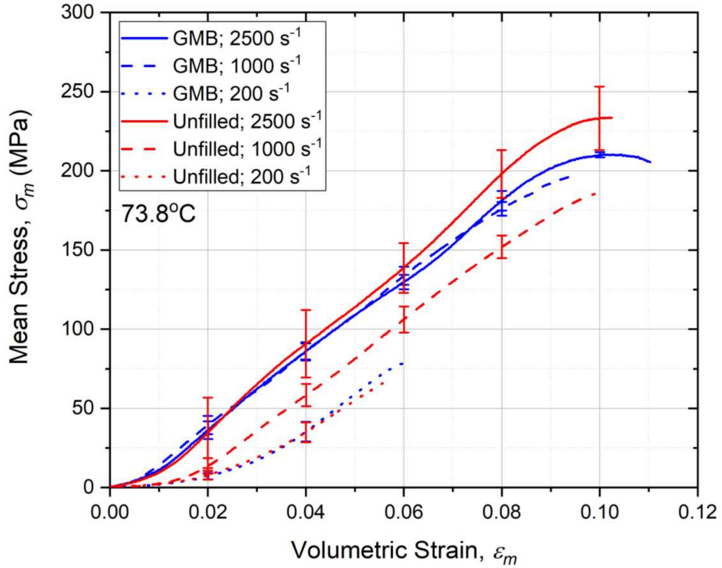


Unfilled vs. Filled EPON828



- Filled and Unfilled have similar overall behavior over the temperature range
- Unfilled may be a little lower stress but is difficult to conclude due to size of error bands





Conclusions and Future Work

Created new sensor

- Direct measurement of radial pressure produced by specimen
- Composed of inner and outer confining tubes with sandwiched PVDF material
- Does not rely on exact placement with respect to specimens

Calibrated the sensor using a pneumatic pressure system and a known applied pressure

- Allowed us to plot mean stress-volumetric strain curve for all conditions

Strain rate and temperature effects

- Showed **strain rate effects** in two materials → Strain rate effect depends on temperature
- Showed **temperature effects** in two materials

Unfilled EPON develops lower stress than filled, but may be comparable given size of error bands

Modeling and simulation teams should use this type of data in simulation of potted systems