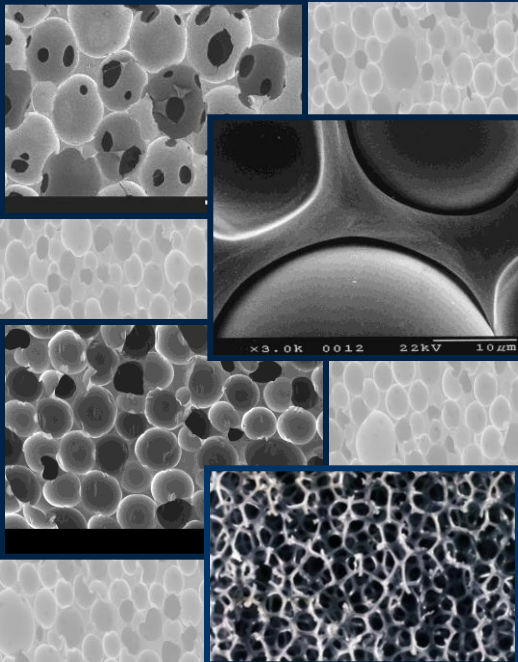


Confined Compression of Rigid Foams - Analysis

*Shivonne Haniff
Michael Neilsen
Terry Hinnerichs*

Experimentalist: Wei-Yang Lu

Sandia National Laboratories



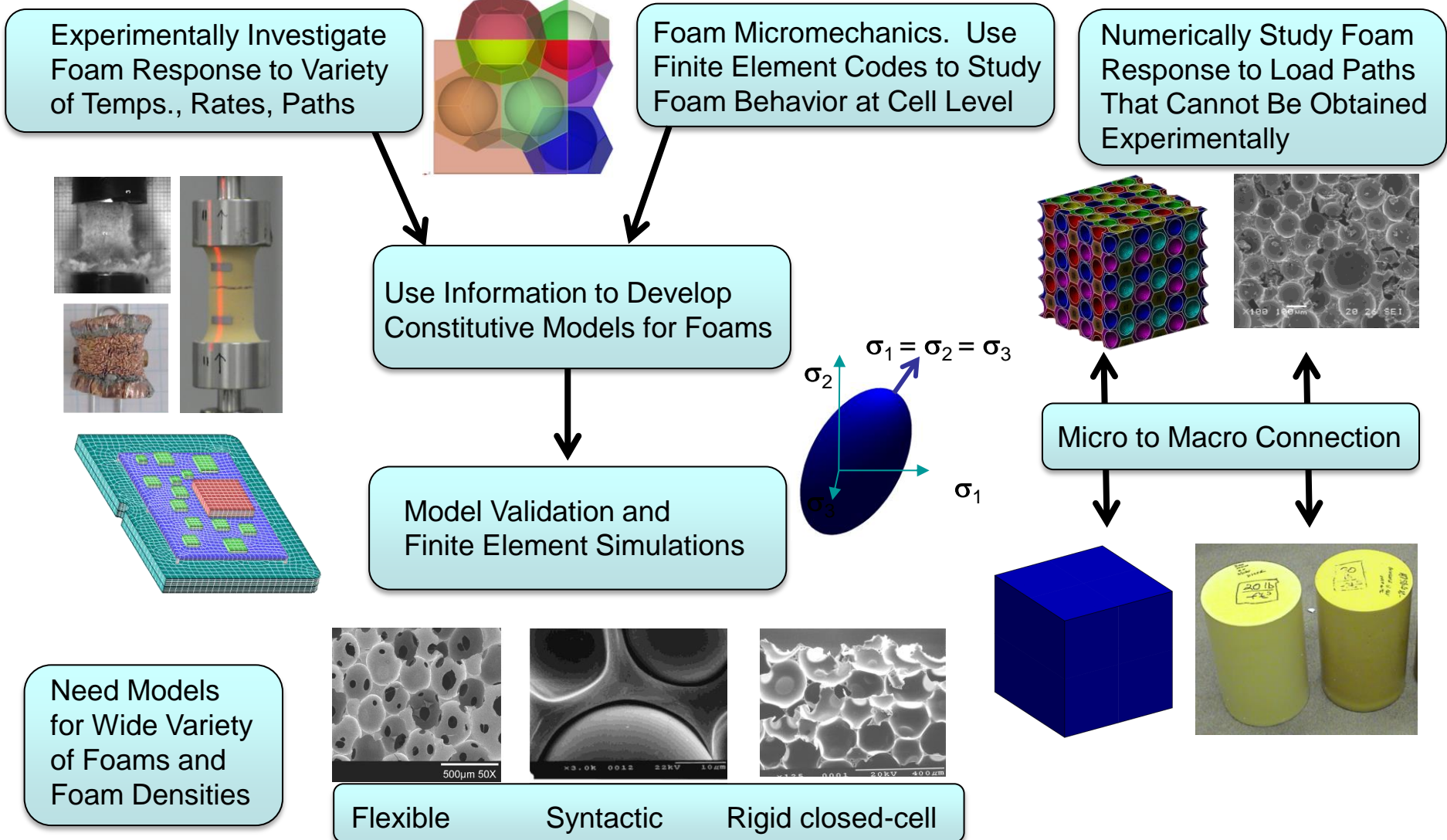
*Exceptional
service
in the
national
interest*



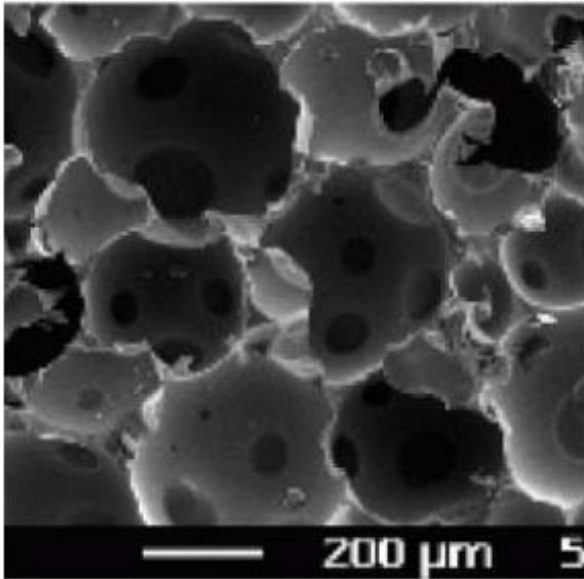
Outline

- ❑ Experimental Characterization
- ❑ Unified Creep Plasticity Model
- ❑ Simulation of Instrumented Confined Compression Test
- ❑ Summary and Future Work

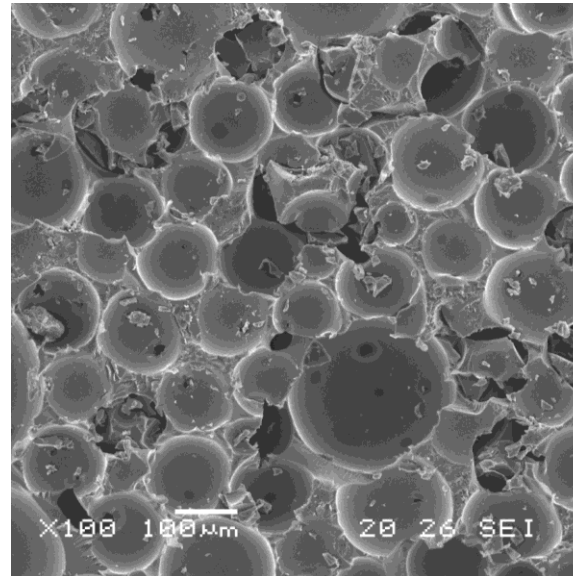
Foam Mechanics – A Collaborative Effort at Sandia



Rigid Polyurethane Foam



176 kg/m³ (11 pcf)
Polyurethane Foam



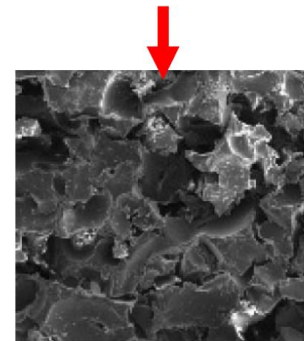
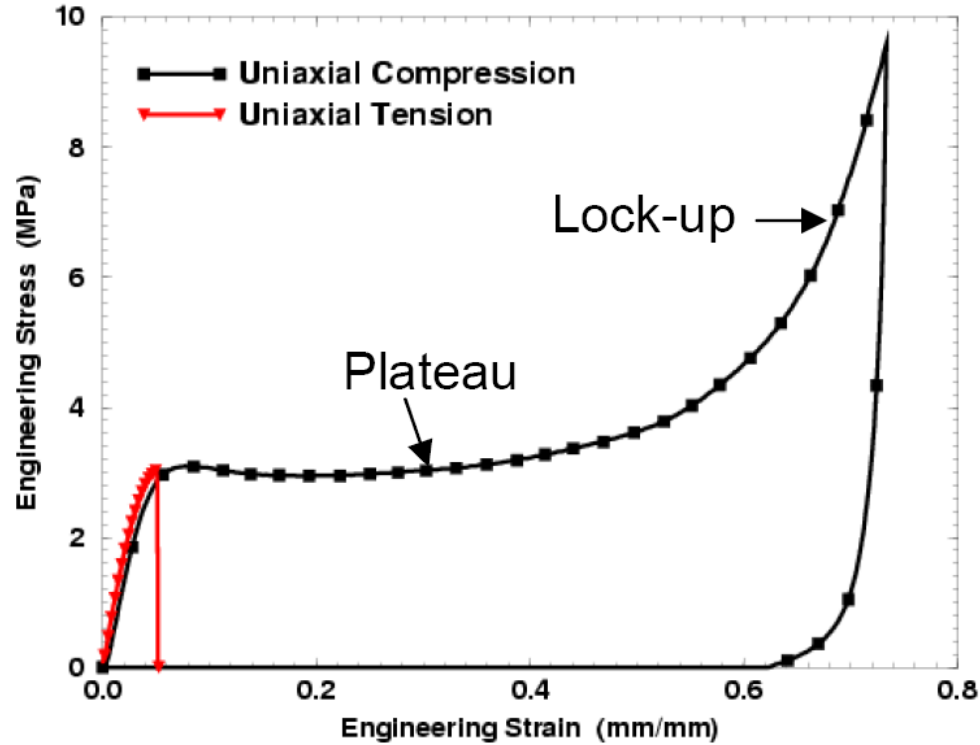
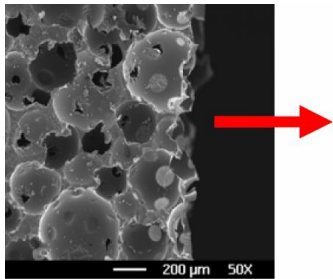
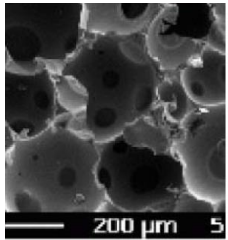
320 kg/m³ (20 pcf)
PMDI Foam

PMDI = Polymethylene Polyphenyl Isocyanate



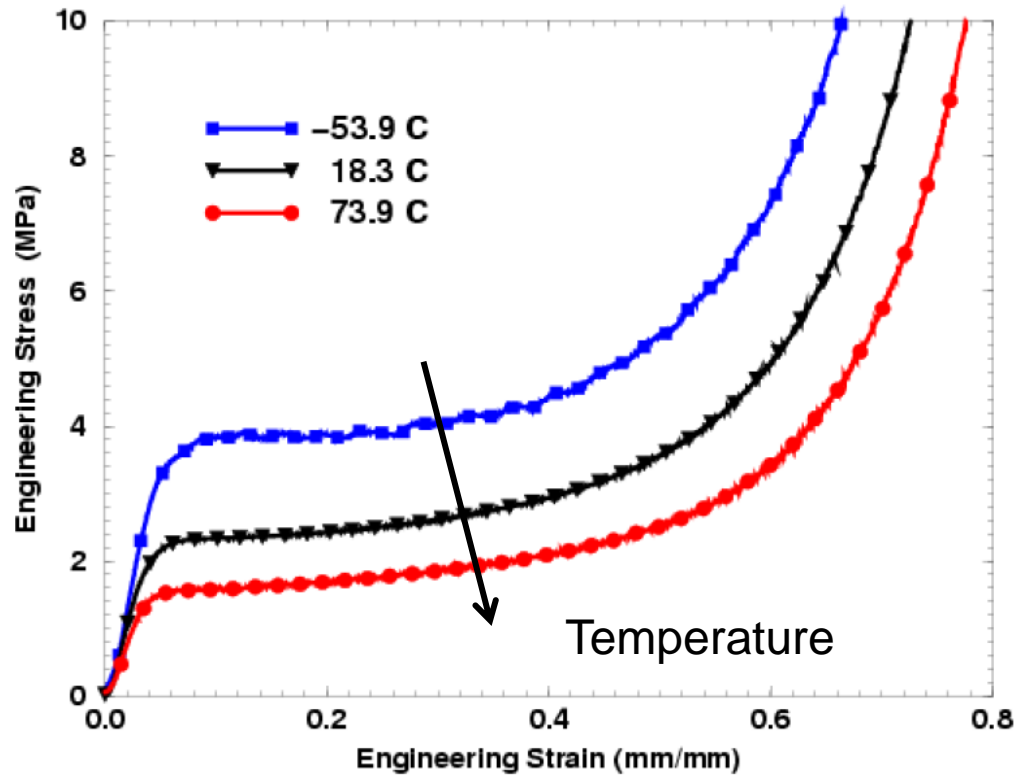
20 pcf PMDI
billet: 8" D x 12" H

Experiments on 176 kg/m³ (11 pcf) Foam



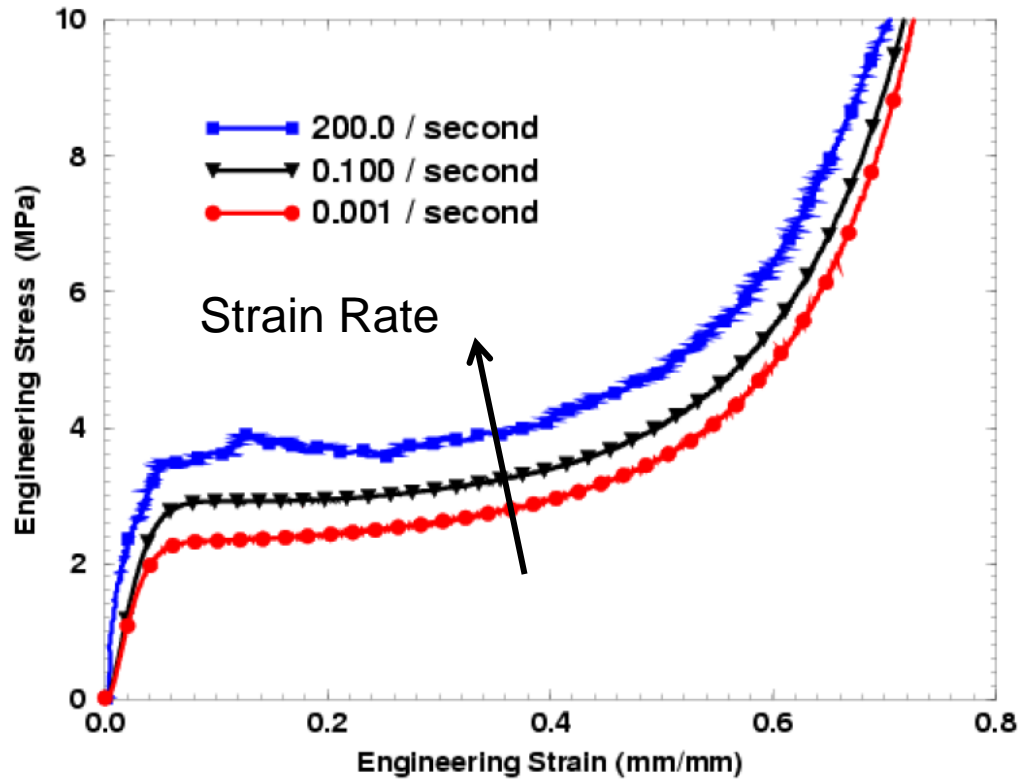
Uniaxial Tension or Uniaxial Compression

Experiments on 192 kg/m³ (12 pcf) Foam



Uniaxial Compression at Different Temperatures

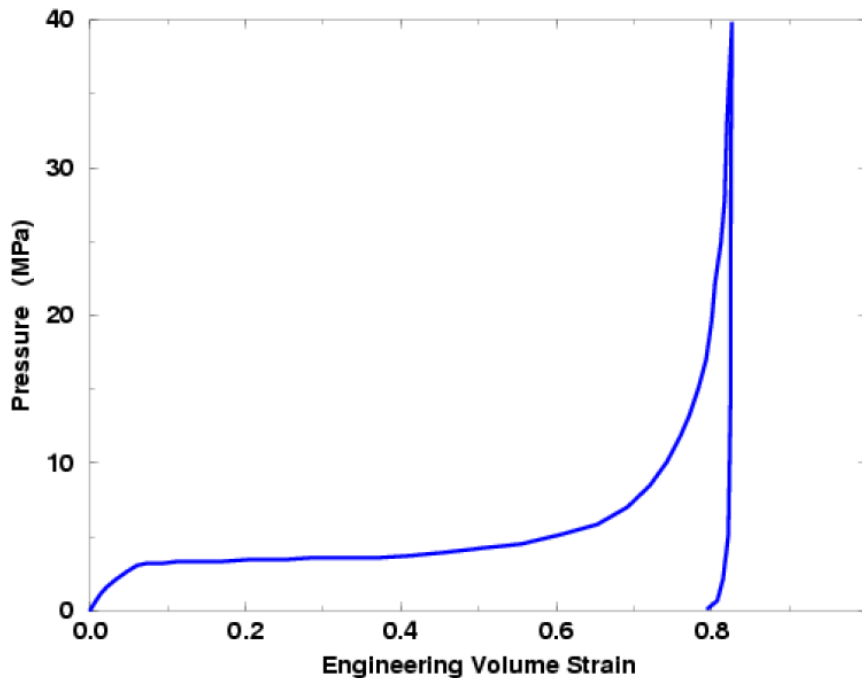
Experiments on 192 kg/m³ (12 pcf) Foam



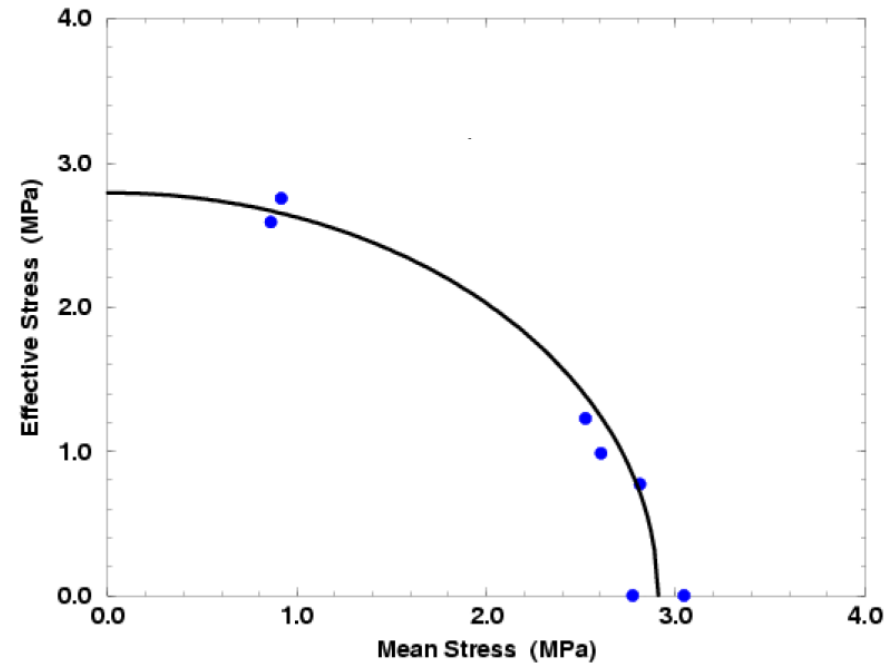
Uniaxial Compression at Different Engineering Strain Rates

Experiments on 192 kg/m³ (12 pcf) Foam

Unlike metals, foams exhibit large permanent volume changes – volumetric plasticity



Hydrostatic Compression
Pressurization Rate 0.1 MPa/sec



Effects of Load Path

Foam Plasticity Model

Yield Function

$$\varphi = \frac{\bar{\sigma}^2}{a^2} + \frac{p^2}{b^2} - 1 = 0$$

vonMises Effective Stress

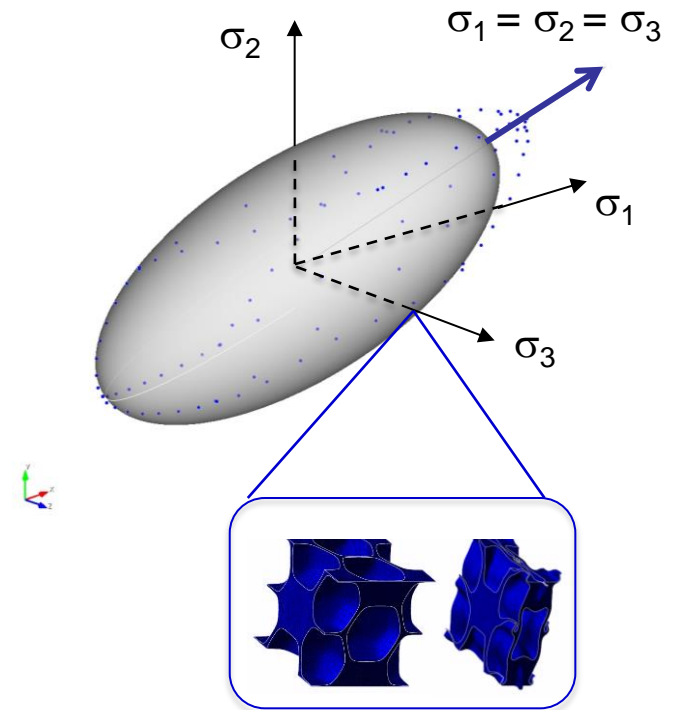
$$\bar{\sigma} = \sqrt{\frac{3}{2} \mathbf{s} : \mathbf{s}}$$

Mean Stress

$$p = \frac{1}{3} \boldsymbol{\sigma} : \mathbf{i}$$

Deviatoric Stress

$$\mathbf{s} = \boldsymbol{\sigma} - p\mathbf{i}$$

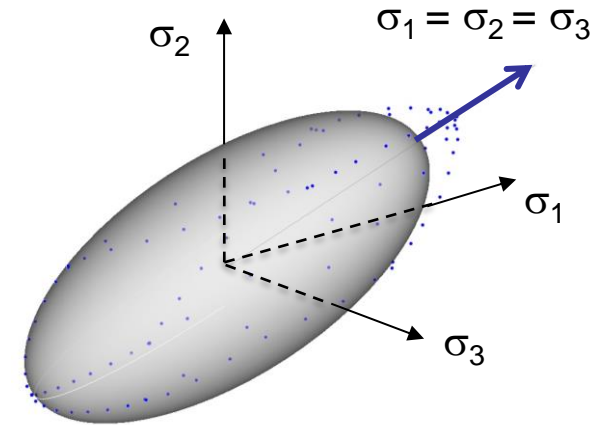


References: Deshpande, V.S. and Fleck, N.A. (2000), *J. Mech. Phys. Solids*, **48**, 1253-83.
 Zhang, J. et al (1998), *Int. J. Impact Engng.*, 21, 369-386.

Yield Function from Plasticity Model $\varphi = \frac{\bar{\sigma}^2}{a^2} + \frac{p^2}{b^2} - 1 = 0$

Rewritten as Follows $\varphi = \sigma^* - a = 0$

where $\sigma^* = \sqrt{\bar{\sigma}^2 + \frac{a^2}{b^2} p^2}$



Inelastic Rate is Given by $\dot{\boldsymbol{\epsilon}}^{vp} = \begin{cases} h(\theta) \left\langle \frac{\sigma^*}{a} - 1 \right\rangle^{n(\theta)} \mathbf{g} & \text{when } \frac{\sigma^*}{a} - 1 > 0 \\ \mathbf{0} & \text{when } \frac{\sigma^*}{a} - 1 \leq 0 \end{cases}$

Non-associated Flow

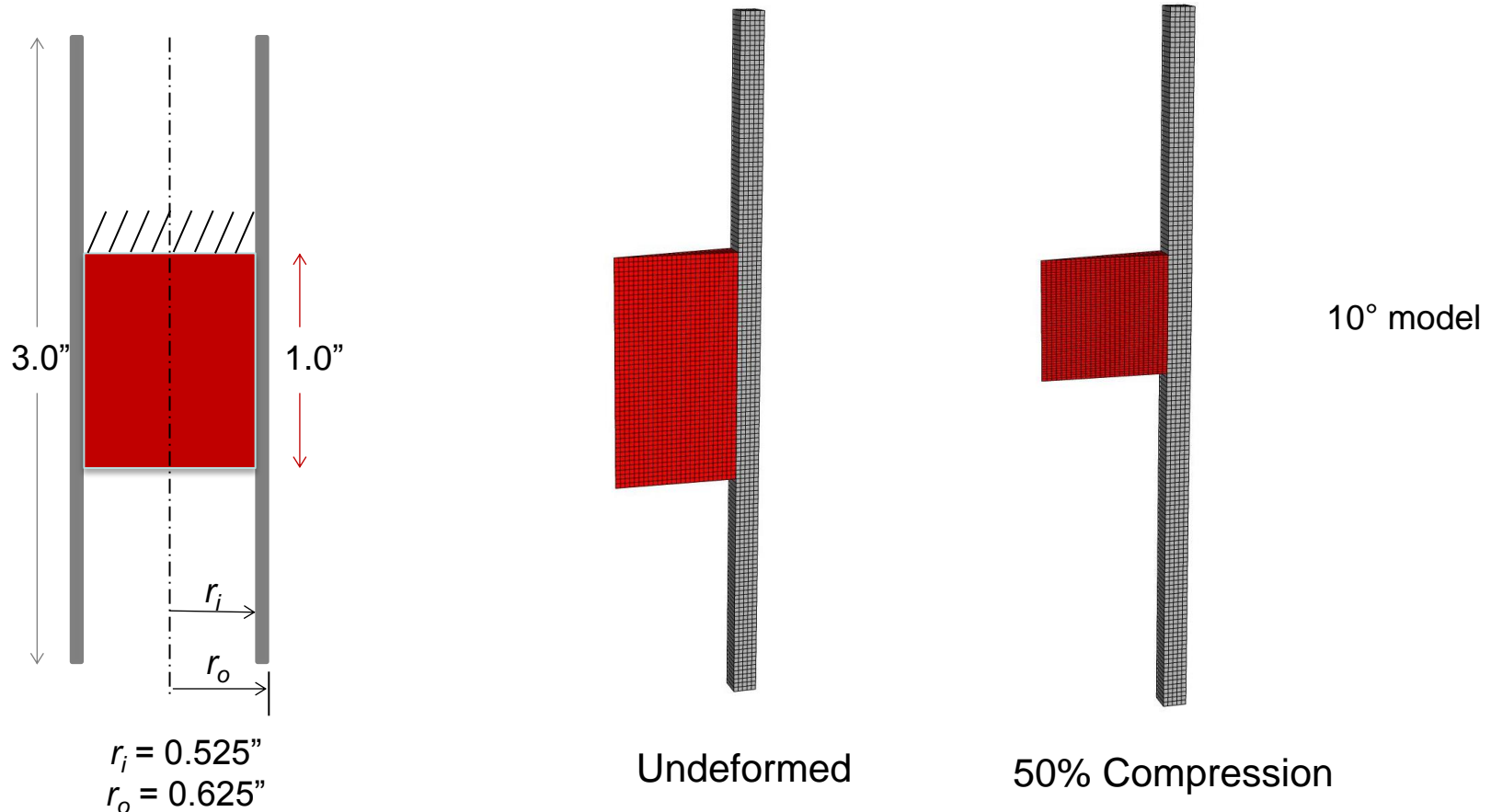
$$\mathbf{g} = (1 - \beta) \mathbf{g}_{associated} + \beta \mathbf{g}_{radial}$$

$$\mathbf{g}_{associated} = \frac{\frac{\partial \varphi}{\partial \boldsymbol{\sigma}}}{\left| \frac{\partial \varphi}{\partial \boldsymbol{\sigma}} \right|} = \frac{\frac{3}{a^2} \mathbf{s} - \frac{2}{3b^2} p \mathbf{i}}{\left| \frac{3}{a^2} \mathbf{s} - \frac{2}{3b^2} p \mathbf{i} \right|} \quad \mathbf{g}_{radial} = \frac{\boldsymbol{\sigma}}{|\boldsymbol{\sigma}|} = \frac{\boldsymbol{\sigma}}{\sqrt{\boldsymbol{\sigma} : \boldsymbol{\sigma}}} \quad \beta = \beta(\phi)$$

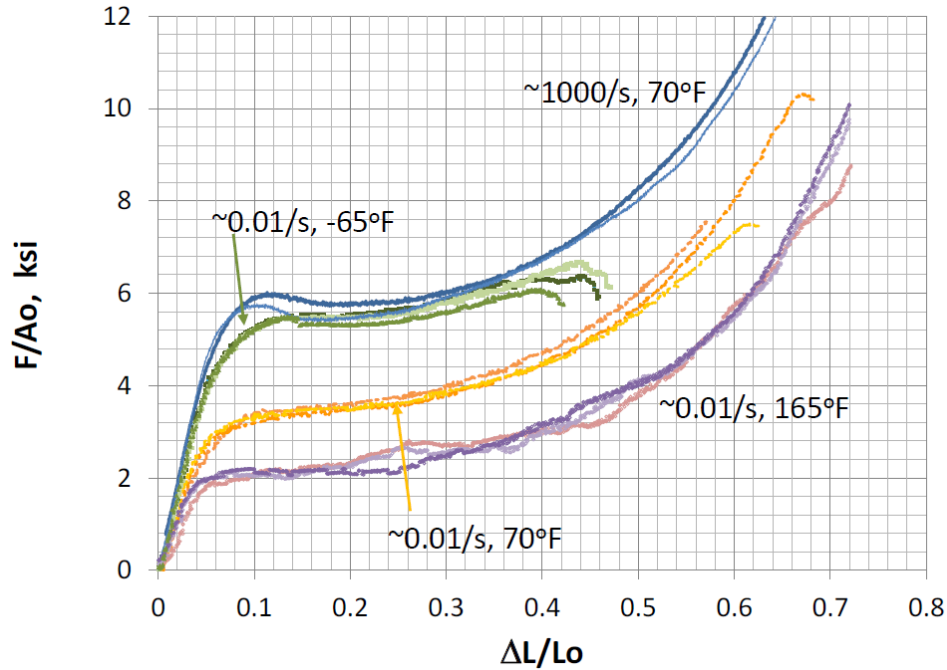
References: Perzyna, P (1971) "Thermodynamic theory of viscoplasticity." *Advances in Applied Mechanics* 11: 313-354.
Neilsen, M et al (2006), IMECE2006-14551, Proceedings of IMECE, ASME Press.

Finite Element Model

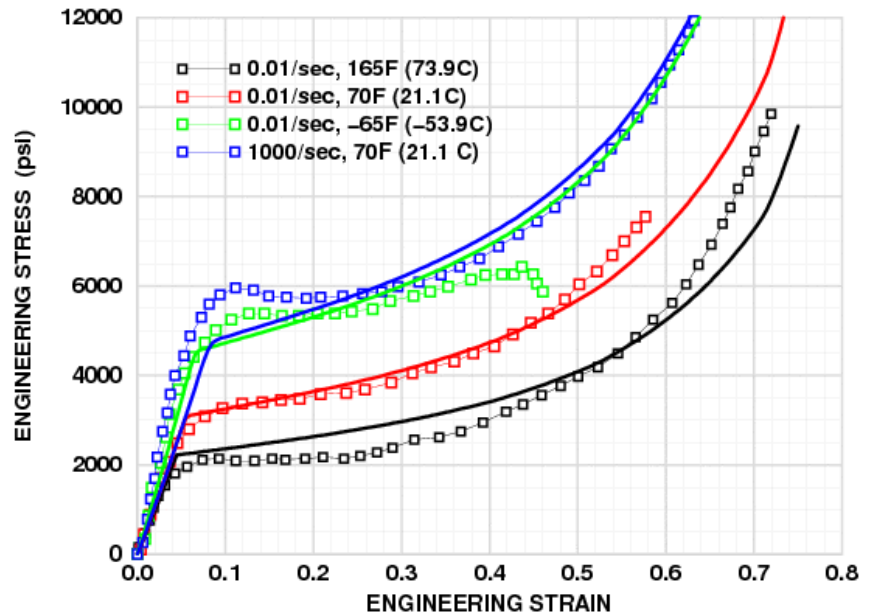
Used Adagio, Sandia's 3D, Lagrangian finite element code for implicit quasistatic and dynamic analyses



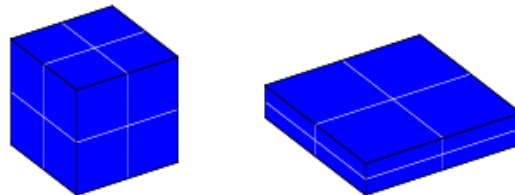
Uniaxial Compression at Different Temperatures and Rates – Tuf35



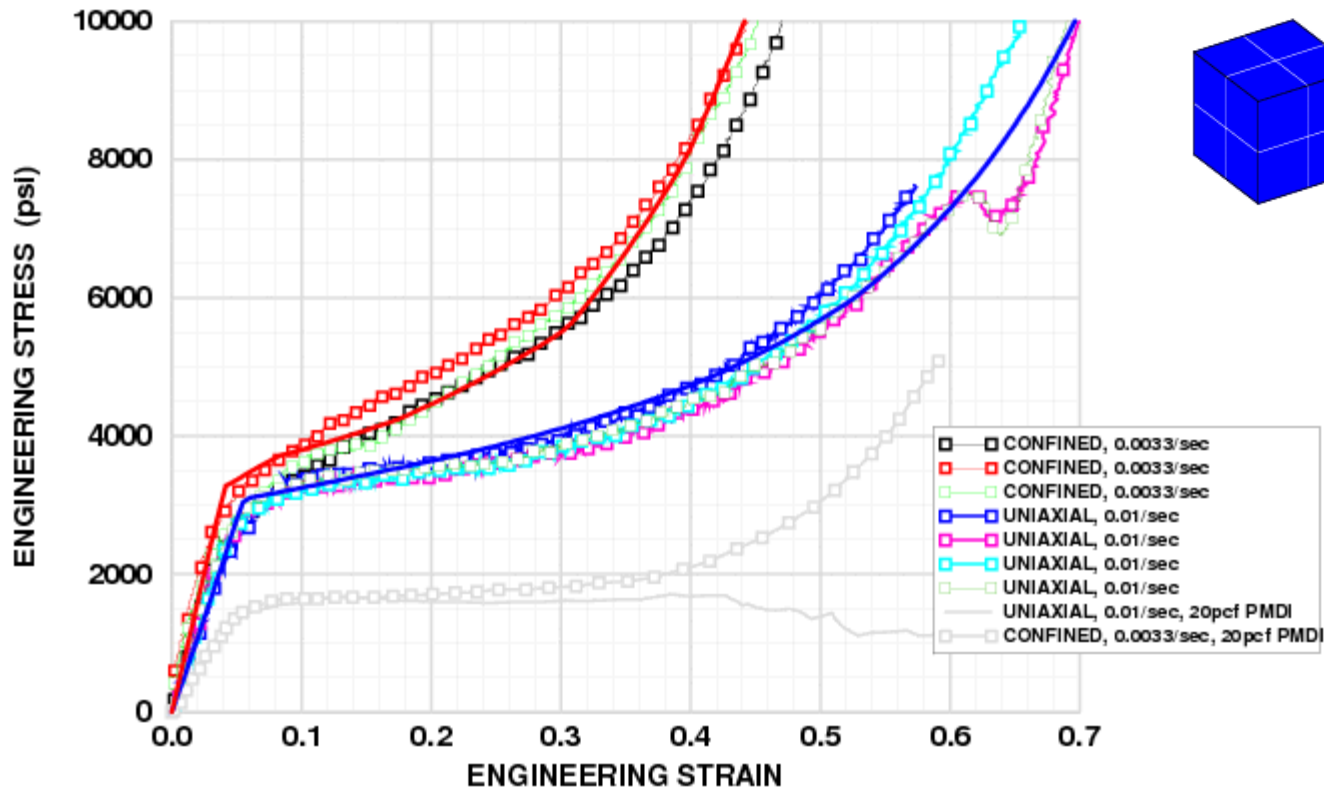
Experiments



Model (solid lines), Experiments (symbols)



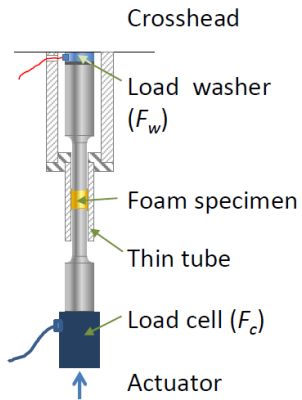
TUF35, 21.2C, Confined vs. Unconfined



Model (solid lines), Experiments (symbols)

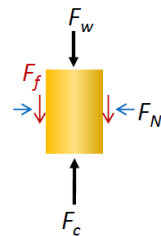
Confined Compression with Measurement Tube – Tuf35

Schematics



Foam specimen

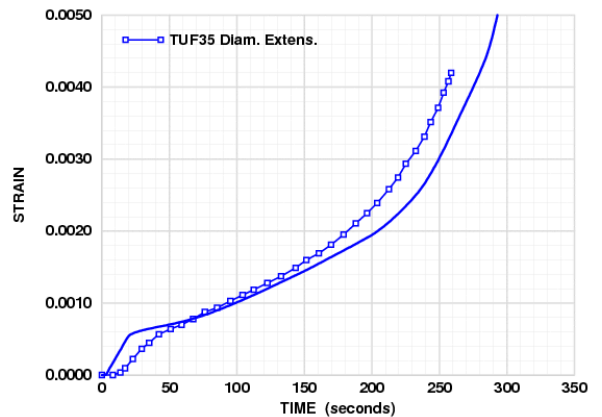
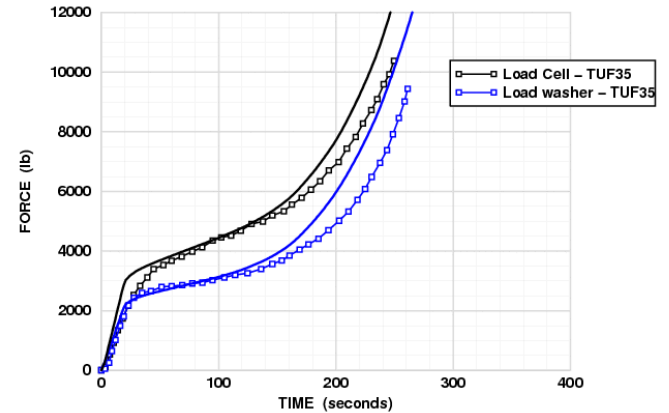
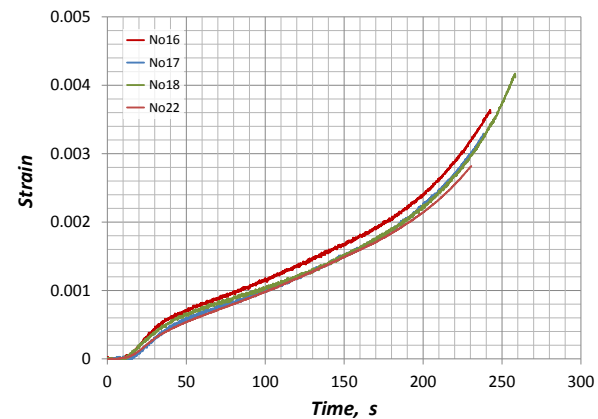
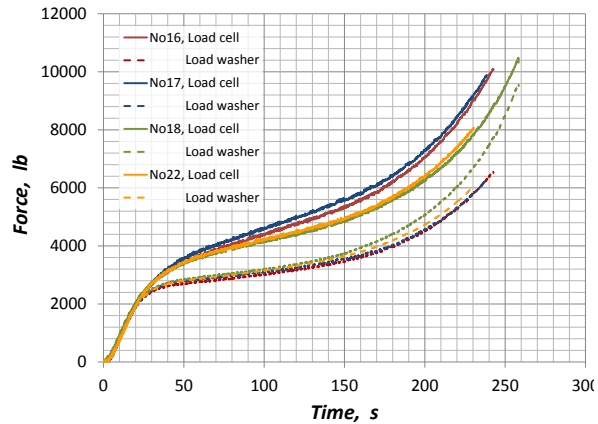
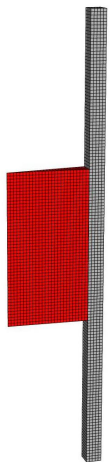
- $h_o = 1''$



$$F_c = F_w + F_f$$

$$\sigma_r = \sigma_\theta = F_N / (2\pi r_o h_o)$$

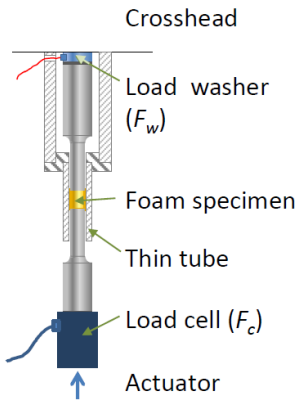
$$\sigma_z = F_w / (\pi r_o^2)$$



solid lines = Adagio simulation with 10° slice model
friction coefficient = 0.20

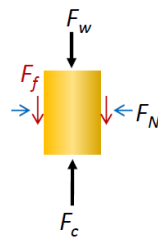
Effect of Wall Gap Between Foam and Tube

Schematics



Foam specimen

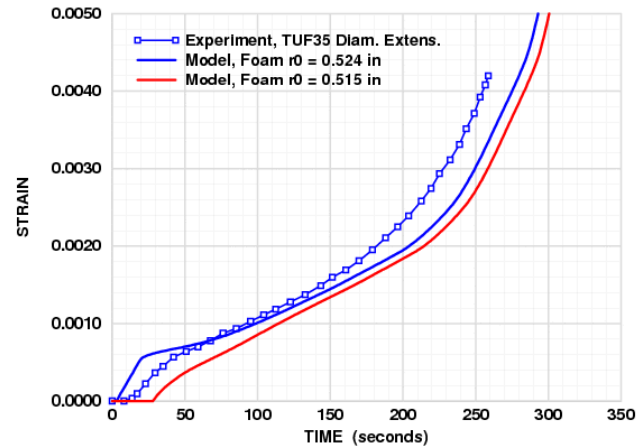
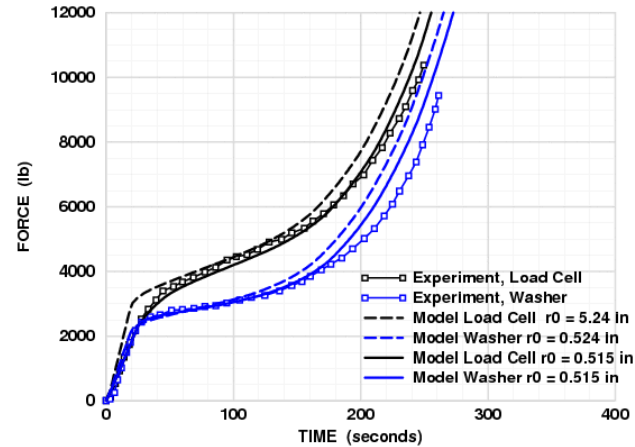
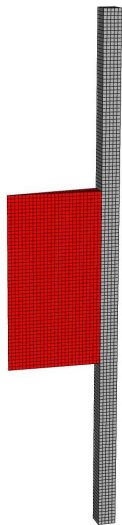
- $h_o = 1''$



$$F_c = F_w + F_f$$

$$\sigma_r = \sigma_\theta = F_N / (2\pi r_o h_o)$$

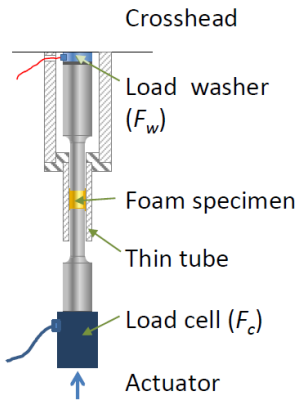
$$\sigma_z = F_w / (\pi r_o^2)$$



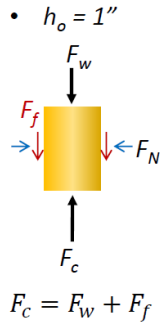
solid lines = Adagio simulation with 10° slice model
friction coefficient = 0.20

Effect of Friction Coefficient Between Foam and Tube

Schematics

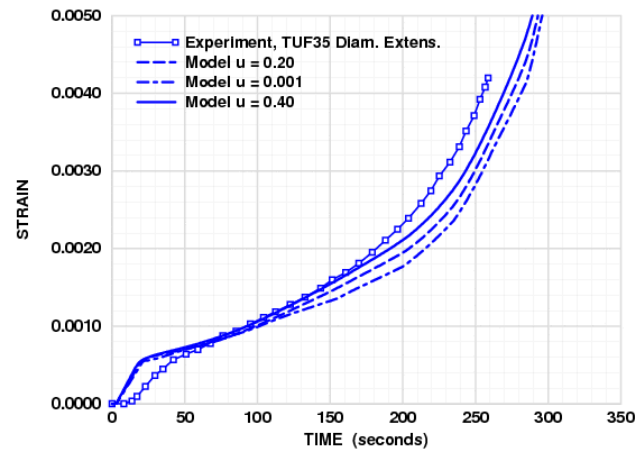
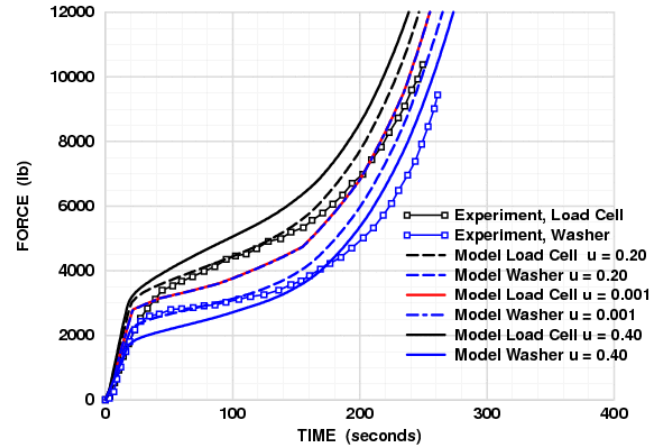
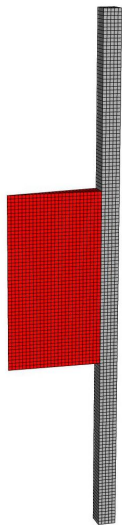


Foam specimen



$$\sigma_r = \sigma_\theta = F_N / (2\pi r_o h_o)$$

$$\sigma_z = F_w / (\pi r_o^2)$$



solid lines = Adagio simulation with 10° slice model
friction coefficient = 0.20

Summary and Future Work

- Polyurethane foam response depends on temperature and strain-rate
- UCP model captures, deviatoric and volumetric plasticity, temperature and strain-rate effects but not fracture
- New confined compression with measurement tube provides data need for selection of UCP foam model parameters
- Future Work
 - UCPD model based on principal stress damage surface is being developed to capture failure in tension.

