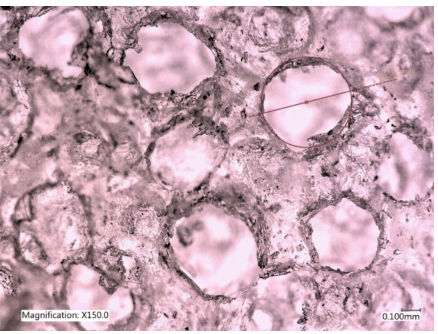
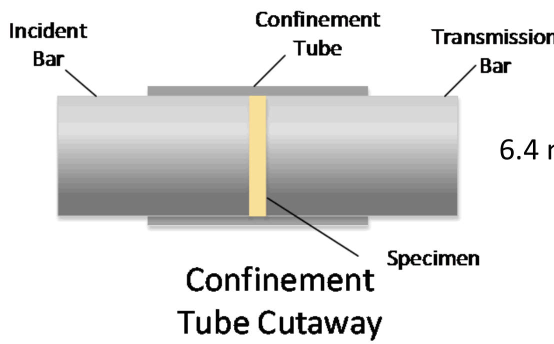
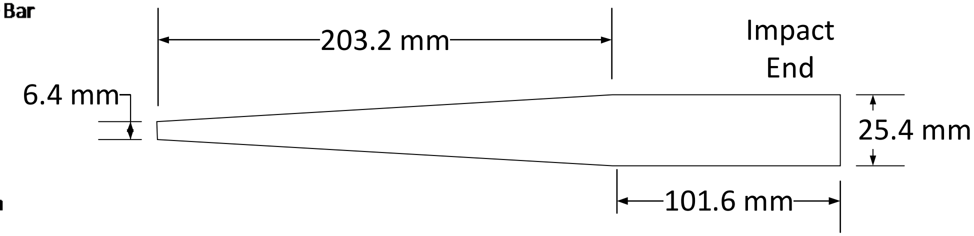
SEM XIII International Congress on Experimental and Applied Mechanics
Orlando, FL, June 6-9, 2016
SAND2016-5191C

Exceptional service in the national interest

Sandia National Laboratories







Effect of Pre-Strain on Impact Energy Dissipation in Silicone Foam Using Frequency-Based Kolsky Bar Analyses

B. Sanborn[1], B. Song[1], S. Smith[2]

[1] Sandia National Laboratories, Albuquerque, NM 87185

[2] College of Engineering, University of Georgia, Athens, GA 30602

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Shock Isolation/Mitigation

- General principle for shock mitigation:

Maximize energy absorption,
Minimize transmitted force and acceleration

- Area under the stress-strain curve prior to densification (**time domain**)
- What about the **frequency-domain**?

- When silicone foam is used as a shock or vibration pad:
  - Stress-state is triaxial
  - Lateral confinement
  - Experiences preloads due to manufacture/assembly process

Shock Isolation/Mitigation

- Foams and rubbers are primary materials used as shock isolators and mitigators
- Foams and rubbers have different properties that affect performance
  - Nonlinear stress-strain response
  - Strain-rate effects
  - Stress-state effects
- Example
  - It might be desirable to completely isolate a battery so that external accelerations, vibrations, and frequencies do not damage the battery
  - No other signals must be passed through the shock isolation material
  - Goal is ***complete isolation*** using Silicone Foam

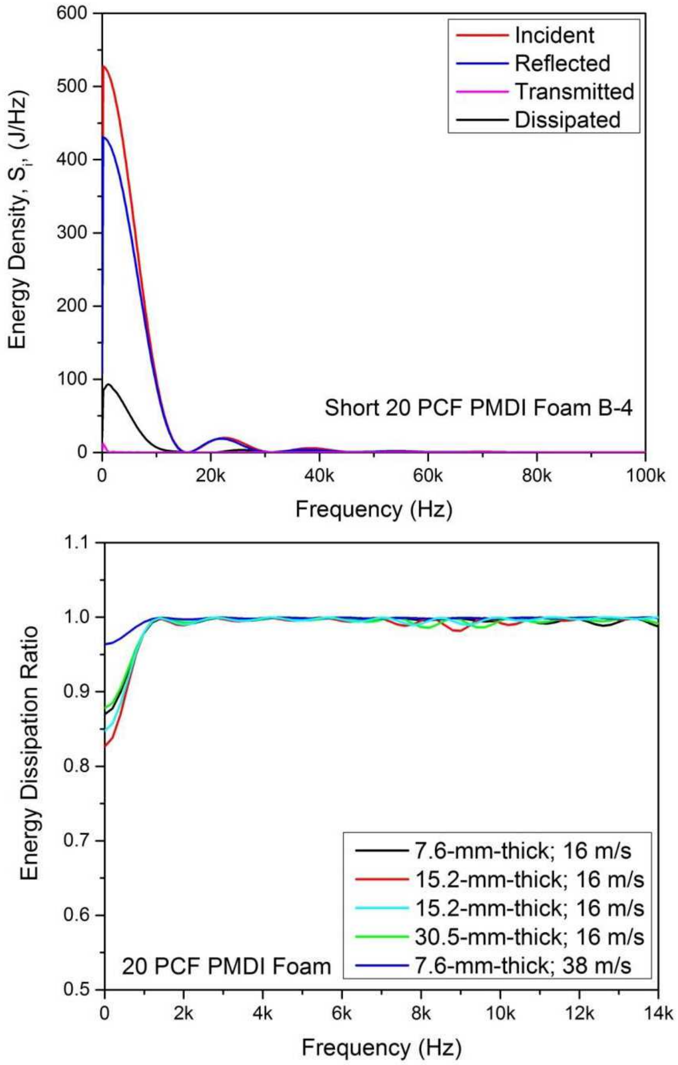
Vibration isolation:
bus driver seat

Fig. 1.
Seats selected for use in this study.

Blood et al. Whole body vibration exposures in metropolitan bus drivers: a comparison of three seats. J Sound Vib, 2010

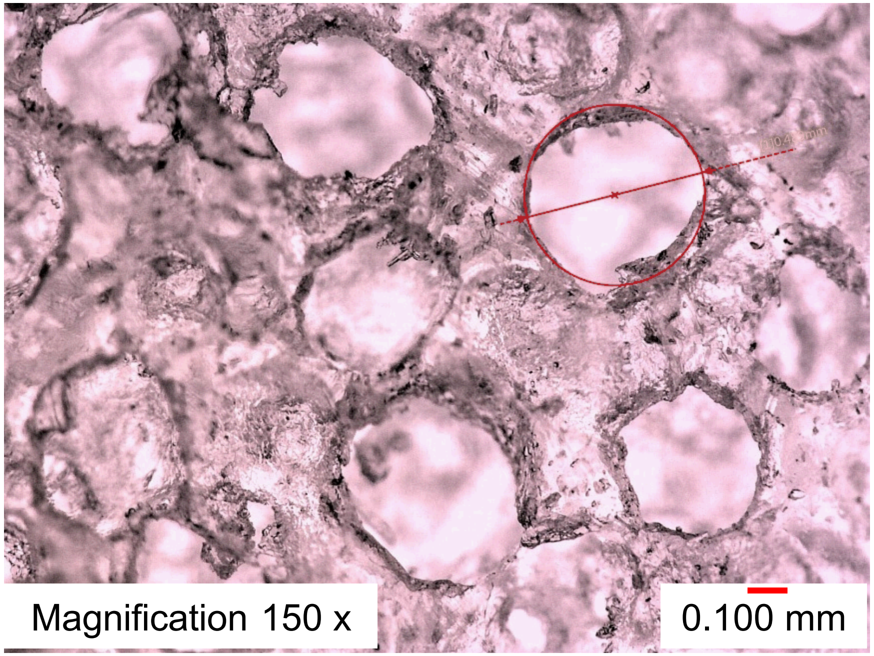
Previous Work

- **B. Song, K. Nelson. (2015) Dynamic Characterization of Frequency Response of Shock Mitigation of a Polymethylene Diisocyanate (PMDI) Based Rigid Polyurethane Foam. *Latin American Journal of Solids and Structures* 12(9):1790-1806**
  - Cutoff frequency was **independent** of **specimen thickness**
  - Cutoff frequency was **dependent** on **impact speed**
  - **Cutoff frequency ~1.5 kHz**
    - **Above 1.5 kHz, almost 100% of the energy was dissipated**
    - **Below 1.5 kHz, dissipation was down to ~83%**
  - **PMDI foam is a good shock mitigation material**



Material and experimental plan

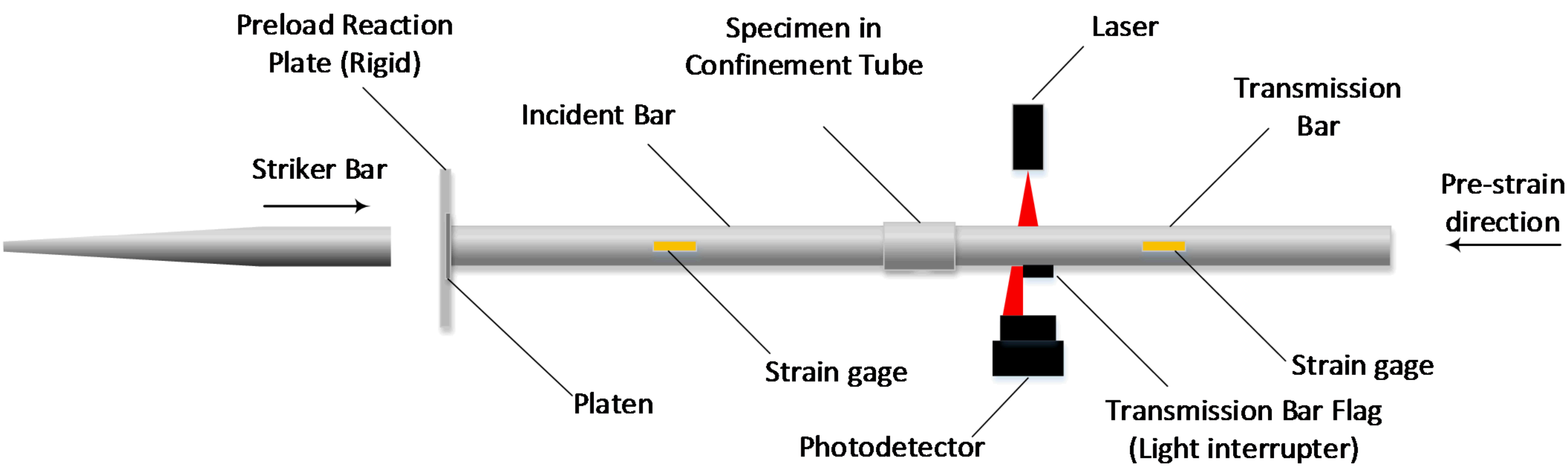
- Open Cell Silicone foam
- **Density**: $608 \pm 21.85\ kg/m^3$
- **Diameter**: 25.37 ± 0.08 mm to match bars
- **Thickness**: 5.33 ± 0.006 mm
- Average cell size: ~0.5 mm



- Pre-strains
  - 0% (non-strained)
  - 13%
  - 23.3%
  - 33.5%

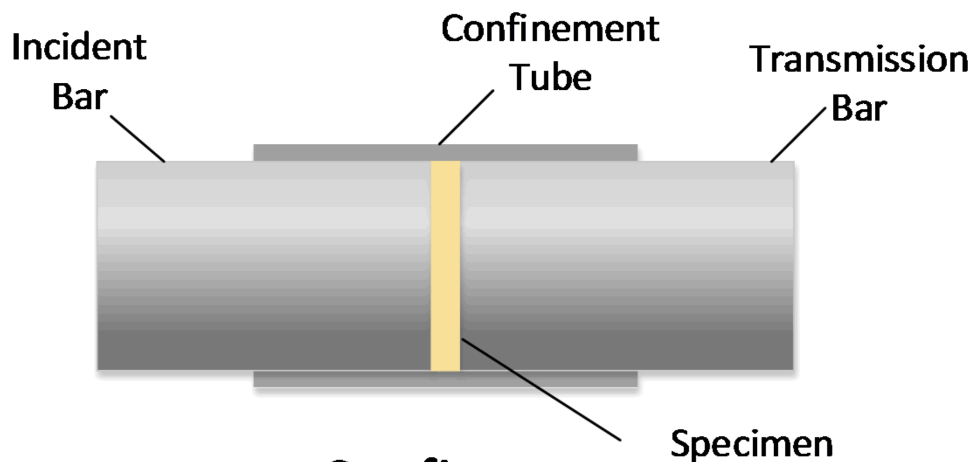
Kolsky Compression Bar with Pre-load Capability

- Kolsky compression bar with passive confinement tube
- Pre-strain is applied to the specimen via the transmission bar
- Laser is used to measure displacement during pre-straining



Confinement Tube

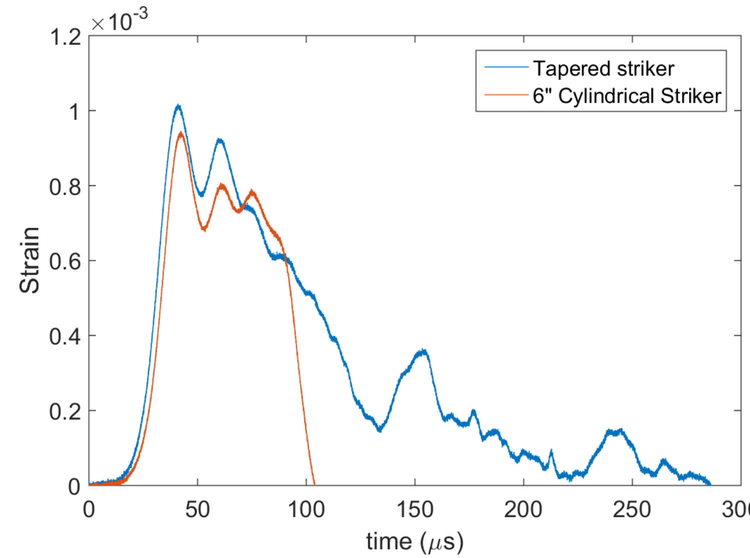
- Silicone foam specimen is held under passive confinement
- Tube material is 4340 steel
- Force generated during pre-strain at the highest level is ~50 N

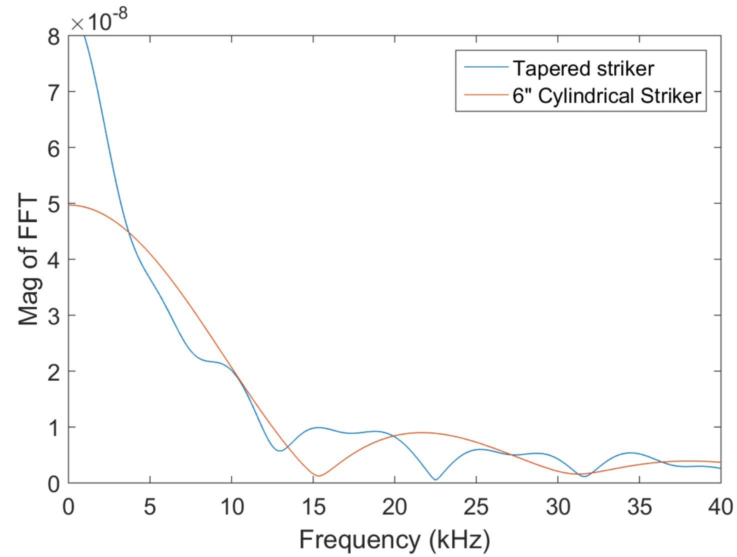


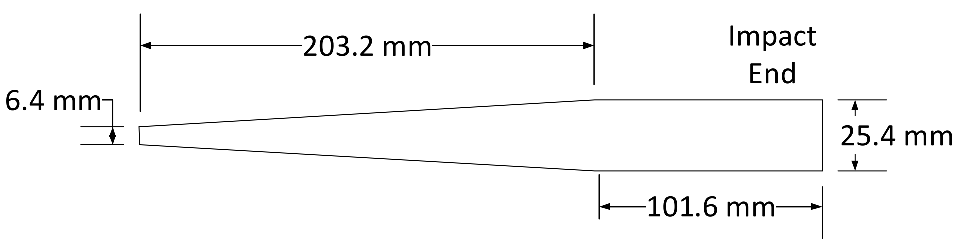
Confinement Tube Cutaway

Tapered Tungsten Striker

- Tapered striker was used to increase the range of frequency content
- Taper + impedance mismatch causes long unloading tail
- Increases the maximum frequency content from 15 to 23 kHz
- No pulse shaper or grease was used







Frequency Domain Energy Dissipation

- Time domain bar strain signals have the Fourier transform

$$\varepsilon(f) = B(f)e^{-j(2\pi f+\phi)}$$

- $B(f)$, f, and ϕ are the magnitude, frequency, and phase of the Fourier transform
- The energy spectrum density for each signal is

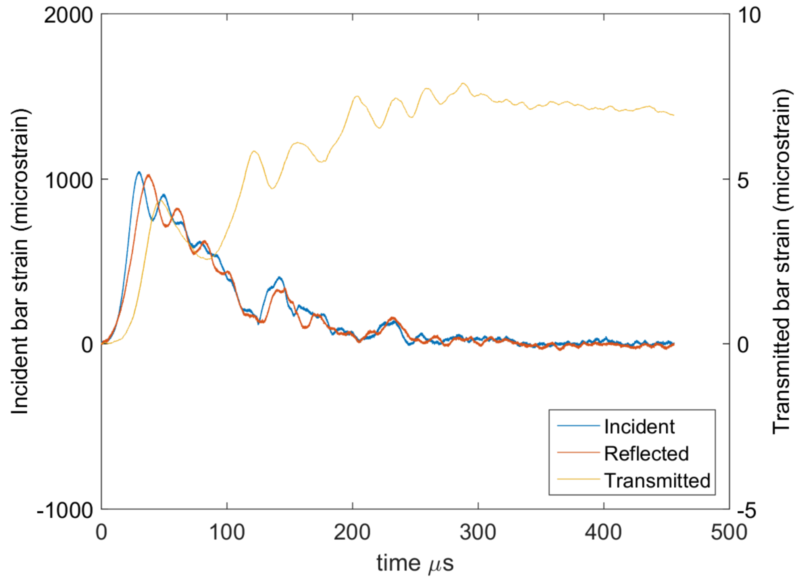
$$S_i(f) = A_0 C_0 E_0 |B_i(f)|^2 \qquad S_r(f) = A_0 C_0 E_0 |B_r(f)|^2 \qquad S_t(f) = A_0 C_0 E_0 |B_t(f)|^2$$

- Energy dissipation ratio as a function of frequency is

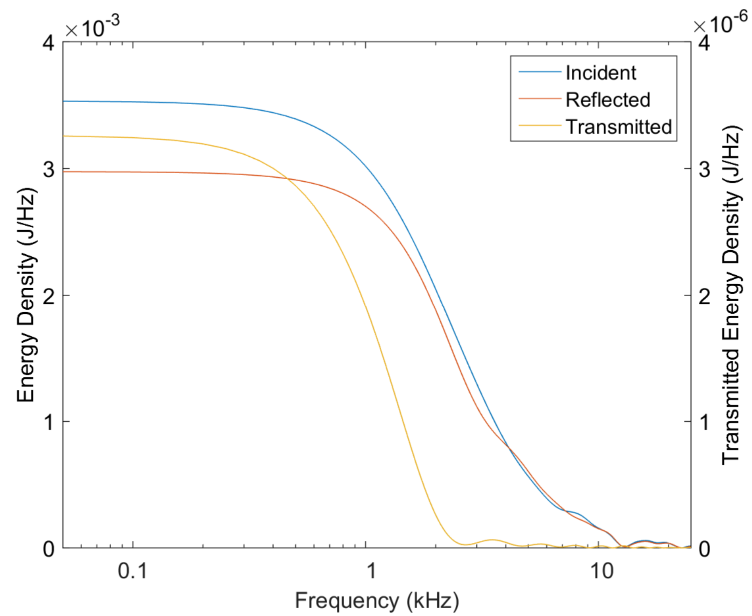
$$\delta(f) = 1 - \frac{|B_t(f)|^2}{|B_i(f)|^2 - |B_r(f)|^2}$$

Experimental Results

- Time-domain strain histories
  - Strain history is taken out until pulse overlap occurs on the transmission bar
  - Trans pulse does not decrease because the foam is not stiff enough to push the bars back

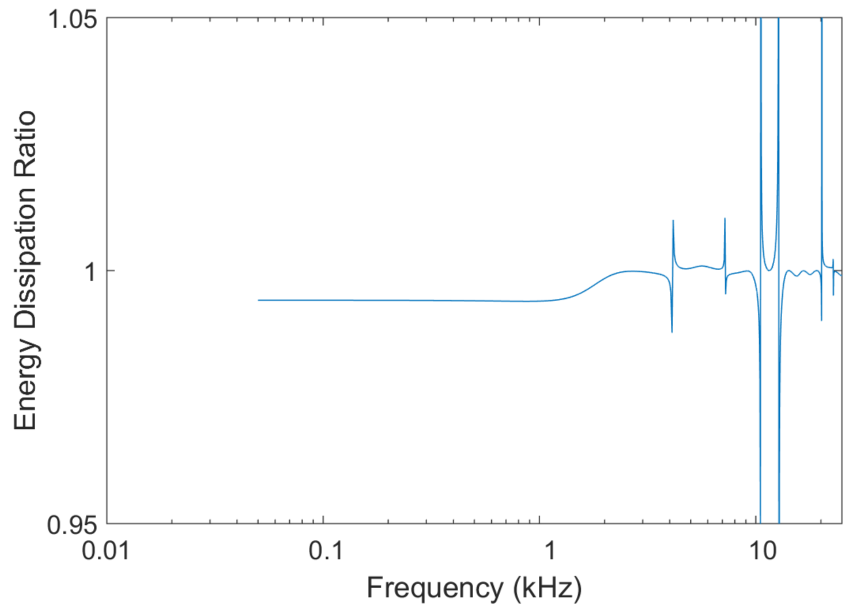


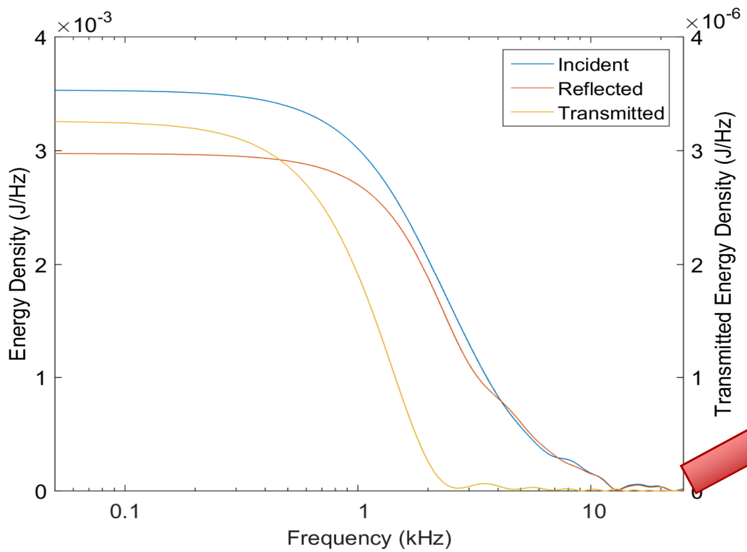
- Frequency-domain energy behavior
  - Reflected energy is higher at 4-7 kHz => discontinuities in energy dissipation ratio
  - What causes this? Frequency shift?

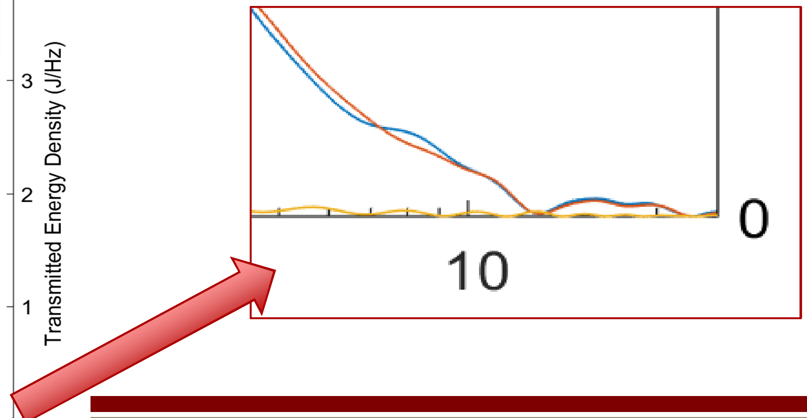


Energy Dissipation Ratio

- Energy Dissipation Ratio
  - Silicone Foam sample pre-strained to 33.5%
  - Initial energy dissipation ratio was 0.995
  - Cutoff frequency of 2.65 kHz
  - After the cutoff frequency, energy dissipation stabilizes at nearly 1 (total dissipation)

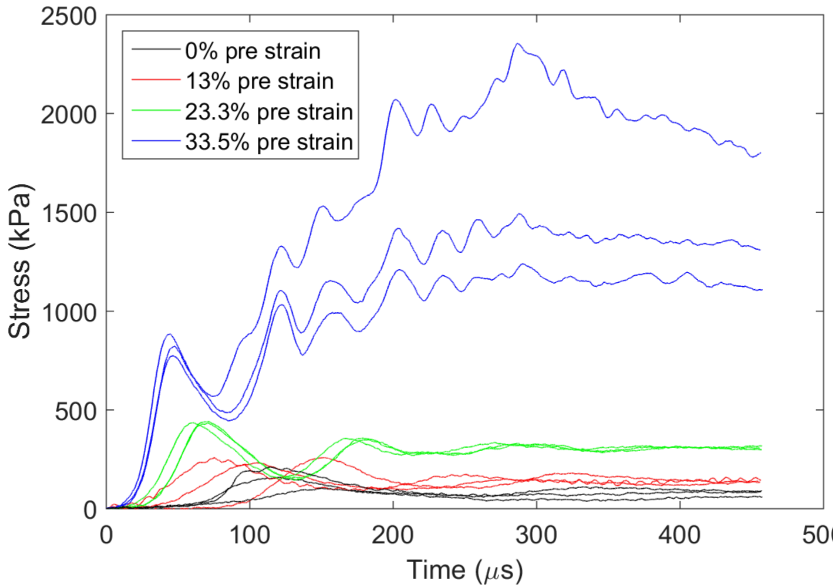




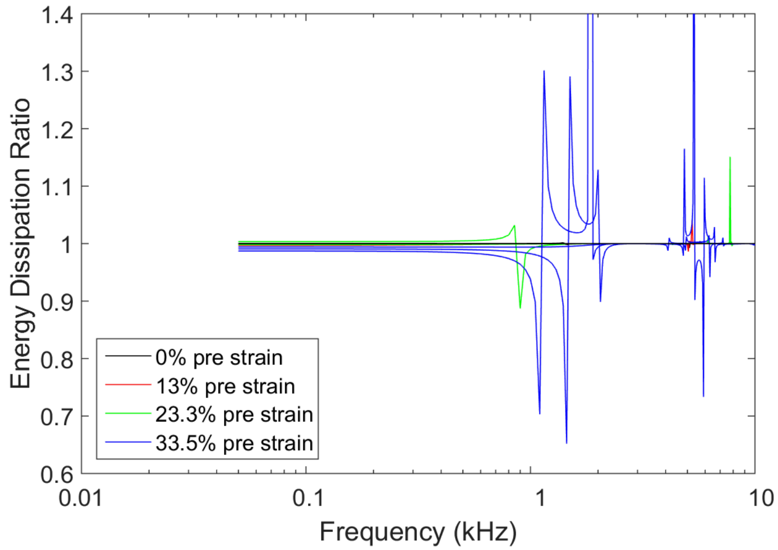


Different Pre-Strains

- Stress-time histories vary due to small differences in pre-strain and/or specimen geometry

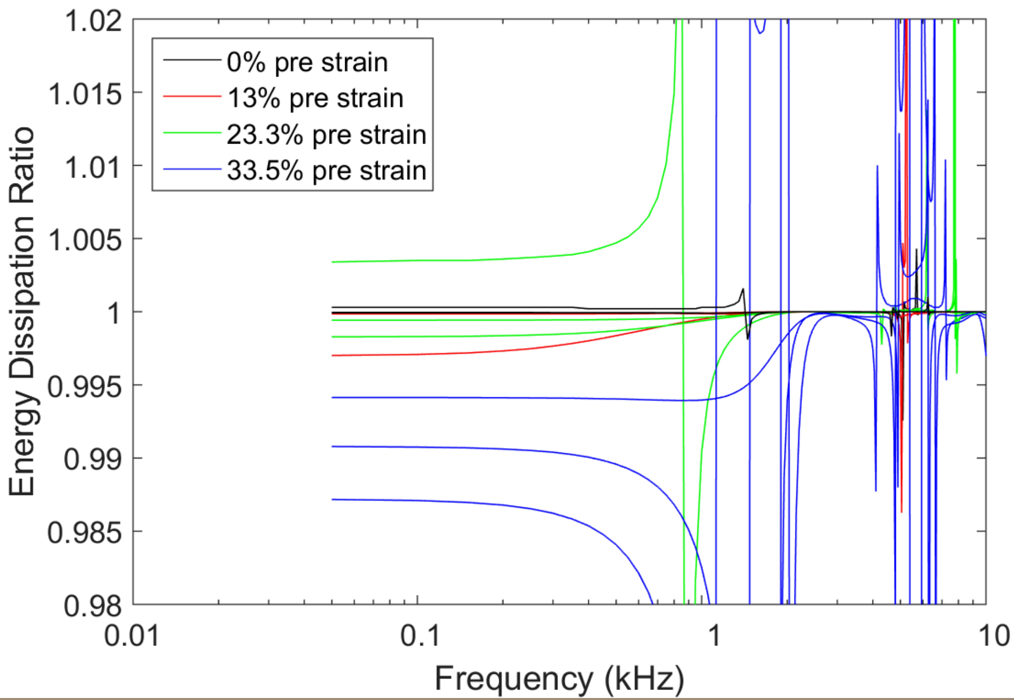


- Energy dissipation ratio for all pre-strain levels are close to 1



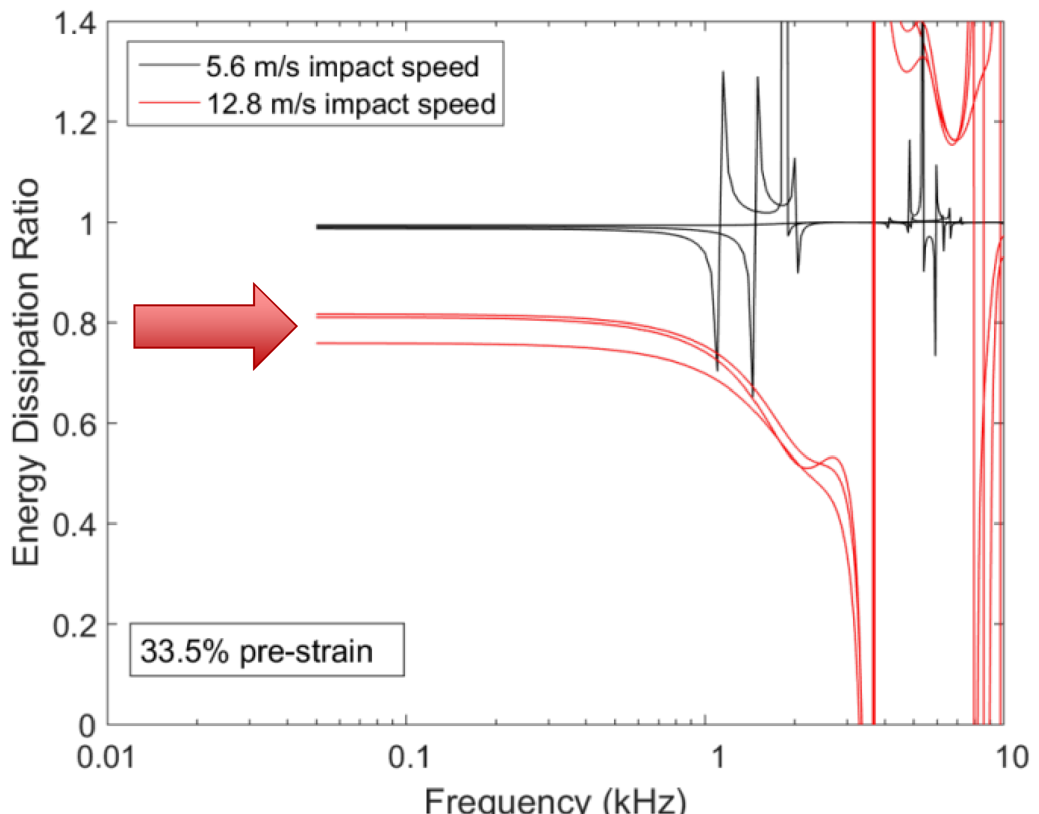
Energy Dissipation Ratio

- Zooming in, a dependency on pre-strain may exist
- With increasing pre-strain, energy dissipation ratio is lower
- Still, the lowest recorded dissipation ratio was 0.985
- Cutoff frequency may increase with increasing pre-strain, but it is difficult to tell



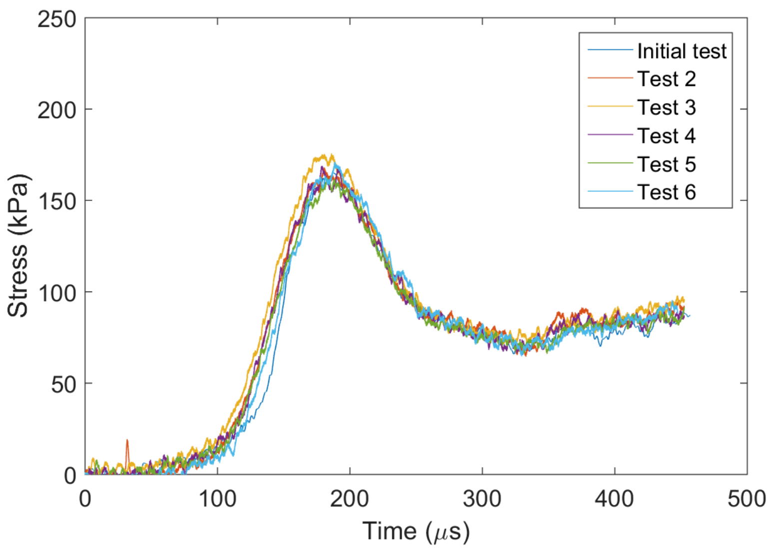
Higher Velocity

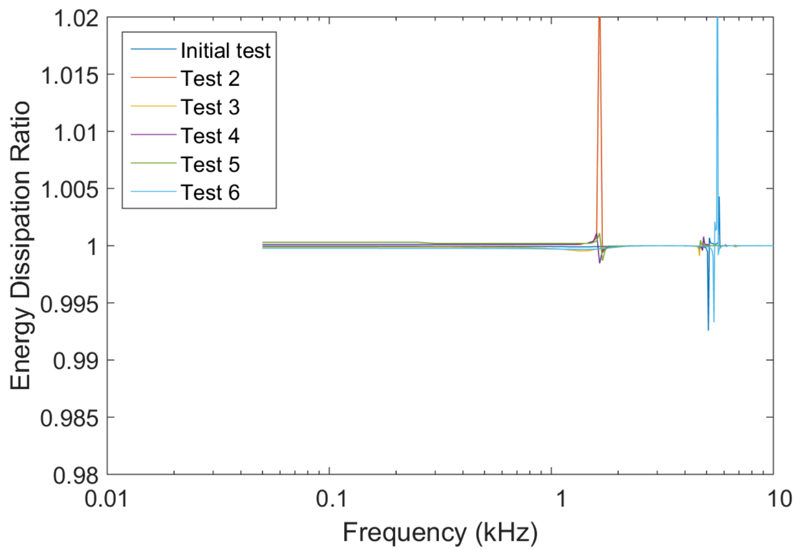
- If the rubber dissipates 100% of the energy at all pre-strains, what's the point?
- Silicone rubber might not isolate the same amount of energy at higher velocity



Energy Dissipation with Repeated Loading

- How does the foam behave when subjected to repeated loading?
- Same sample, 7 total loadings
- Stress history is repeatable
- Silicone foam dissipated nearly all of loading energy
  - Dissipation ratio of 1 ± 0.05%





Conclusion

- Passive confinement Kolsky compression bar
- Silicone foam compressed at elevated strain rate, different pre-strains
- Frequency domain energy dissipation behavior
- Foam dissipated more than 98% of input energy at all pre-strains (low impact speed)
- Effect of pre-strain level on the energy dissipation is indicated, but more study is needed at higher pre-strains or velocities
  - There appears to be an effect at higher velocities at the same pre-strain
- Stress-time and energy dissipation in frequency domain were repeatable on a single sample loaded seven times