SAND2011-3829C
2011 SEM Annual Conference and Exposition on Experimental and Applied Mechanics
Uncasville, CT, June 13-16, 2011

Dynamic Tensile Characterization of Foam Materials

Bo Song

Helena Jin

Wei-Yang Lu

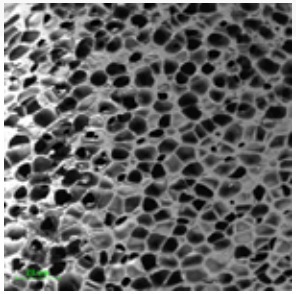
Sandia National Laboratories, Livermore, CA

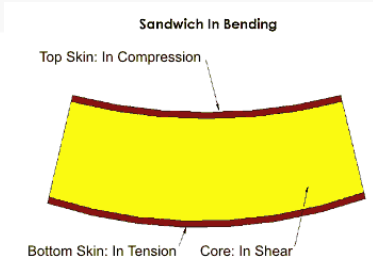
Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

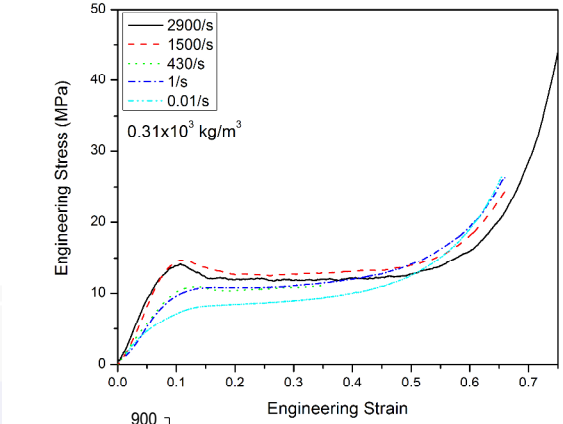
Sandia National Laboratories

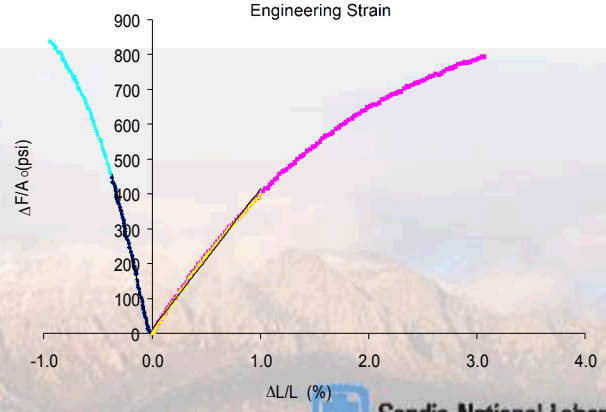
Polymeric Foams

- Polymeric Foams
  - Light weight
  - Superior energy absorption capabilities
  - Applications to impact events
    - Core material in sandwich structures
- Unique mechanical response in compression and tension
- Significant difference in stress-strain response under compression and tension
  - Foam materials may be subjected to impact tension in applications
    - Bending
    - Spalling
    - …
  - Dynamic tensile response is desirable

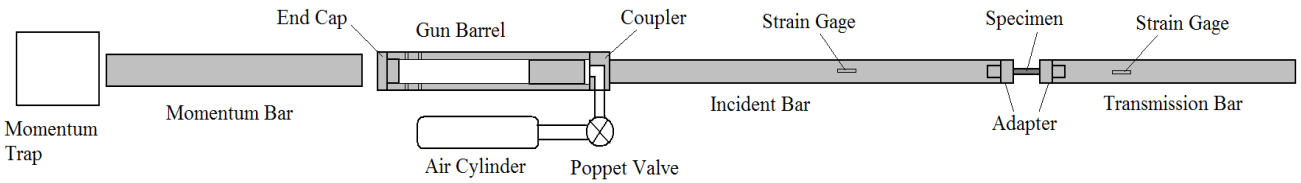


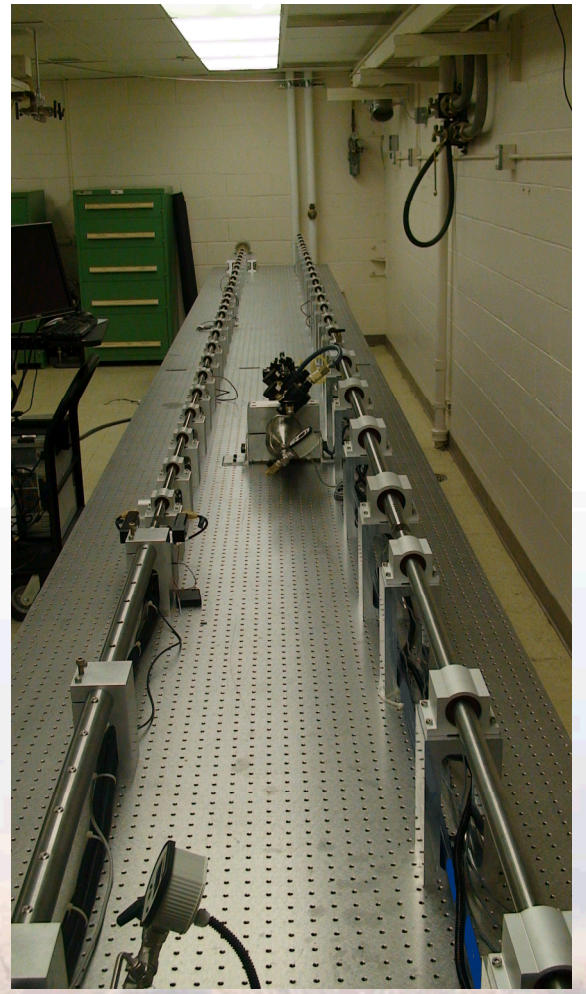




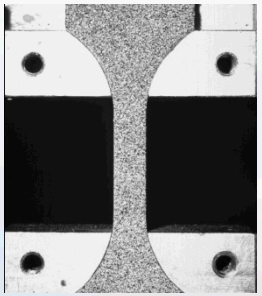


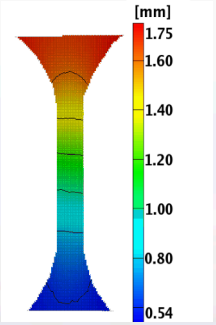
High-Rate Tensile Characterization with Kolsky Tension Bar





Kolsky Tension Bar Developed at Sandia California
(presented at 2010 SEM Annual Conference)





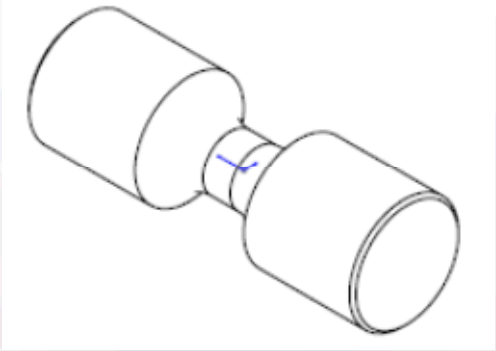
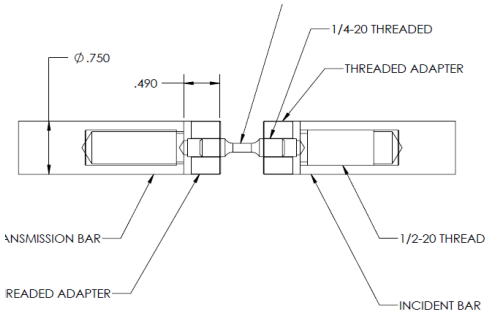


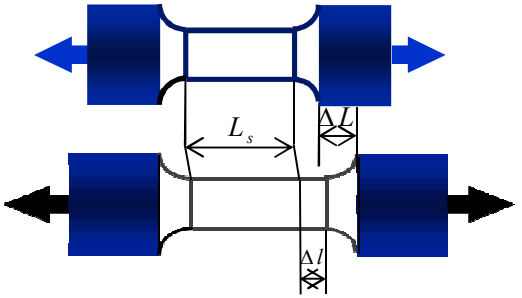
Plate Specimen

Dumbbell Cylinder Specimen

Challenges

- Stress measurement
  - Low yield/failure strength
  - Stress equilibrium
    - Short specimen gage length
    - Control of initial loading rate



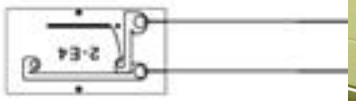


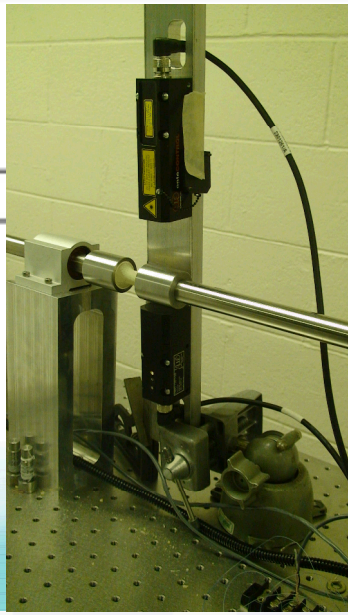
- Strain measurement
  - Displacement measurement of incident bar end
    - Using incident and reflected pulses may not give precise measurement of displacement due to possible wave disturbance by adapters, …
  - Determination of gage length of dumbbell specimen

- Synchronization of stress and strain histories
  - Determination of the time for the stress wave propagating in the specimen
    - Longitudinal stress wave in the specimen material

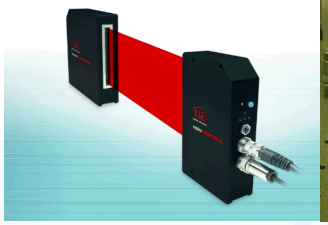
Remedies

- Semiconductor strain gages
  - Specimen stress measurement
  - 70 times more sensitive in comparison to regular resistor strain gages

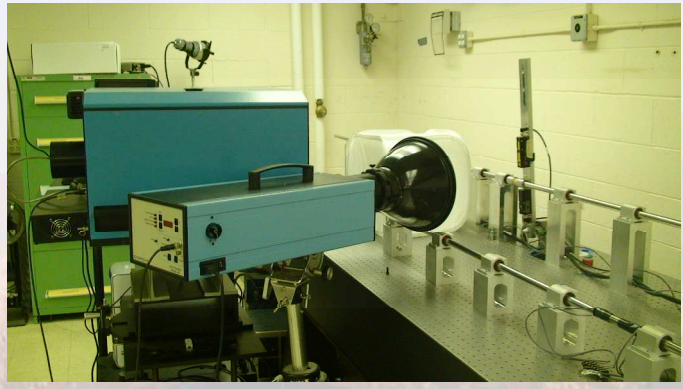




- High-frequency-response laser beam system
  - Micro-epsilon OptiControl Laser Beam System
    - 100 kHz frequency response
    - High resolution: 100 µm
  - Direct displacement measurement of the incident bar end

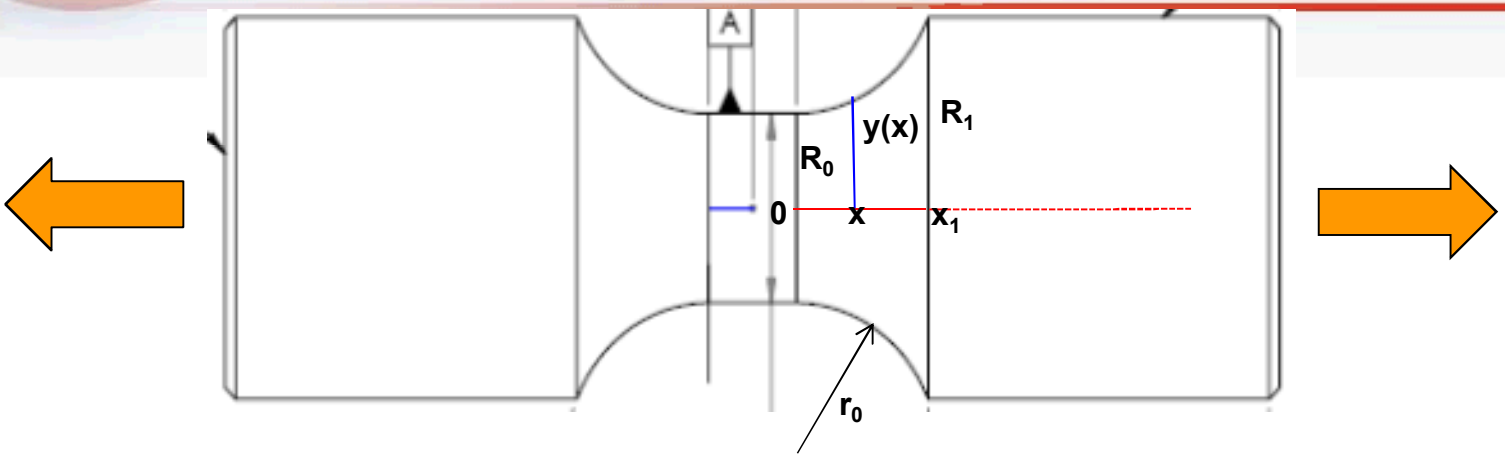


$$\varepsilon(t) = \frac{c' \cdot (\Delta L(t) - C_0 \int_0^t \varepsilon_T(\tau) d\tau)}{L_s}$$



- High-speed digital image correlation (DIC)

Displacement Correction



Radius

$$y(x) = R_0 + \left(r_0 - \sqrt{r_0^2 - x^2} \right)$$

$$y(x=0) = R_0$$

$$y(x=x_1) = R_1$$

Area

$$A(x) = \pi \cdot y^2(x) = \pi \cdot \left[R_0 + \left(r_0 - \sqrt{r_0^2 - x^2} \right) \right]^2$$

Strain

$$\varepsilon(x) = \frac{\sigma(x)}{E} = \frac{F}{E\pi \cdot \left[R_0 + \left(r_0 - \sqrt{r_0^2 - x^2} \right) \right]^2}$$

Stress

$$\sigma(x) = \frac{F}{A(x)} = \frac{F}{\pi \cdot \left[R_0 + \left(r_0 - \sqrt{r_0^2 - x^2} \right) \right]^2}$$

Displacement

$$dl = \varepsilon(x)dx = \frac{F dx}{E\pi \cdot \left[R_0 + \left(r_0 - \sqrt{r_0^2 - x^2} \right) \right]^2}$$

Displacement Correction

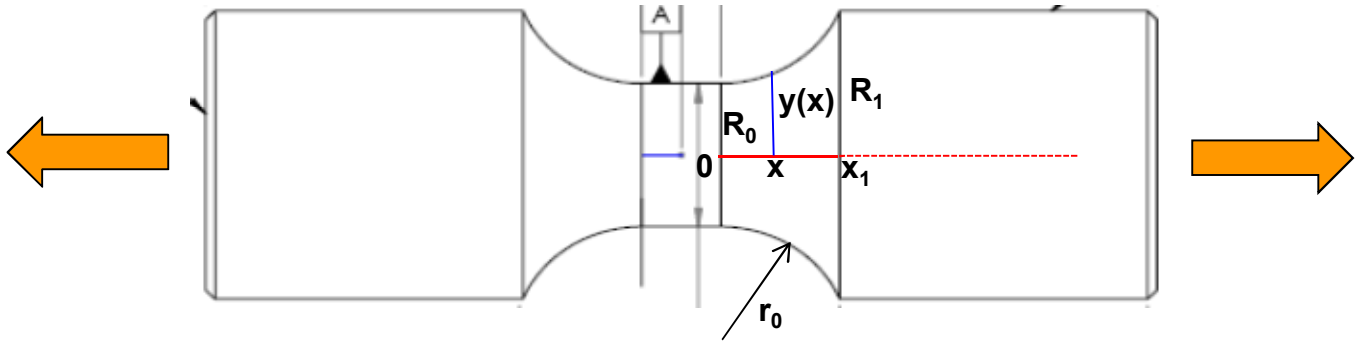
$R_0 = 0.25$

$r_0 = 0.406$

$L_s = 0.25$

$x_1 = 0.375$

$R_1 = 0.5$



Total Displacement (non-gage section)

$$2l = \frac{2F}{E\pi}\int_0^{x_1} \frac{dx}{\left[R_0 + \left(r_0 - \sqrt{r_0^{\,2} - x^2}\right)\right]^2} = \frac{2F}{E\pi} \times 4.122$$

Total Displacement (gage section)

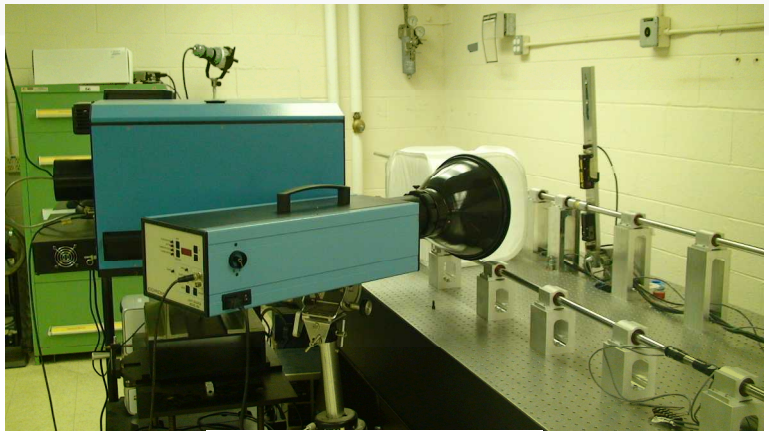
$$l_g = \varepsilon_g L_s = \frac{F}{E\pi} \cdot \frac{L_s}{R_0^{\,2}} = \frac{4F}{E\pi}$$

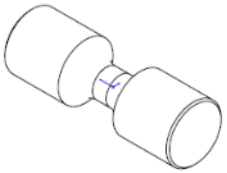
Correction Coefficient

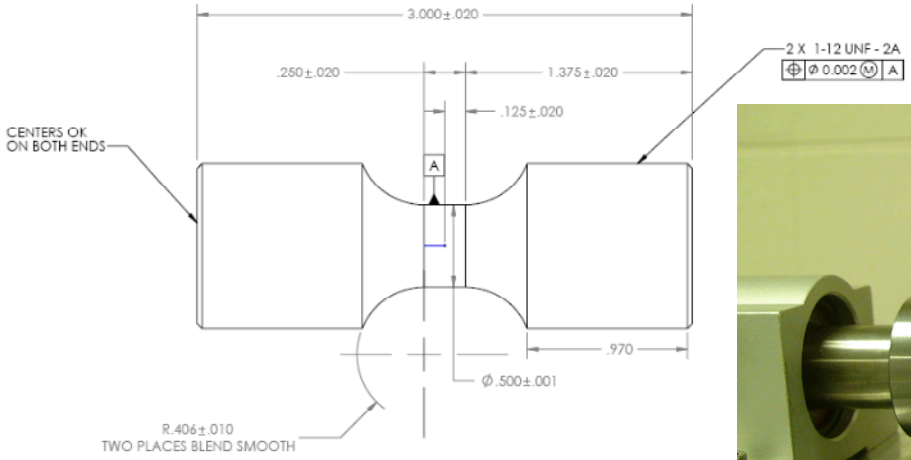
$$c' = \frac{l_g}{L} = \frac{l_g}{l_g + 2l} = \frac{1}{1 + \frac{2l}{l_g}} = 0.3267$$

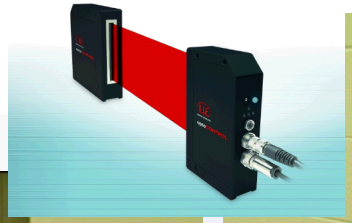
Example: Dynamic Tensile Characterization of PMDI Foam

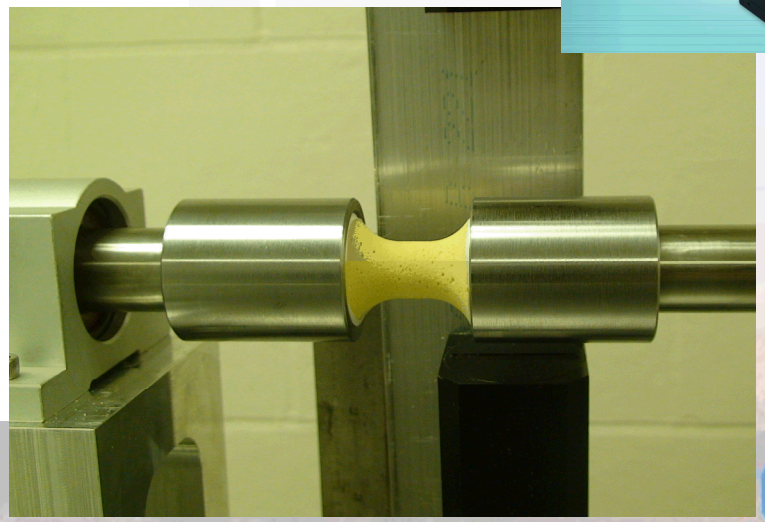
- Material and specimens
  - Polymethylene diisocyanate (PMDI) foam: 16PCF
  - Specimens

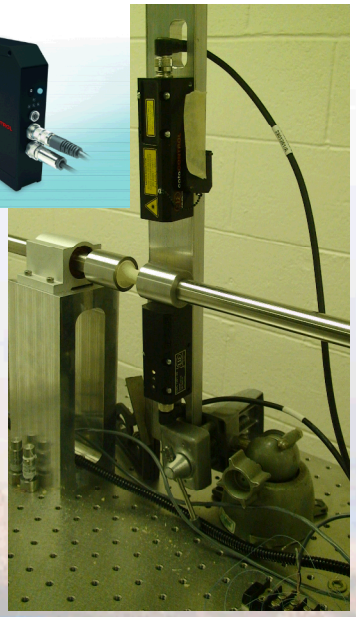




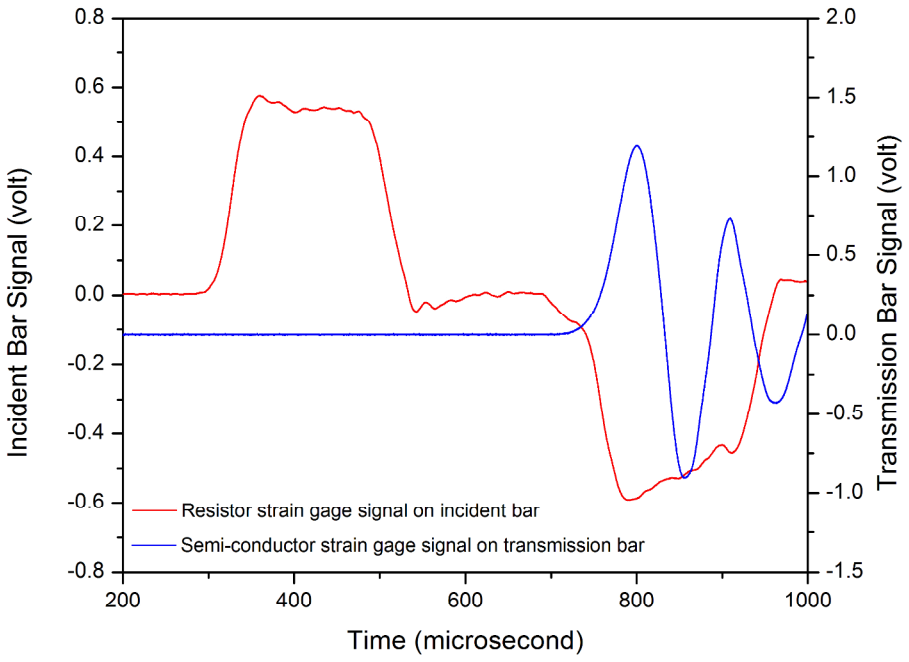






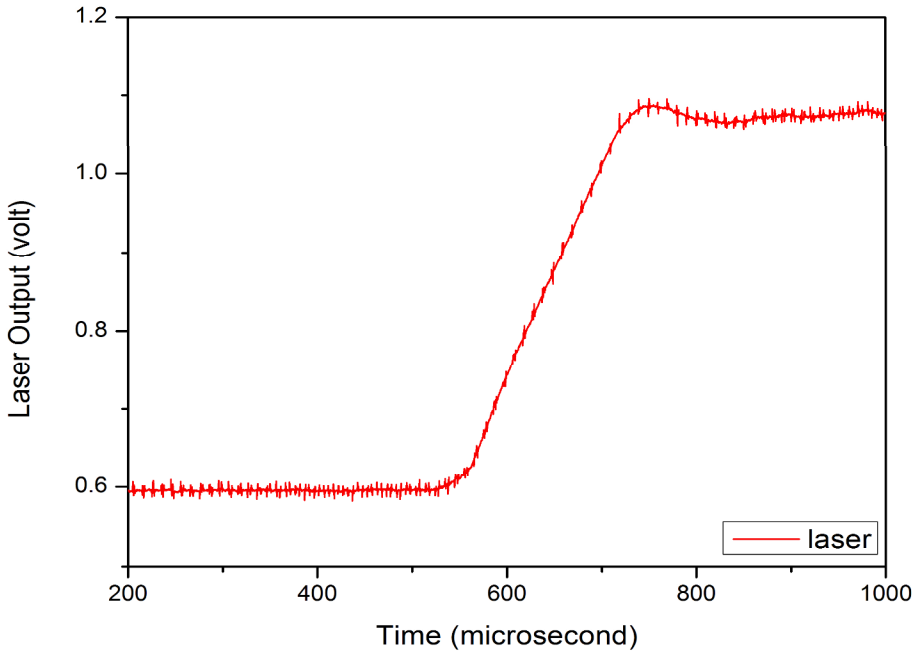


Oscilloscope Records

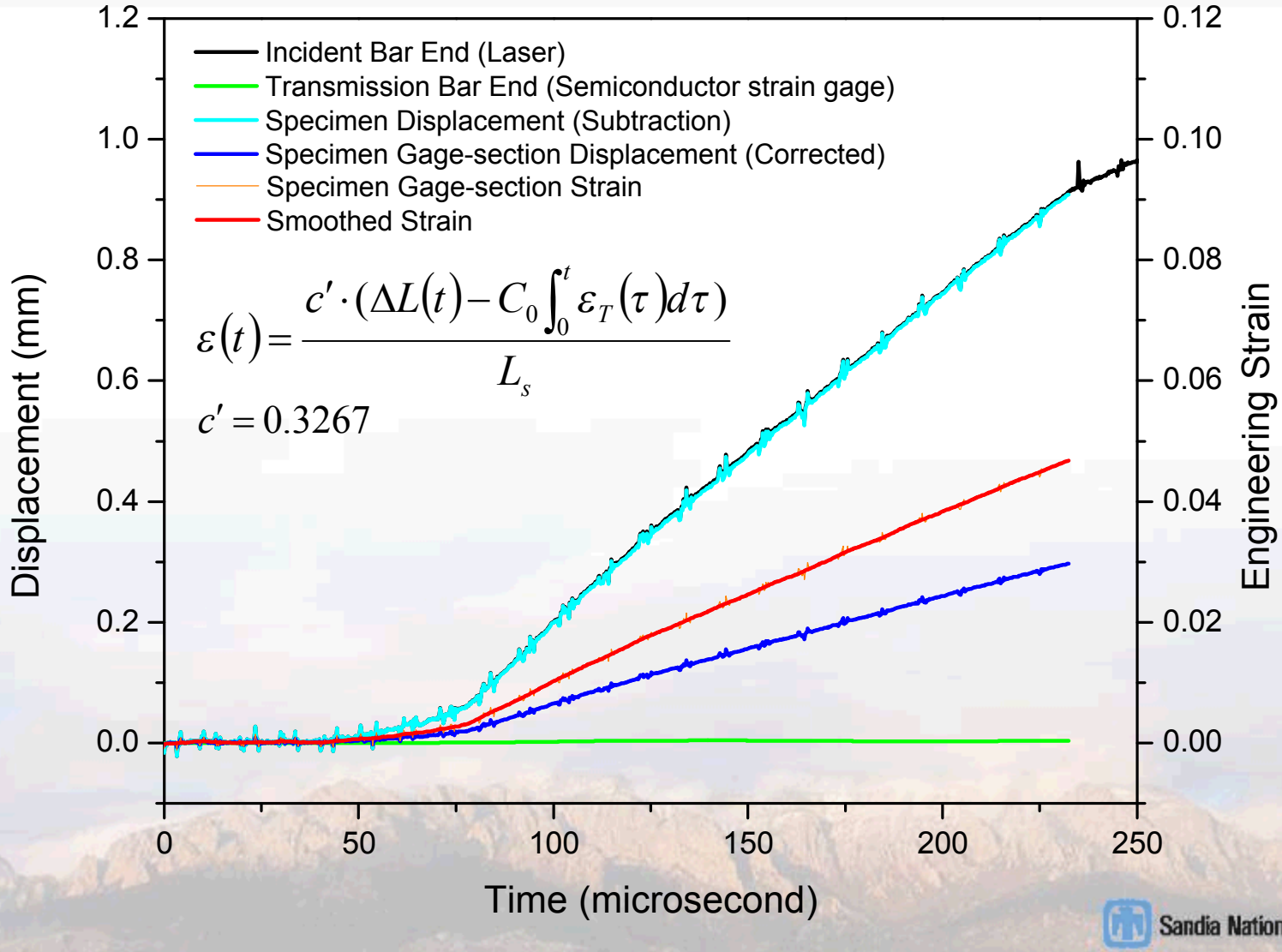


Bar-strain-gage Output

Laser Beam Output

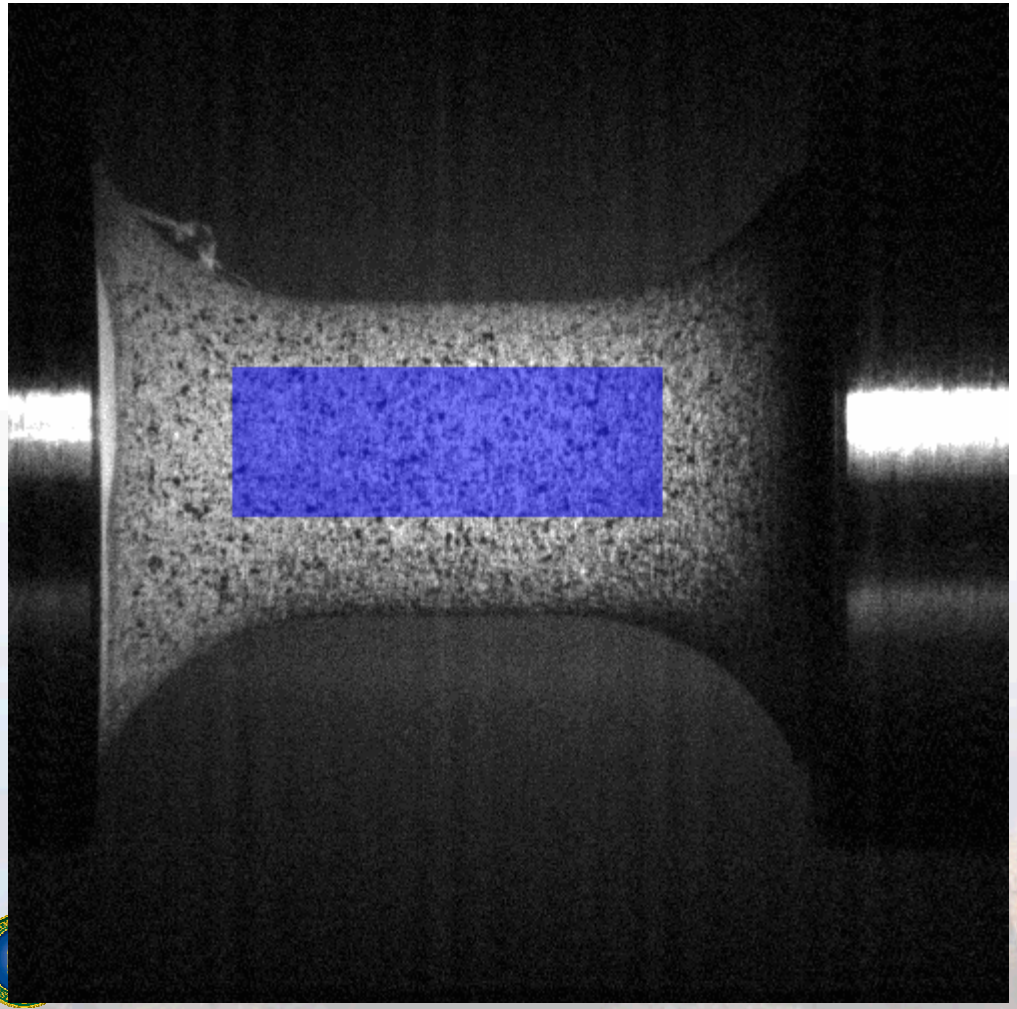


Displacement and Strain Histories

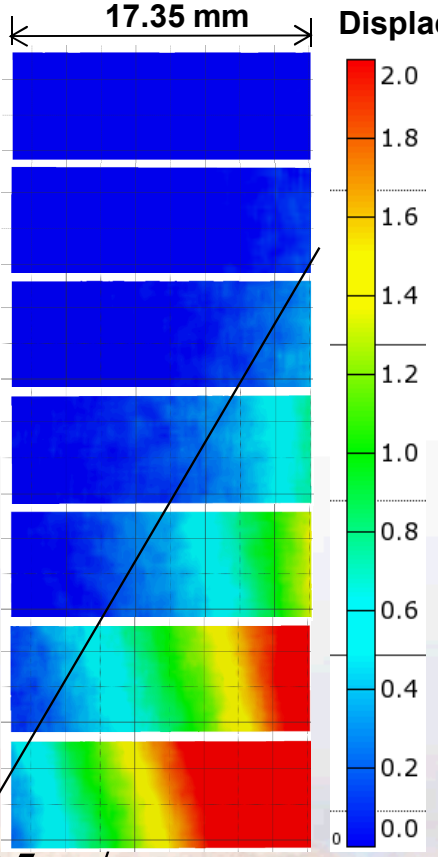


Longitudinal Wave Speed in Foam Specimen

High-rate Digital Image Correlation (DIC)



0.375” gage length
(3.125” total length)

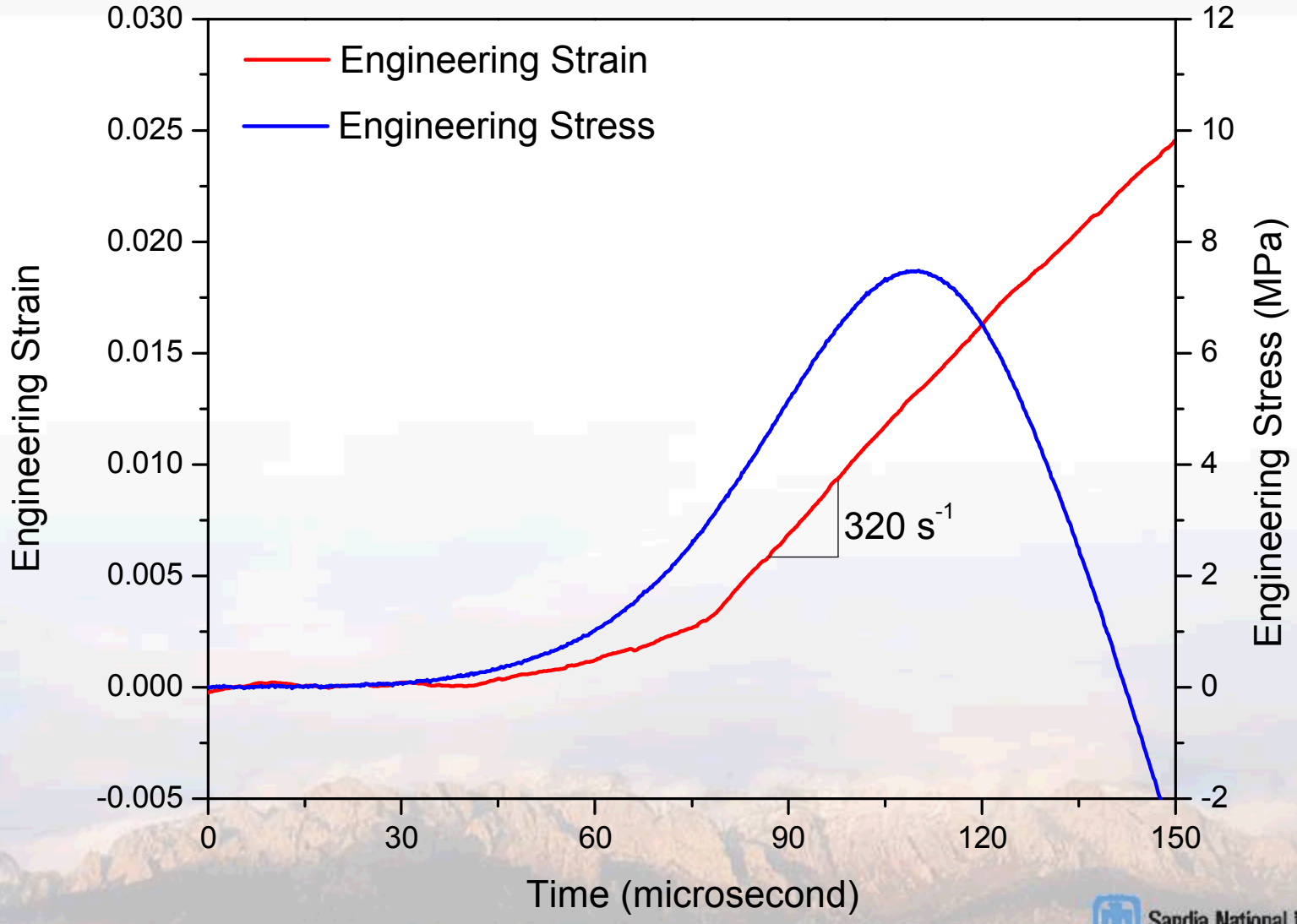


$C \approx 525 m/s$

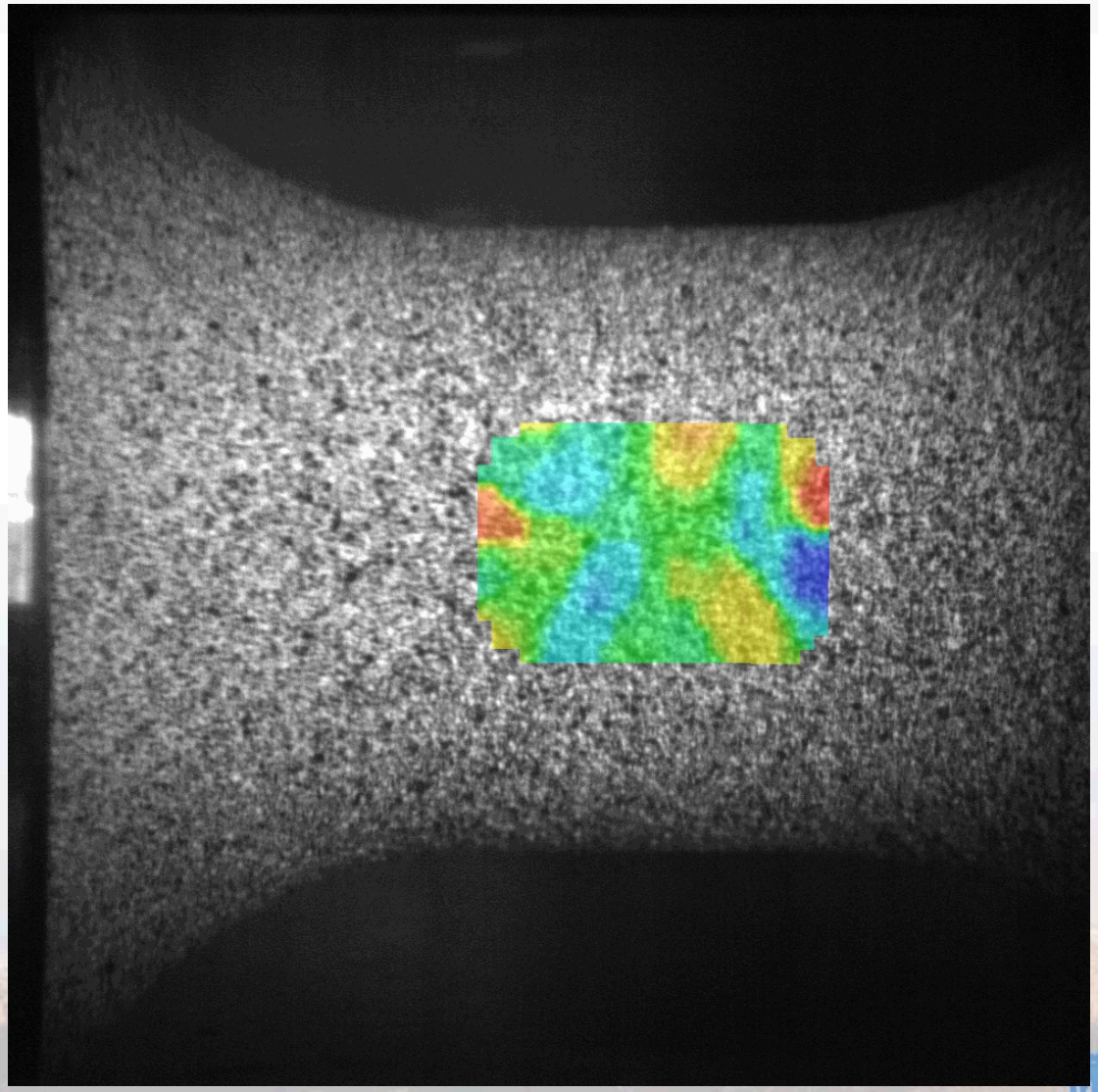
X0.04 mm

Time interval: 6.6 microsecond

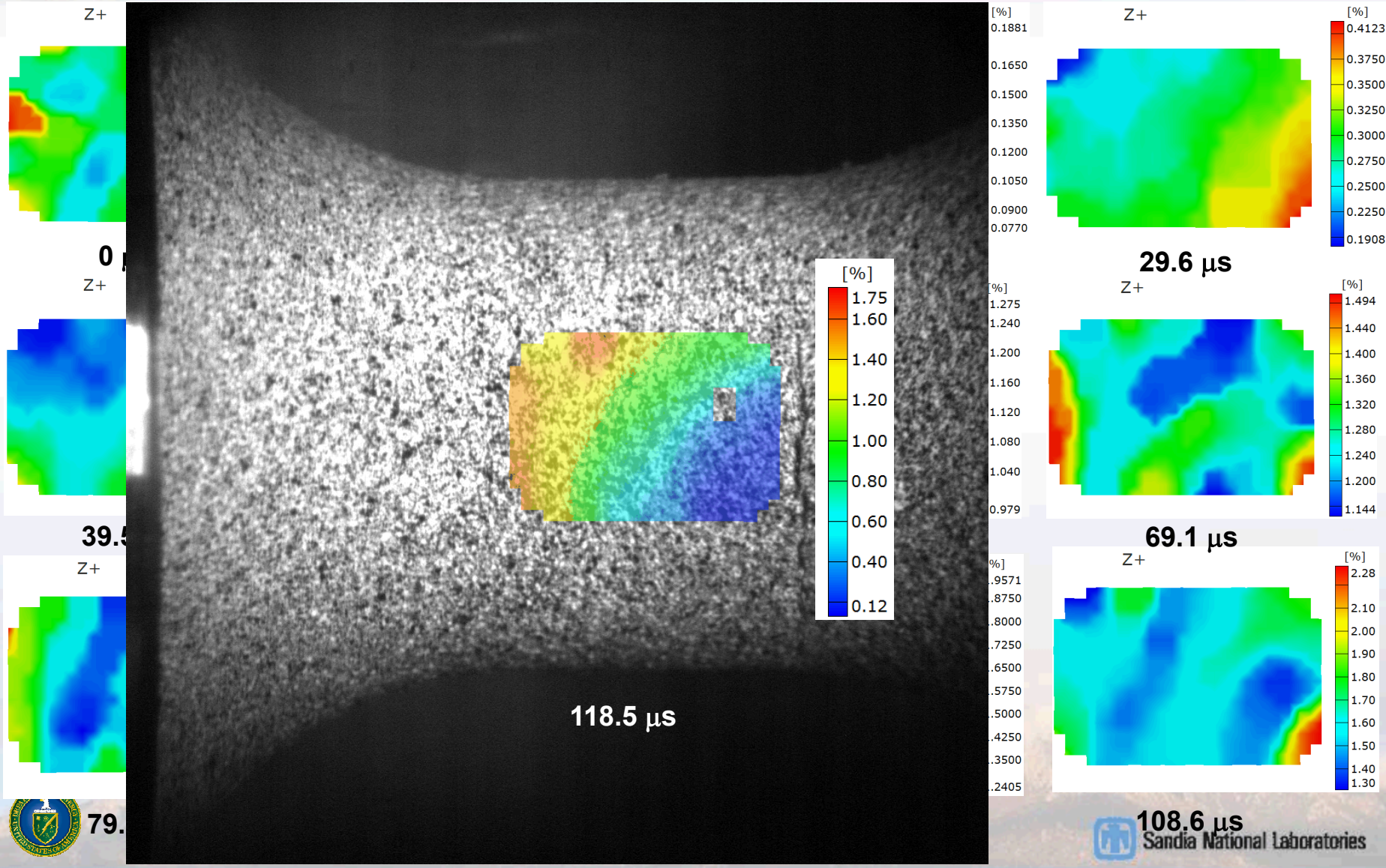
Synchronized Stress and Strain Histories



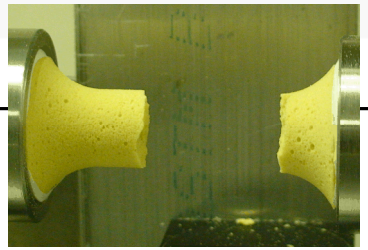
Uniform Deformation

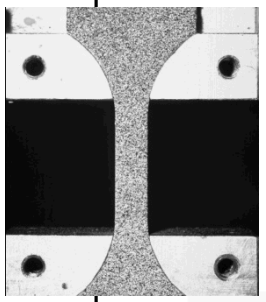


Uniform Deformation



Stress-Strain Curve





Summary

- **High-rate tensile experimental procedure with the Kolsky tension bar has been developed for characterization of foam materials**
  - **Stress measurement: semiconductor strain gages**
  - **Strain measurement:**
    - **Laser beam measurement**
    - **Specimen gage length correction**
  - **Stress/strain synchronization:**
    - **Determination of longitudinal wave speed in foam material (high rate DIC)**
  - **Validation and verification of testing conditions (stress equilibrium/uniform deformation)**
    - **Pulse shaping technique**
    - **Short specimen gage length**
    - **High-rate digital image correlation**

As an example, dynamic tensile stress-strain curve of PMDI foam (16PCF) was obtained at 320 s^{-1}