# Radial shock response of brittle materials

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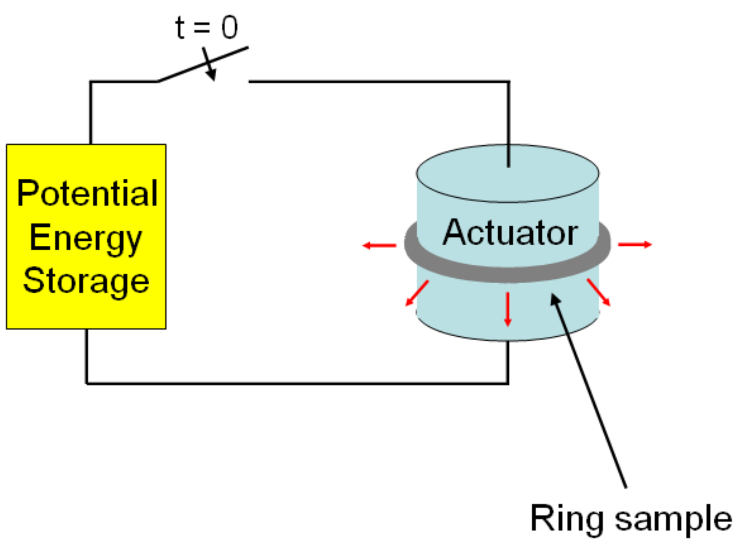
1: Ohio State University
2: Idaho National Laboratories

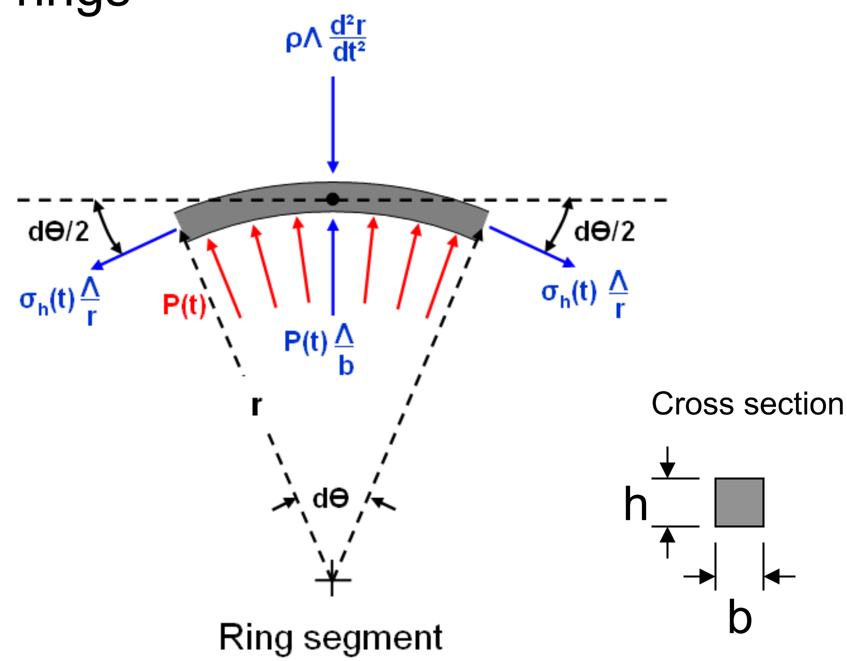
# Overview

- High rate axisymmetric materials testing
- Analyses for ductile/brittle solids
- Experimental setup
  – Actuators and impulse source
  – PDV
- Examples
  – Zr based Bulk Metallic Glass
  – Super bainite
  – Dyneema

# Analyses for ductile solids

- "Traditional" ring expansion
  - Driven and/or freely expanding rings
  - Composite samples




$$\Lambda = bhrd\theta \quad \longrightarrow \quad \rho\Lambda\frac{d^2r}{dt^2} = P(t)\frac{\Lambda}{b} - \sigma_h(t)\frac{\Lambda}{r}$$

# Analyses for brittle solids

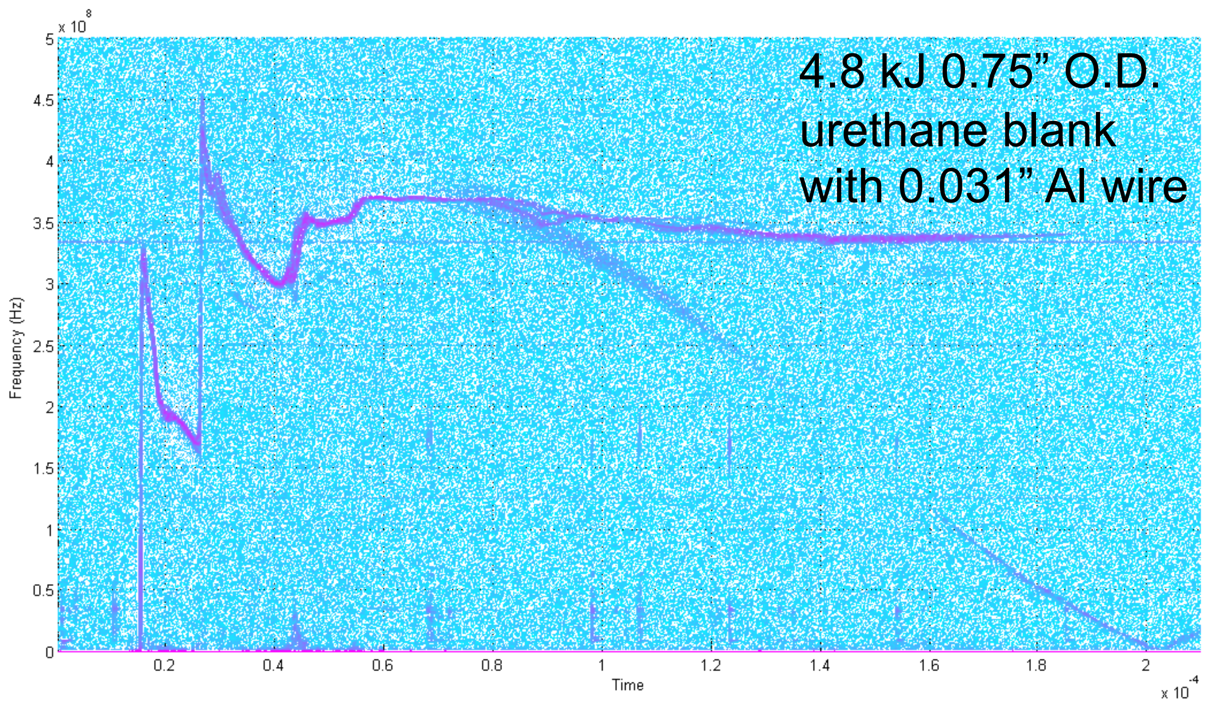
- Forcing function → Delta function
  - Exploding wire, urethane pressure medium
- Characterize pressure medium ($U_s$ – $u_p$)
- Measure $u_p$ in pressure medium
  - Equal to ½ the free surface velocity
  - Utilize Rankine – Hugoniot relations to determine the magnitude of incident compressive stress

$$\sigma - \sigma_0 = \rho_0 (U_s - u_0)(u_p - u_0)$$

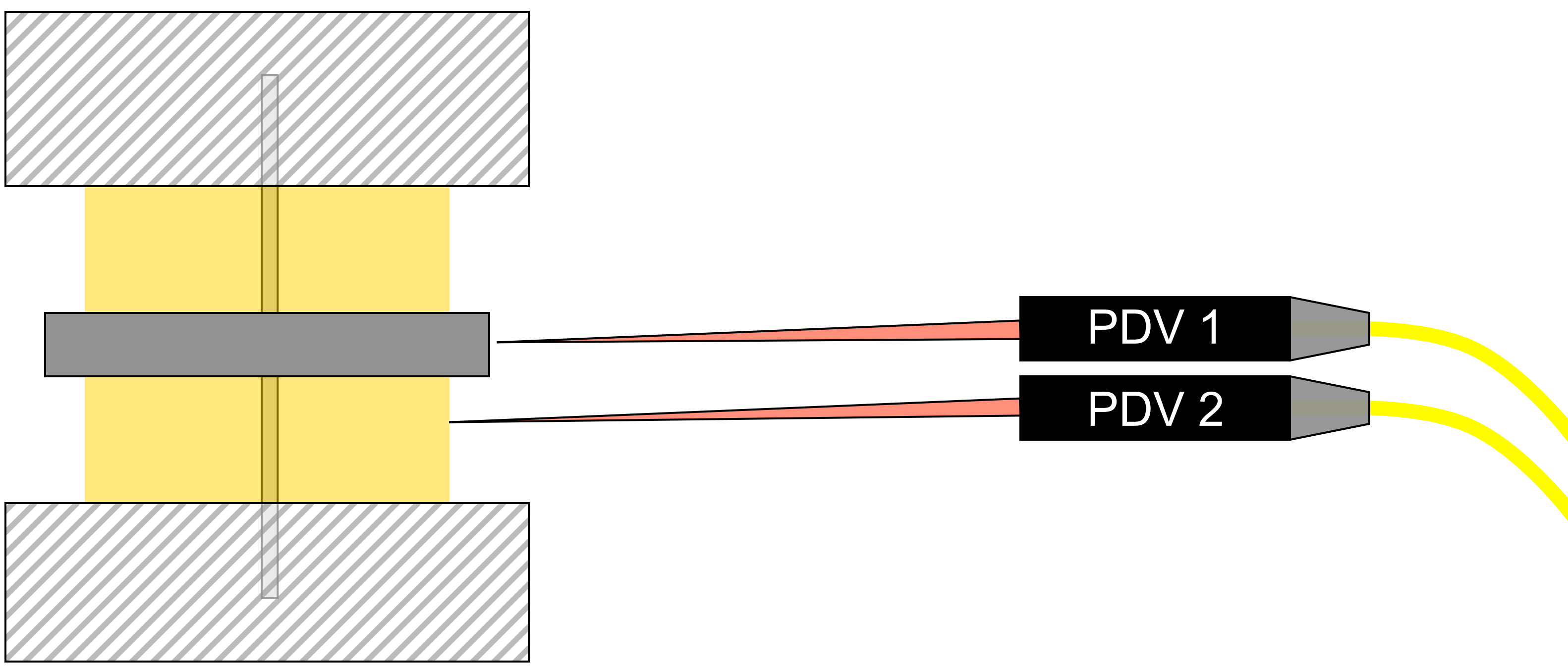
- Stress state (tensorial) can then be determined with geometric considerations and elastic constants

# Analyses for brittle solids

- Urethane characteristics
  - $U_s = 1.92 + 2.00\ u_p$ (mm/μs)
  - $\rho_o = 1.242$ (g/cm$^3$)

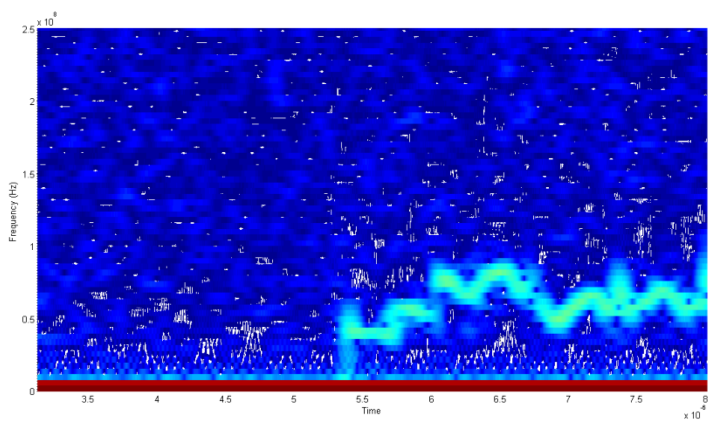


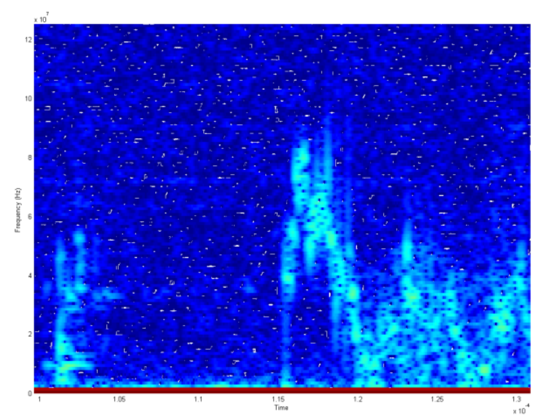
# Experimental setup



# Bulk Metallic Glass

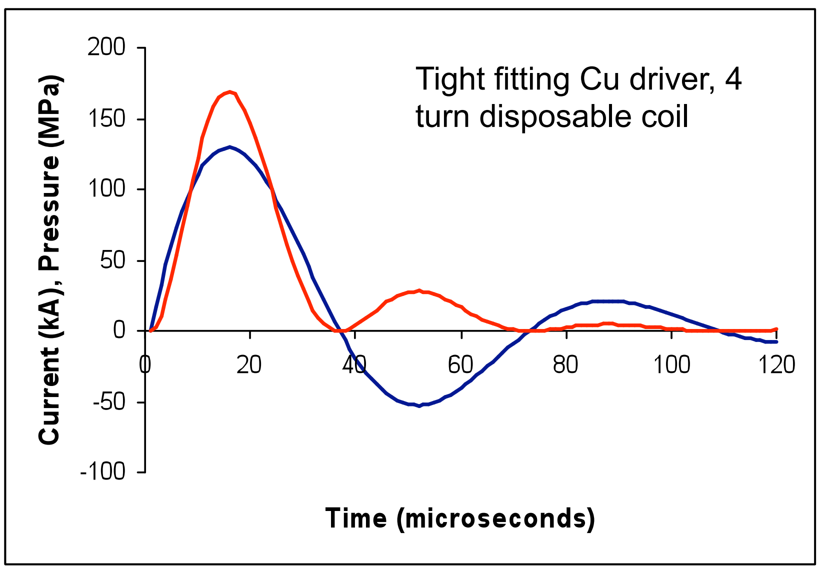
- Ring expansion
  - 0.75” I.D. x 1.00” O.D. x 0.11” rings
  - Exploding wire actuator (3.2 – 6.4 kJ)
- PDV – 2 channels w/ 30 cm focusing probe on each, Sharpie silver paint marker
- Failure energy between 4960 – 5040 J
  - Tensile fracture stress of ~3.4 GPa

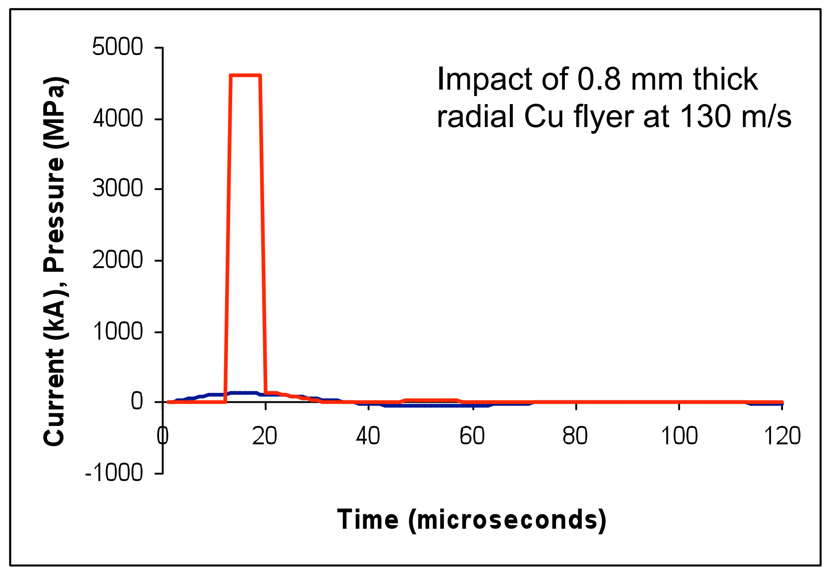


# Bulk Metallic Glass

- Disk Compression
  - 0.94” O.D. x 0.11” disk
- Two types of stress history
  - $Sin^2(t)$ load & impact load
- PDV – two channels, 10 cm focusing probes

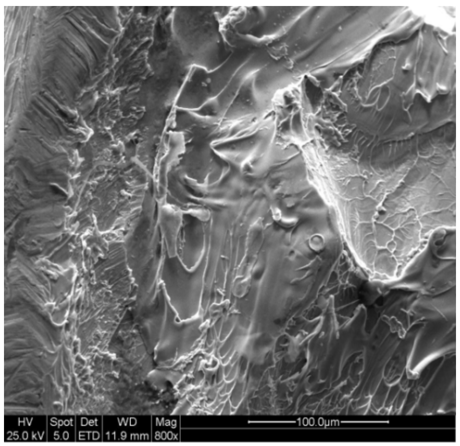


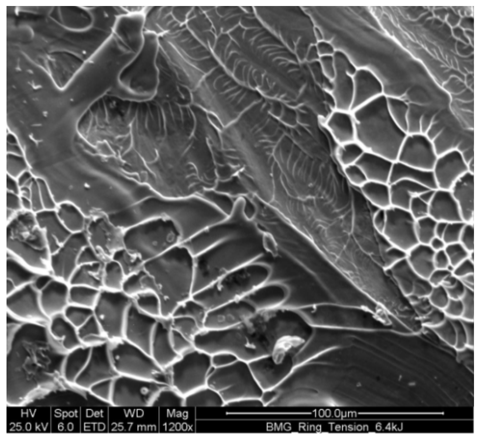



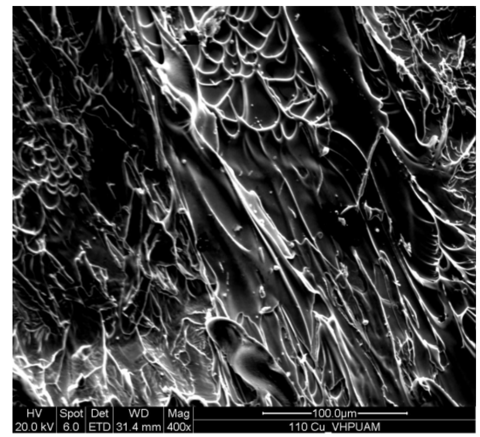
# Bulk Metallic Glass

Ring expansion

Disk compression

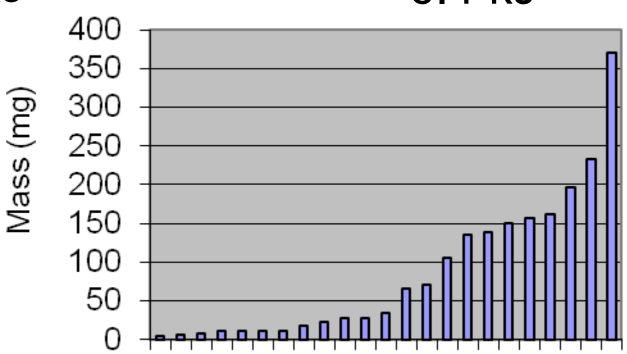


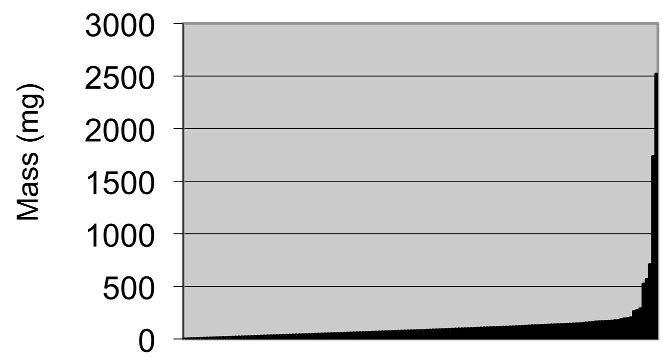




5.6 kJ

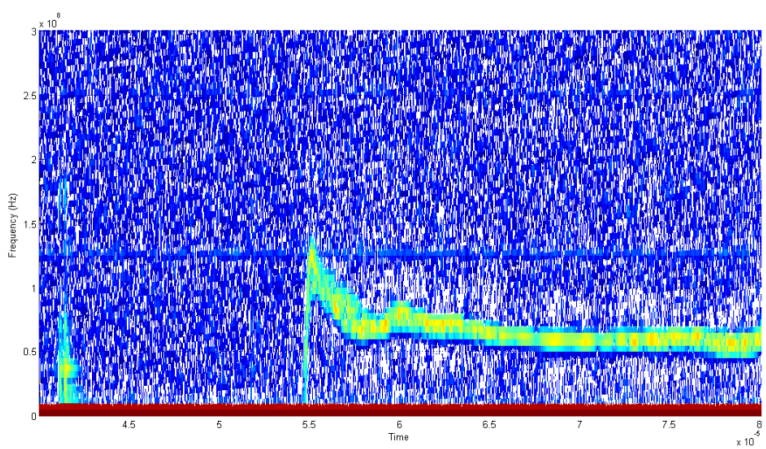
6.4 kJ

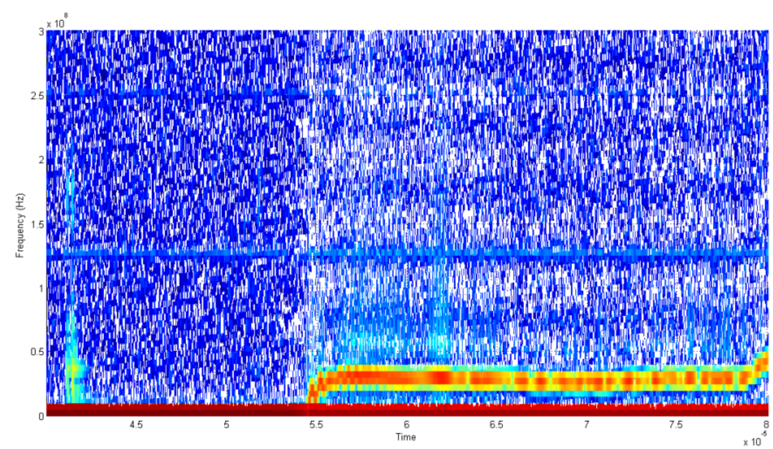


# Super Bainite

- Ring expansion
  - 2.00” I.D. x 2.05” O.D. x 0.05” rings (supplied by INL)
  - Exploding wire actuator (3.2 – 6.4 kJ)
  - PDV: two channels, 1 mm collimated & 30 cm focusing probes; Sharpie and/or 3M retro tape



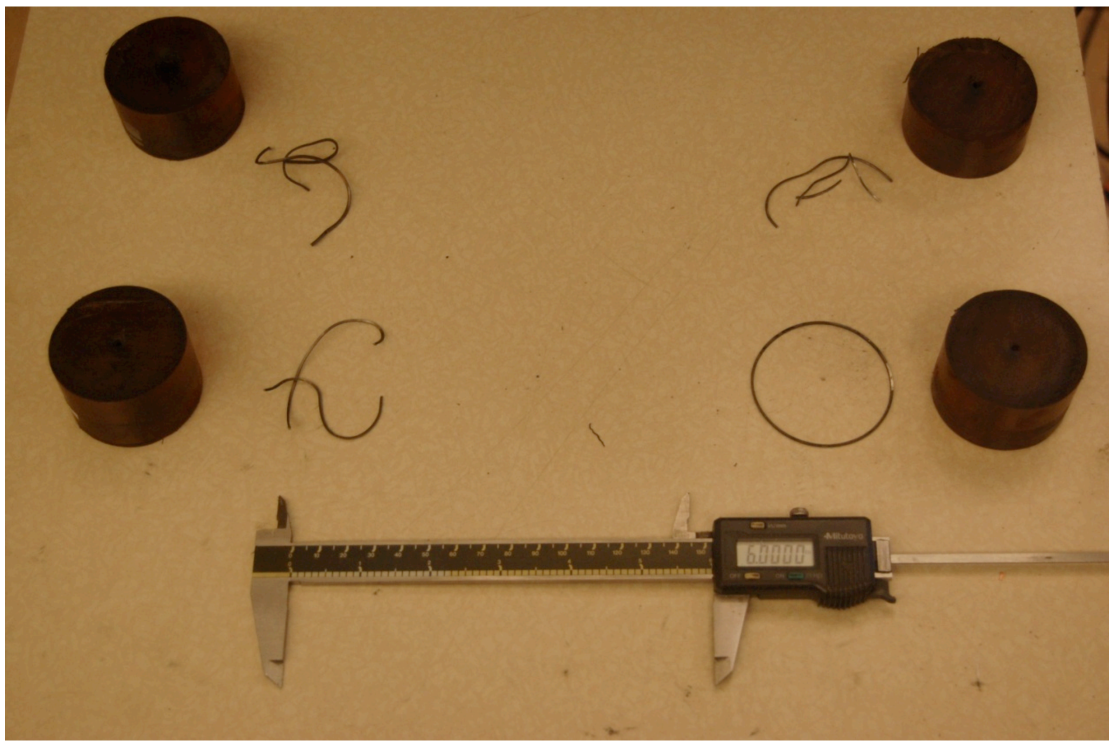




*Note: scales are identical

# Super Bainite

4.8 kJ
Strain: 3.1%
Strain rate: 4207 $s^{-1}$
Stress ~1006 MPa

4.8 kJ
Strain: 0.4%
Strain rate: 4356 $s^{-1}$
Stress ~1199 MPa

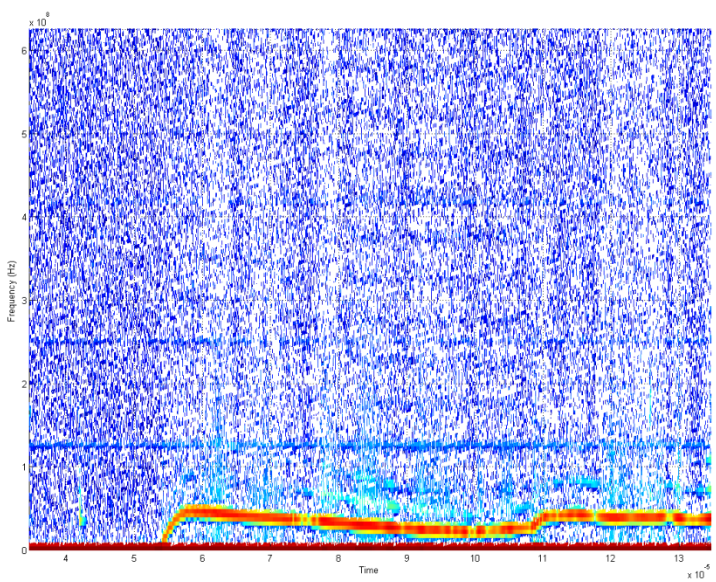


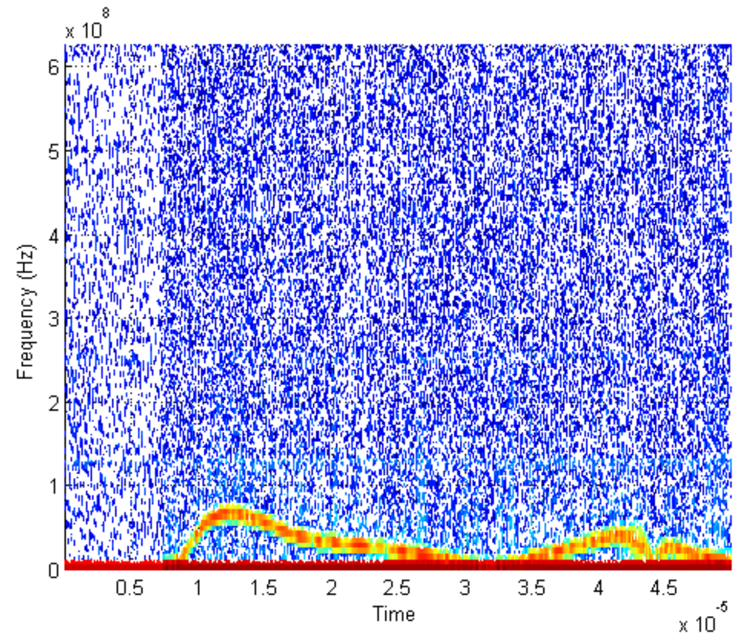
3.2 kJ
Strain: 2.4%
Strain rate: 2553 $s^{-1}$
Stress ~710 MPa

3.2 kJ
Strain: 2.8%
Strain rate: 3758 $s^{-1}$

# Dyneema

- Fiber ring expansion
  - Annealed OFHC copper drivers: 1.88” I.D. x 2.00” O.D. x 0.50” rings
  - Exploding wire actuator



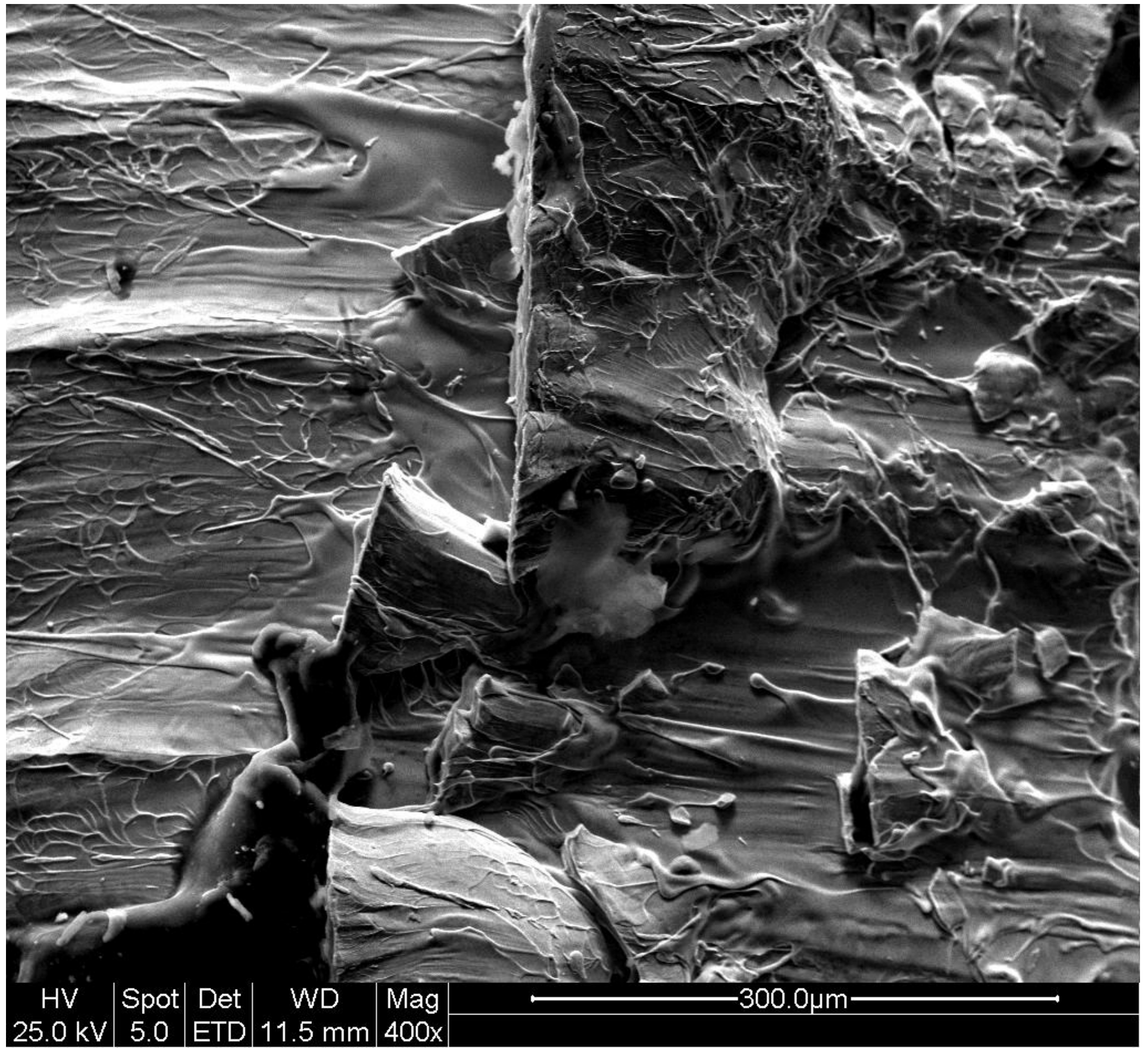



*Note: vertical scales are identical, horizontal scales are <u>not</u>

# Dyneema

- 0.4g fiber on 28.8g Cu ring – (0.97 g/cc and 8.94 g/cc, respectively)
  - This yields a fiber volume fraction of 11.3% and composite ring density of 8.04 g/cc
- Using an average deceleration of 2.77 (m/s)/μs the composite has a strength of 566 MPa
  - Annealed OFHC copper driver yields at 110 MPa
  - Dyneema yields at 4.3 GPa
  - Peak strain rate is 2127 $s^{-1}$

# ?




5.6 kJ Ring Expansion