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Sandia National Laboratories

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Development of Bench-Top Intermediate-Strain-Rate Test Capability for Soft Materials

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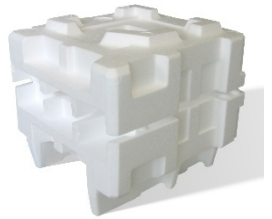
Intermediate-Strain-Rate Applications

- Crash, collision, impact, drop at “moderate” speed
- Very common in our daily life
- How to protect ourselves?
  - Effective and efficient shock/impact mitigation design – material selection and optimization for maximizing energy absorption
    - “Soft” materials
      - Soft polymers
      - Polymeric foams



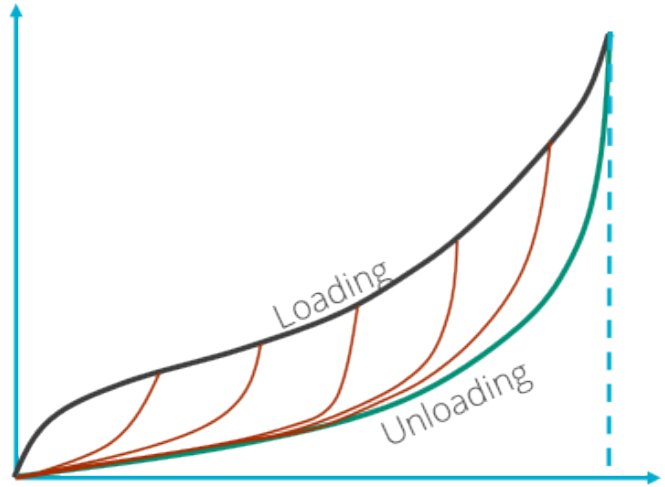
Mechanical characterization of soft materials at intermediate strain rates (10^0 – 10^2 s^{-1})

Intermediate-strain-rate test capabilities (apparatus and diagnostic techniques)

Preferred Intermediate-Strain-Rate Test Capability

An intermediate-strain-rate test apparatus is preferred to be capable of

- obtaining both loading and unloading stress-strain curves at intermediate strain rates
- covering the entire range of intermediate strain rates

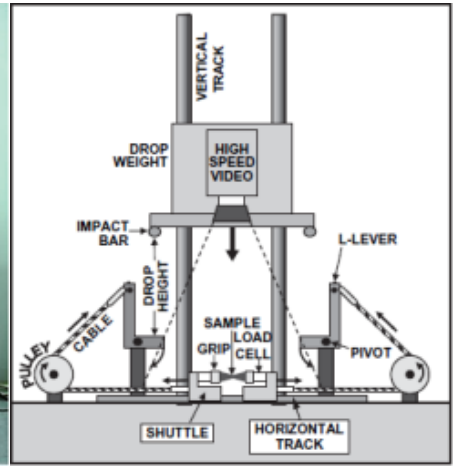


"Closed-loop" intermediate-strain-rate apparatus

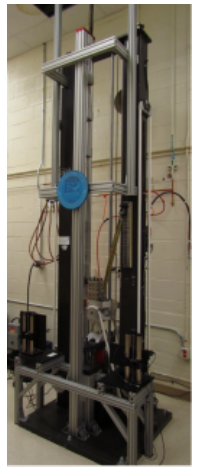
All these are "Open-loop"

Hydraulic Based

Liu et al. 2017

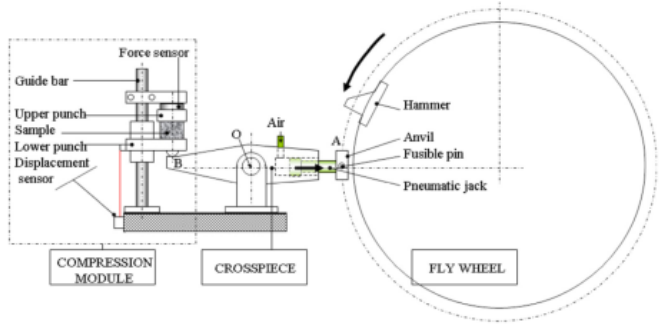


Roland et al. 2007



Song et al. 2019

Drop-tower Based



Viot et al. 2008

Fly Wheel

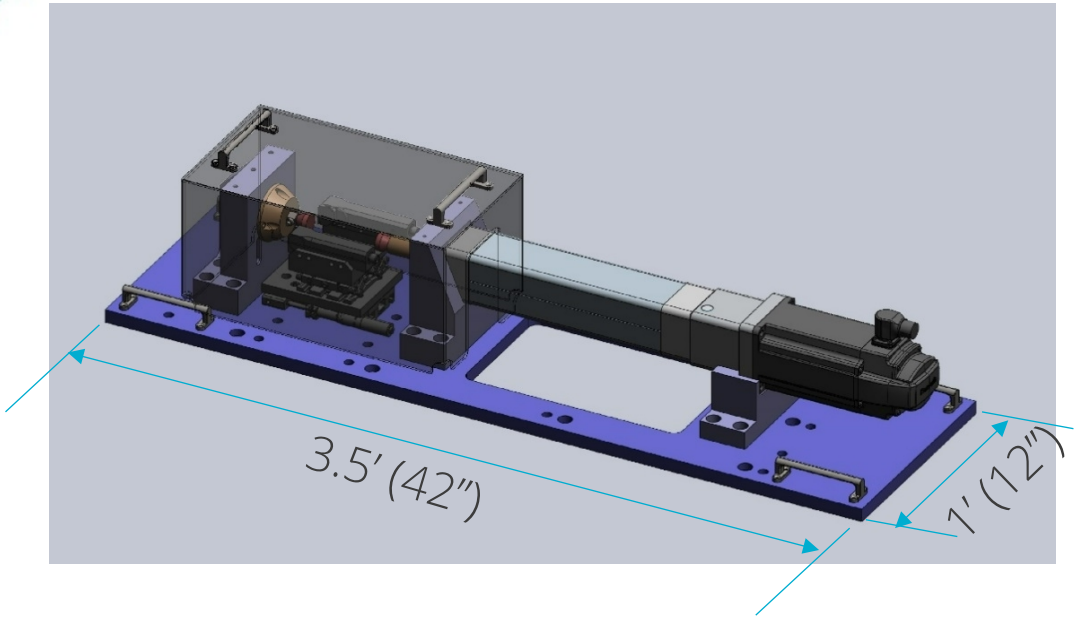
"Long" Kolsky Bar for Intermediate-Strain-Rate Tests

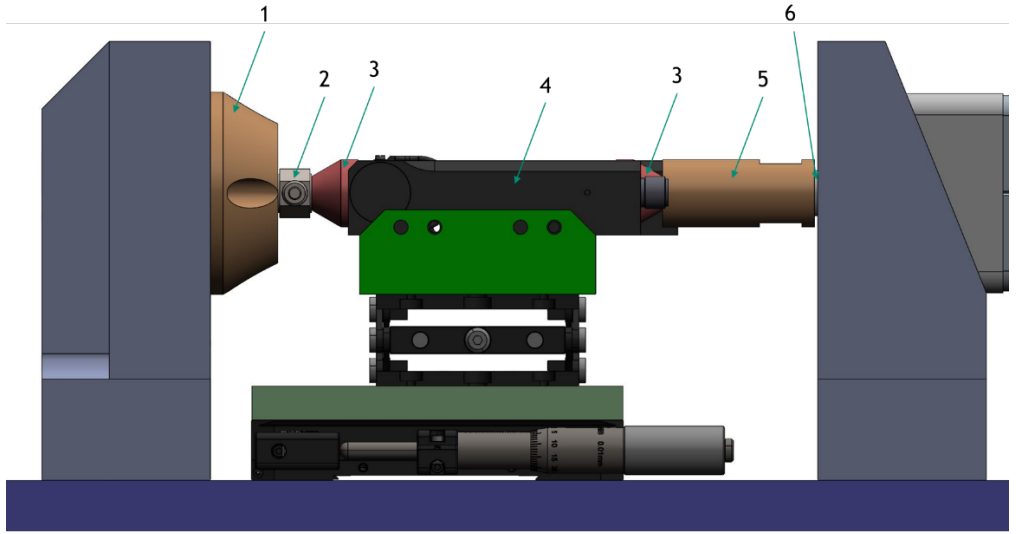
- *May still not be sufficient long for intermediate-strain-rate compression to large deformation, particularly for soft materials (>50% strain)*
  - *Example: 10-ms duration of loading needed for 50% strain at 50 s*[1]
- *Loading stress-strain curve only, particularly for soft materials*
  - *The force during the recovery of soft specimens may not be sufficient to compensate bar friction to push back*

Currently existing intermediate-strain-rate test apparatus are not capable of obtaining stress-strain loop (both loading and unloading) beyond low strain rates.

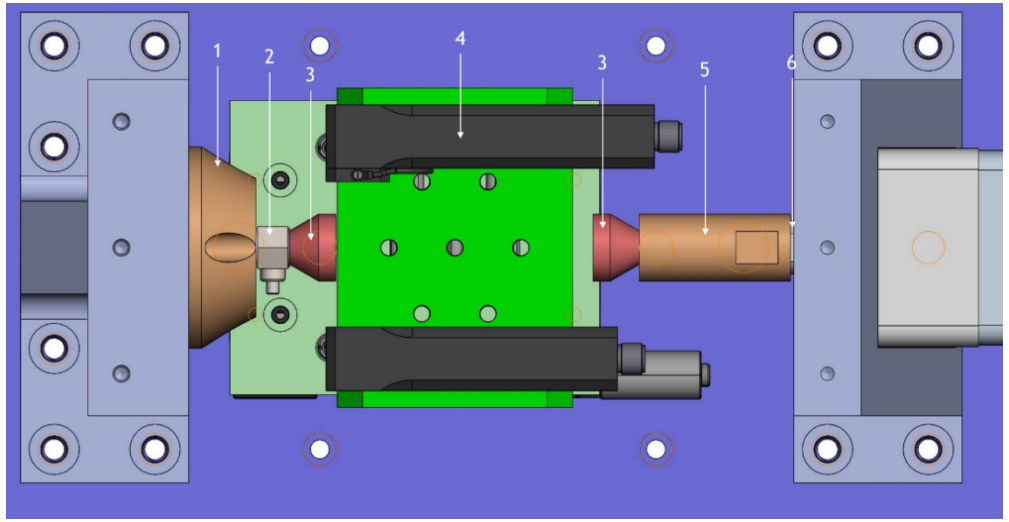
New development of bench-top intermediate-strain-rate test capability at Sandia National Laboratories

Bench-top Intermediate-Strain-Rate Test Apparatus





1. Back plate
2. Load cell
3. Adapting platens
4. Laser measurement system
5. Adapting rod
6. actuator



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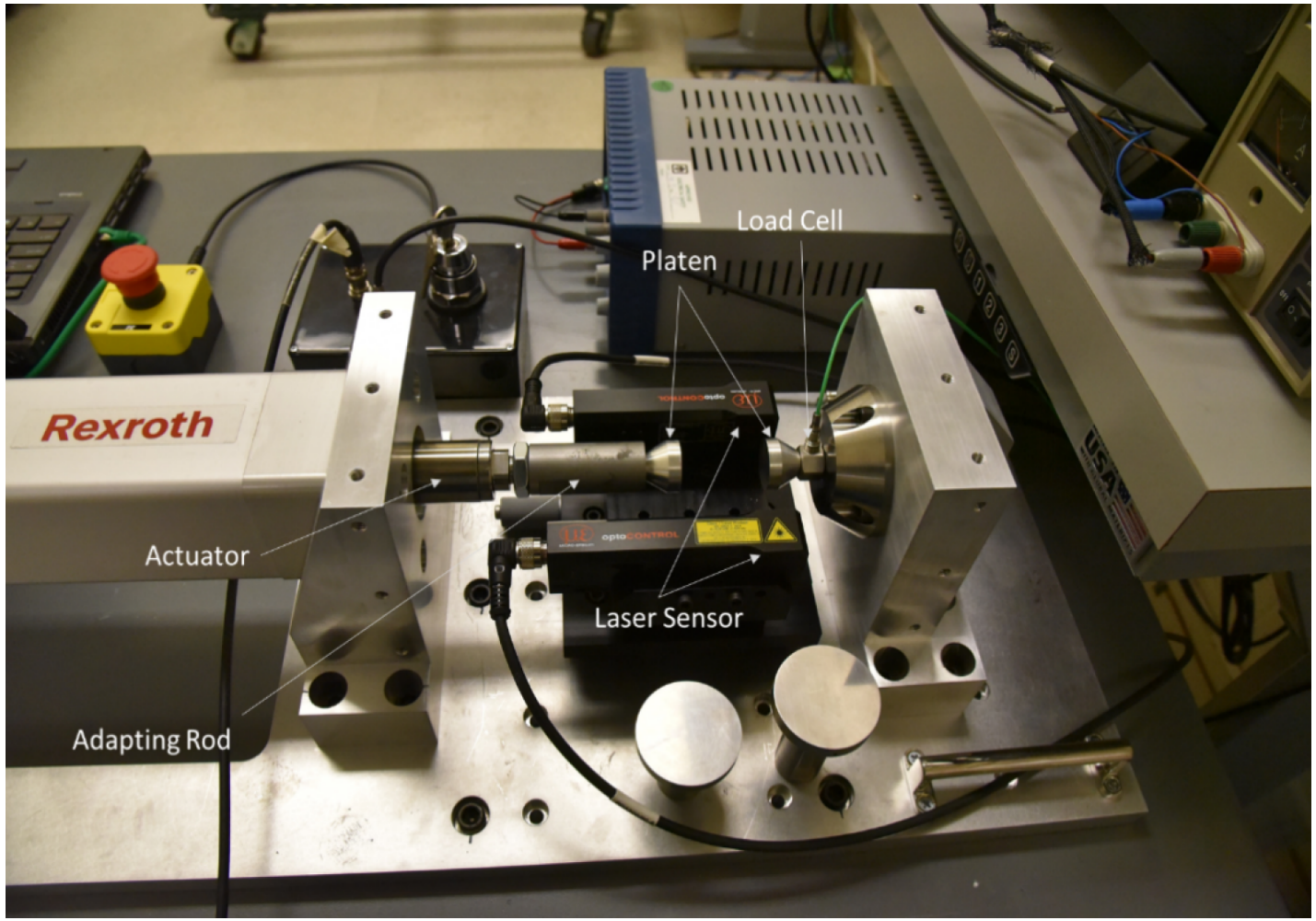


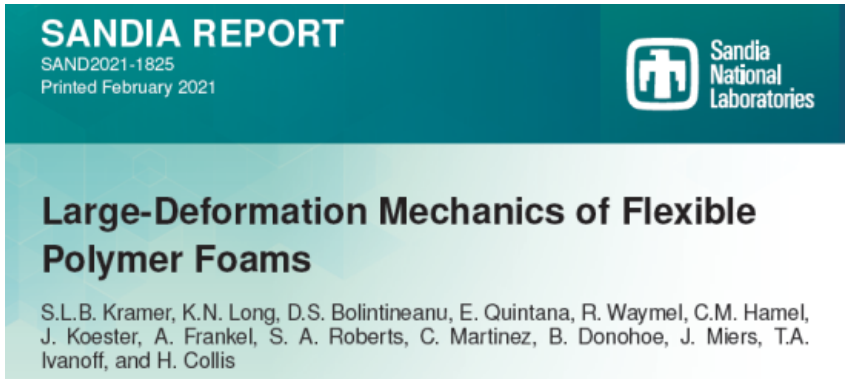
Rexroth® high speed electromechanical actuator

- Maximum impact velocity: ~1.9 m/s
- Maximum travel distance: 6″ (~150 mm)
- Maximum acceleration: ~400 m/s^2
- Load capacity: 3000 lbs (~13300 N)

For a 10 mm (diameter) by 5 mm (thickness) specimen,

- Maximum stress: ~170 MPa
- Maximum strain rate: ~380 s^{-1}

Experimental Verification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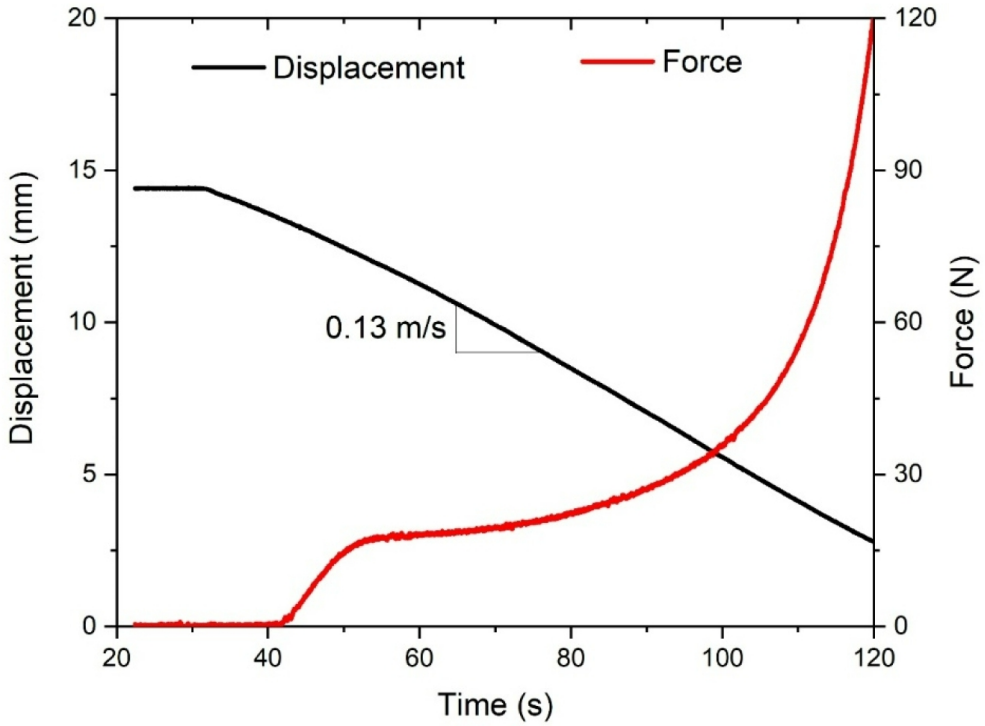
Sandia National Laboratories

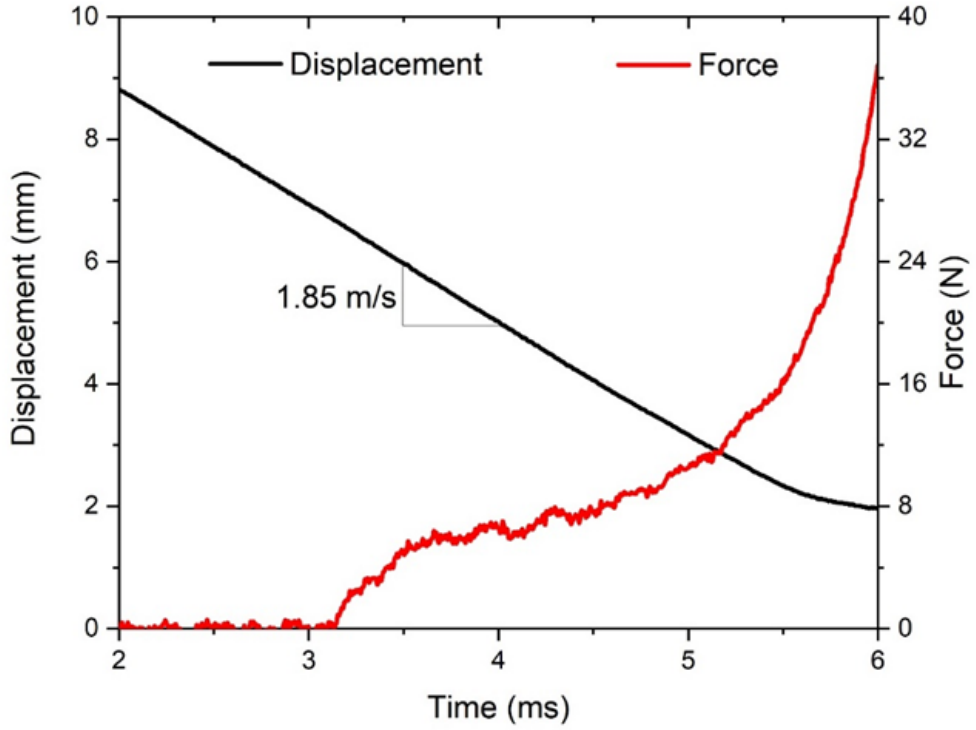
Large-Deformation Mechanics of Flexible Polymer Foams

S.L.B. Kramer, K.N. Long, D.S. Bolintineanu, E. Quintana, R. Waymel, C.M. Hamel, J. Koester, A. Frankel, S. A. Roberts, C. Martinez, B. Donohoe, J. Miers, T.A. Ivanoff, and H. Collis

10 PCF (160 kg/m^3) TF-6070 flexible polyurethane foam by General Plastics (Tacoma, WA)

- 0.01 s^{-1} (MTS)
- 260 s^{-1} (Kolsky compression bar)





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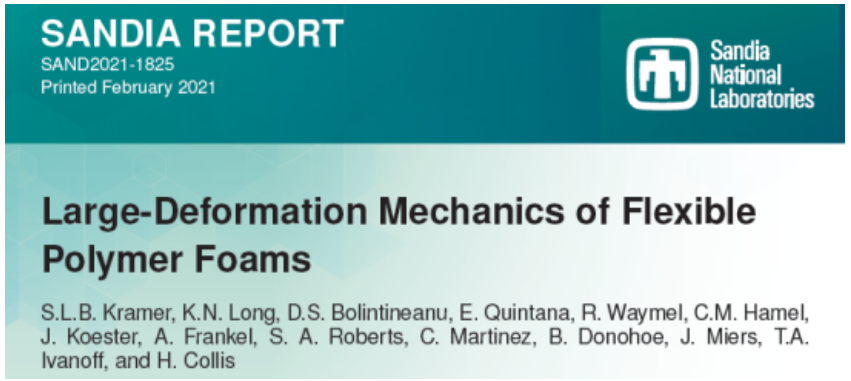
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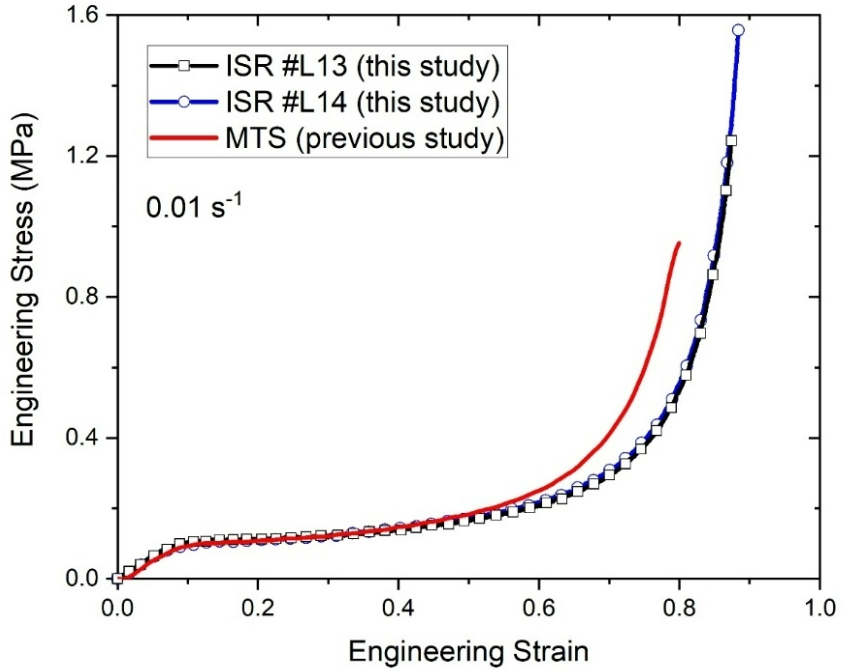
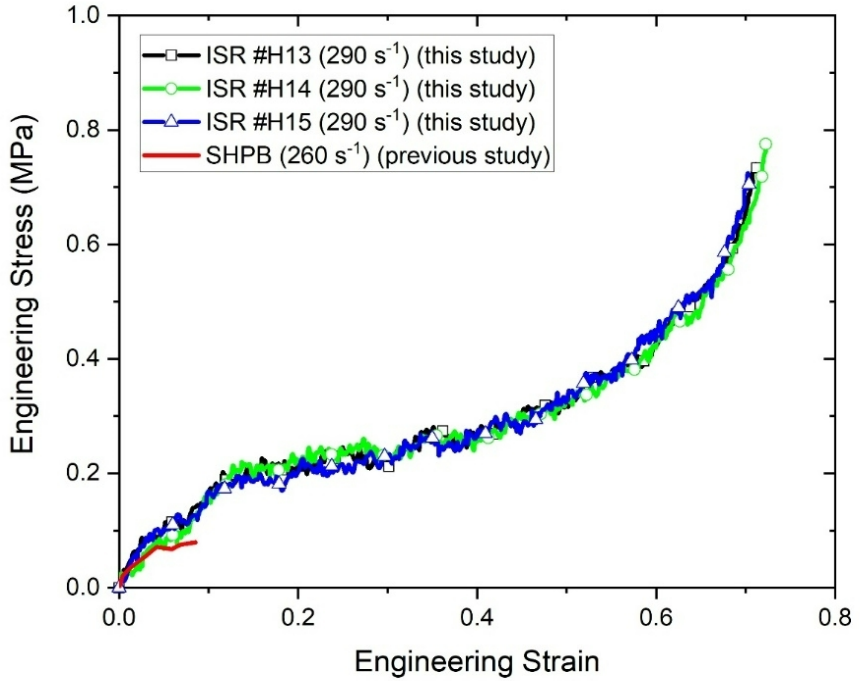


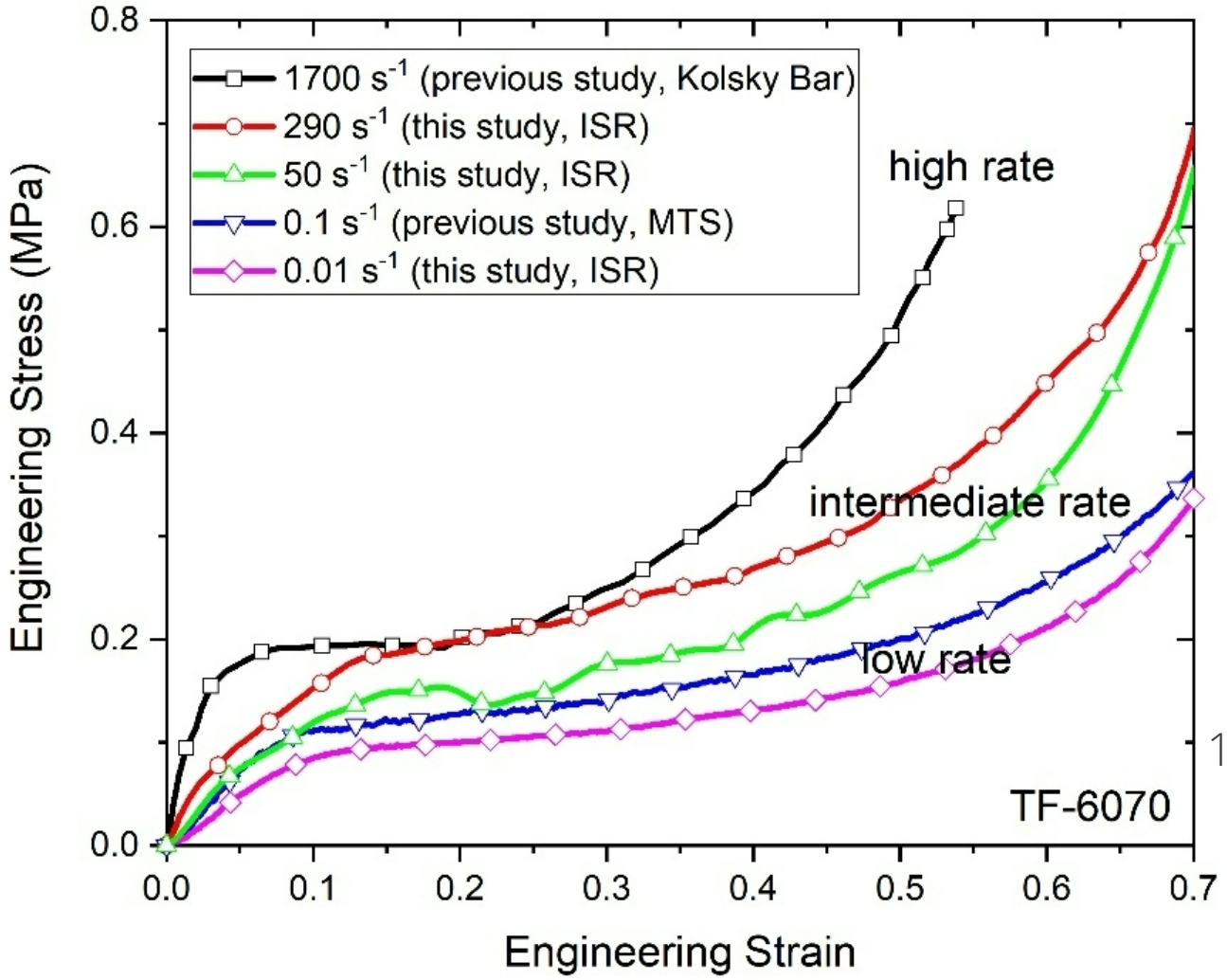


Due to the limit of duration of loading, the Kolsky bar was not abled to compress the specimen to large deformation at intermediate strain rates.

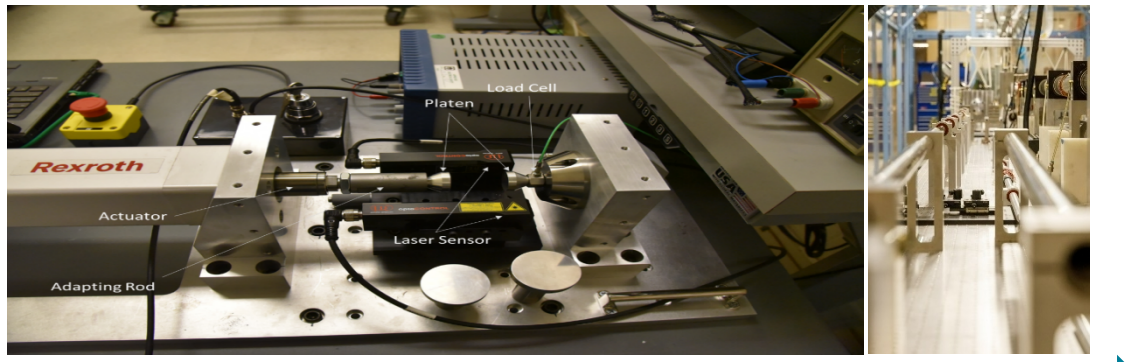
Example Applications

Compressive stress-strain characterization from low, intermediate, to high strain rates (without gap) for investigating

- Strain-rate effect on compressive stress-strain response



The intermediate-strain-rate (ISR) apparatus is capable of stress-strain characterization covering entire low and intermediate strain rates.



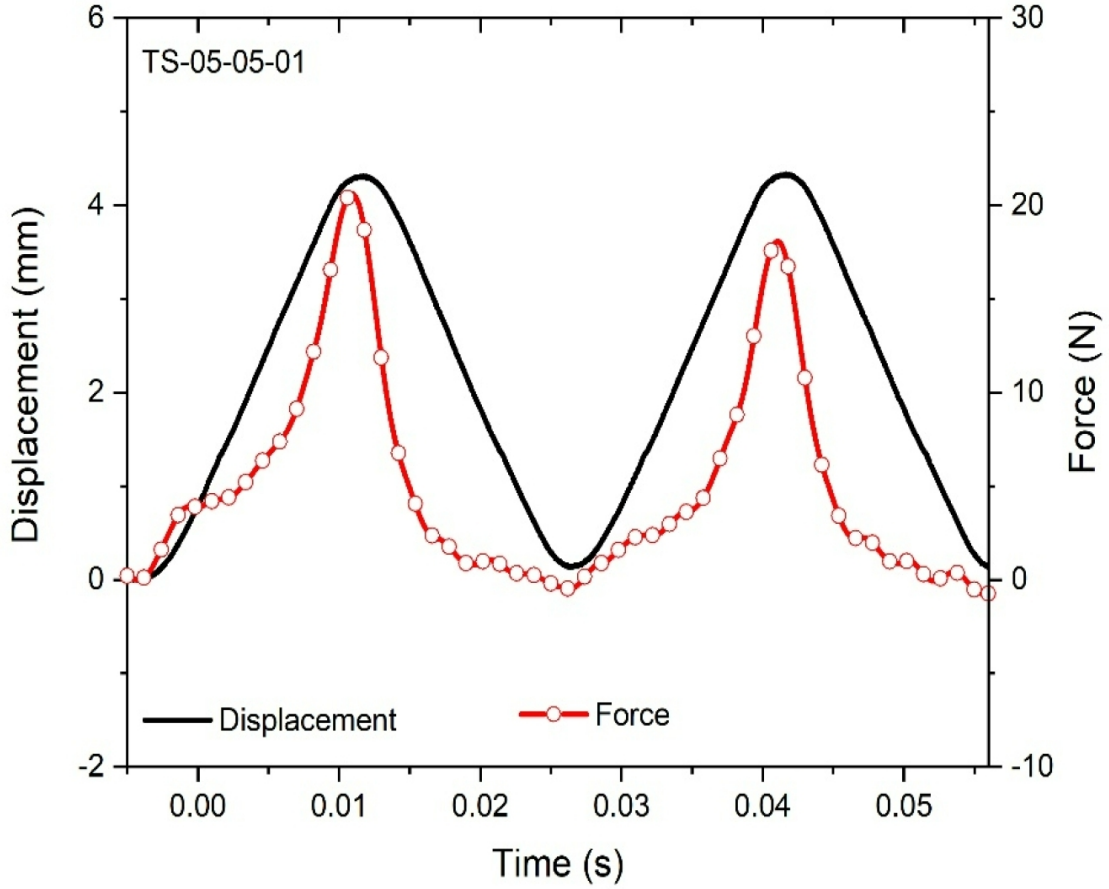
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4}

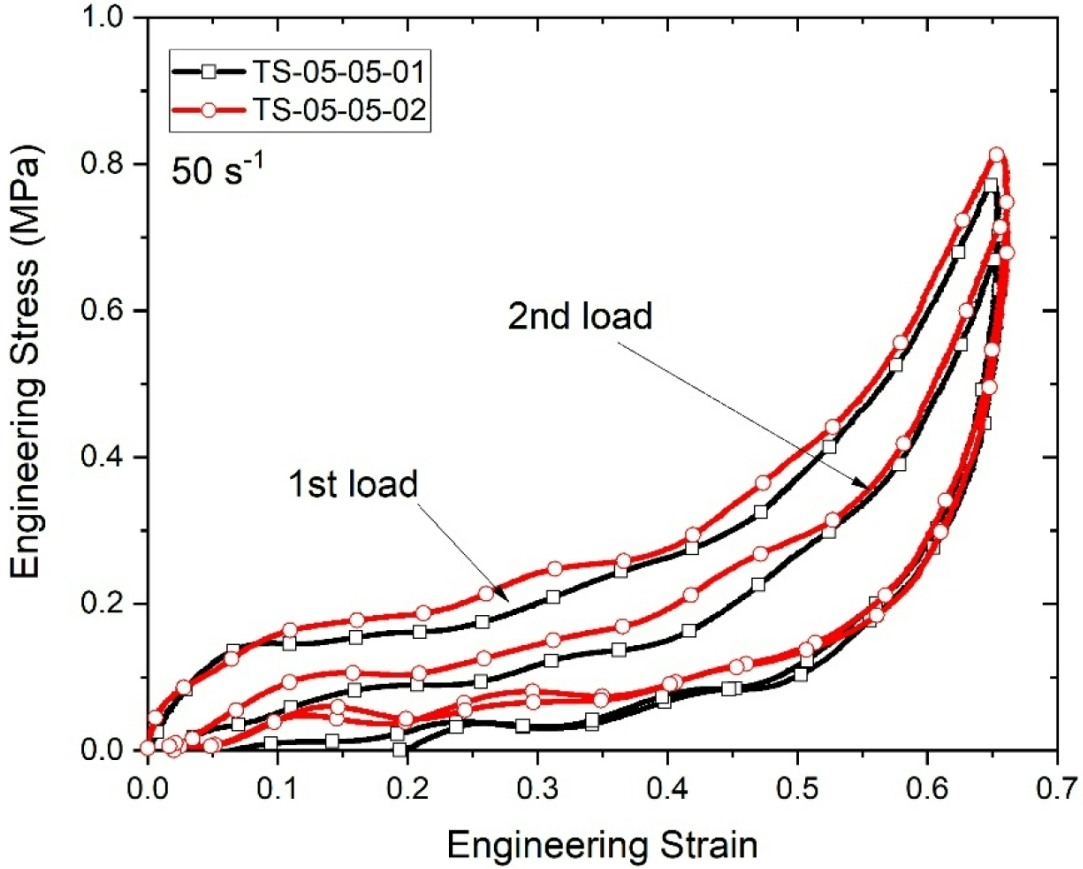
Strain rate (s^{-1})

Example Applications

Single or cyclic loading and unloading stress-strain response from low to intermediate strain rates for investigating

- strain-rate effect on energy dissipation
- loading cycle/history effect on energy dissipation
- Mullins effect



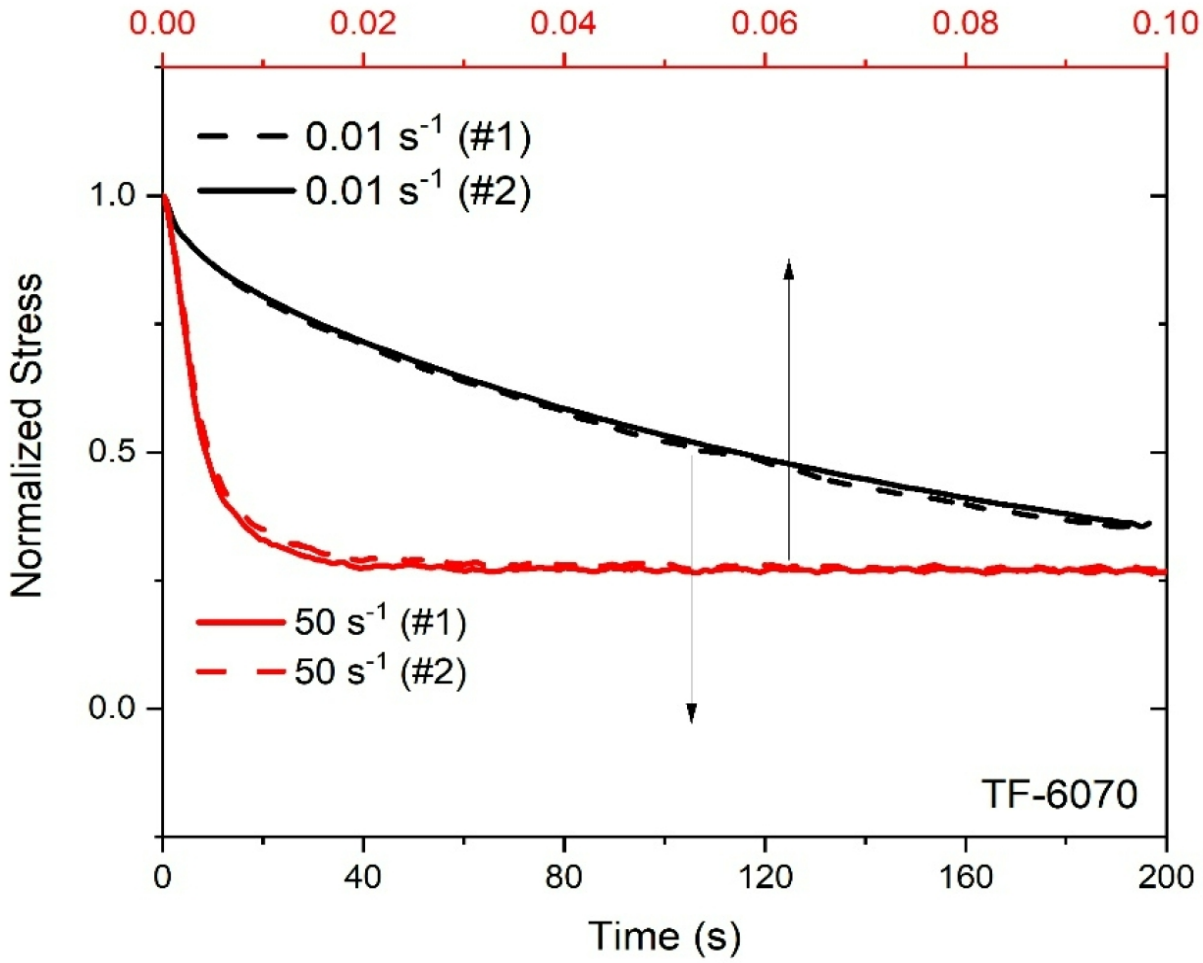


Example Applications

Stress relaxation response from low to intermediate strain rates for investigating

- strain-rate effect on stress relaxation time

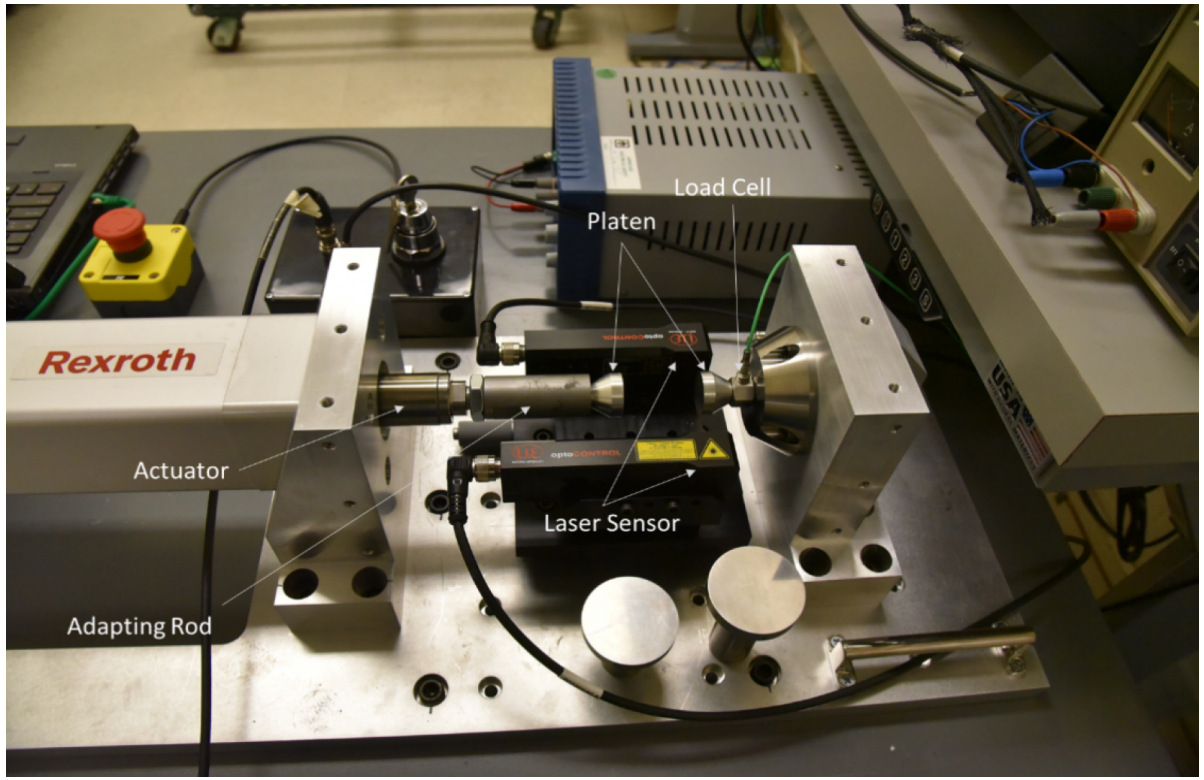
LOAD-HOLD



The material relaxed much faster at higher strain rates than lower strain rates.

Summary

- An intermediate-strain-rate (ISR) apparatus has been developed at Sandia National Laboratories for mechanical property characterization of soft materials from low to intermediate strain rates (up to 500 s^{-1})
  - "Closed-Loop" operation
    - Single load
    - Load-Unload
    - Load-Hold
    - Load-Hold-Unload
    - Cyclic load
    - etc
  - Characterization
    - Stress-strain
    - Energy dissipation
    - Stress relaxation
    - etc



- The ISR apparatus will be extended for tensile tests and other applications