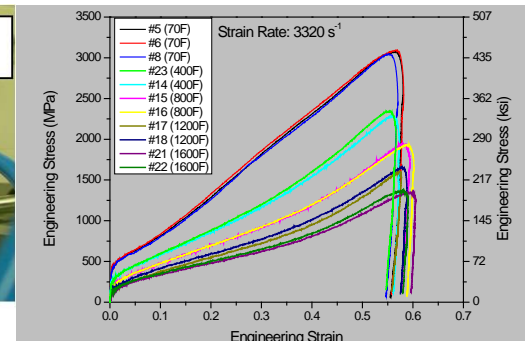
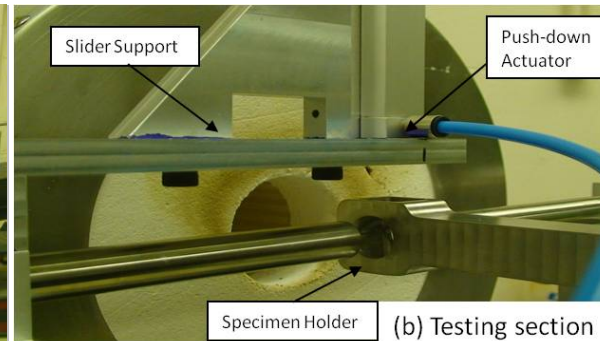
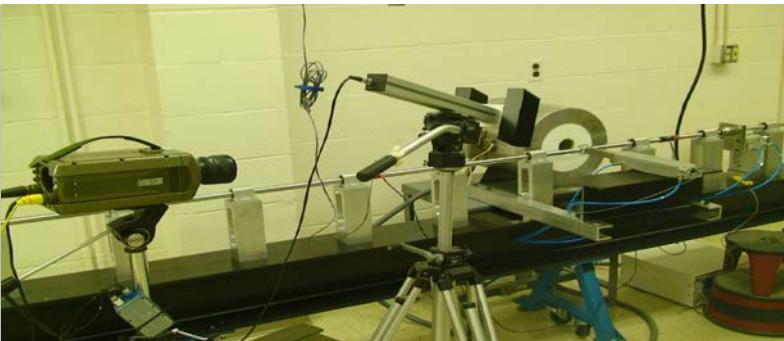


*Exceptional service in the national interest*



*SAND2015-XXXX*



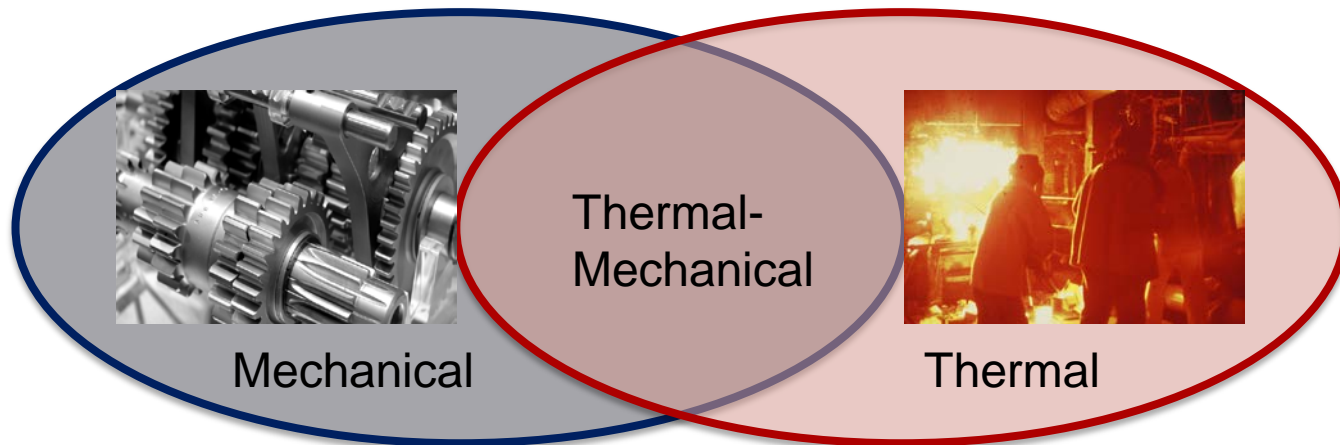
# Dynamic High-Temperature Characterization of 304L Stainless Steel for Recrystallization Investigation

**Bo Song**

*Experimental Environment Simulation Department*

# Experimental Environment Simulation

- We design, develop, and execute experiments to simulate the environments to which the test articles are actually subjected in applications



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*Normal Environments*

*Abnormal Environments*

# Abnormal Thermal-Mechanical Environments



**Forging** is a [manufacturing process](#) involving the shaping of [metal](#) using localized [compressive](#) forces.

Mechanical

Forging is often classified according to the temperature at which it is performed: cold forging (a type of [cold working](#)), warm forging, or hot forging (a type of [hot working](#)).

Thermal-Mechanical

Drop forging is a forging process where a hammer is raised and then "dropped" onto the workpiece to deform it according to the shape of the die.



Abnormal Thermal-Mechanical Environment

# Structure-Property Relationship

## ■ Forging Process

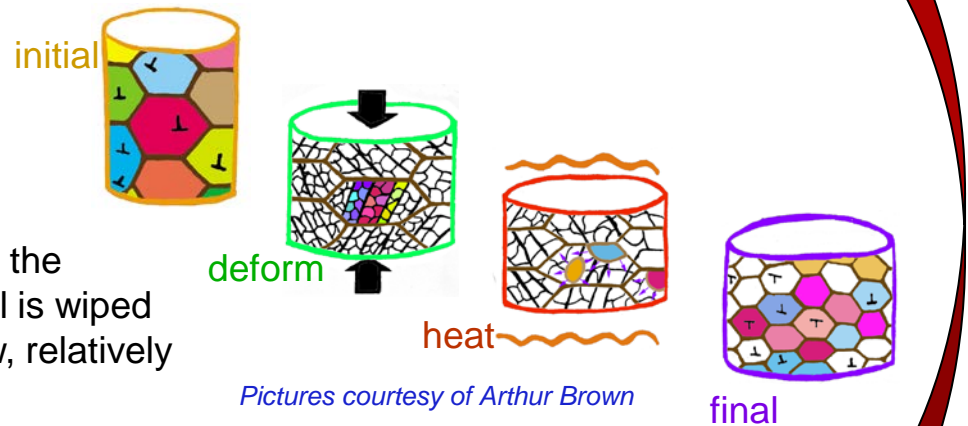
- High temperature
- Impact (intermediate/high rate)
- Large Deformation
- Quench



## ■ Microstructural Change

### ■ Recrystallization

- *Recrystallization* is the process by which the dislocation structure in a worked material is wiped away by growth of nuclei that form a new, relatively dislocation-free set of grains

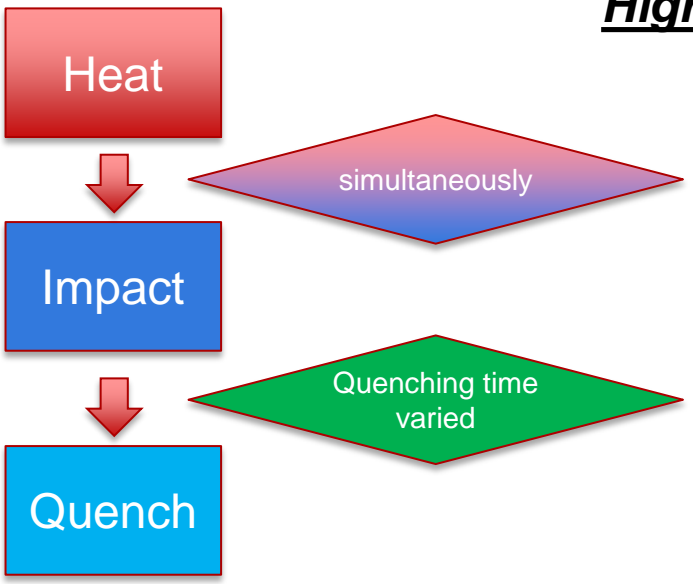


## ■ Material Property Change

- Reduction in material strength and hardness
- Increase in ductility

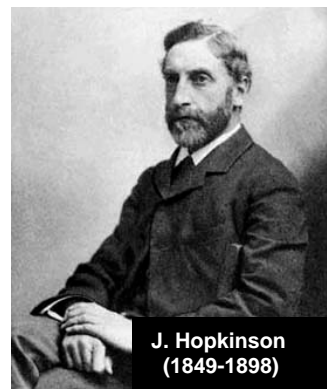
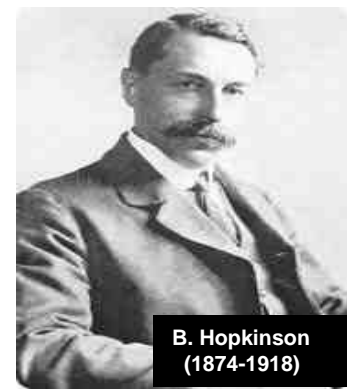
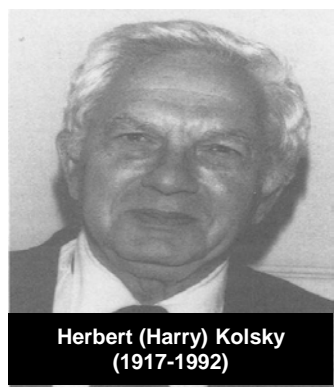
# Experimental Design for Simulating Forging Process

## High temperature impact test with quenching control!

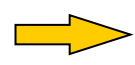


High temperature Kolsky compression bar tests

Split Hopkinson pressure bar (SHPB)



$$\dot{\epsilon} = \frac{u_1 - u_2}{l_0} = \frac{C_b}{l_0} (\epsilon_i - \epsilon_r - \epsilon_t)$$



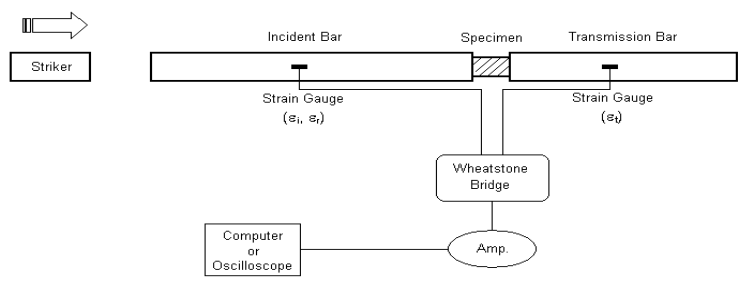
$$\epsilon = \int_0^t \dot{\epsilon}(\tau) d\tau$$



$$\sigma = \frac{F_1 + F_2}{2A_0} = \frac{E_b A_b}{2A_0} (\epsilon_i + \epsilon_r + \epsilon_t)$$

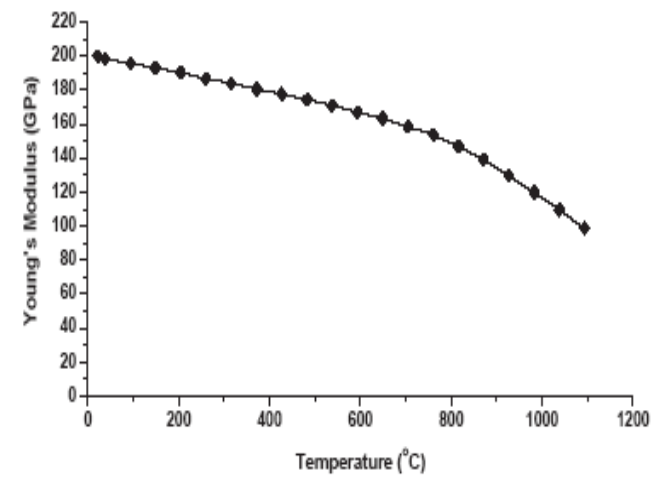
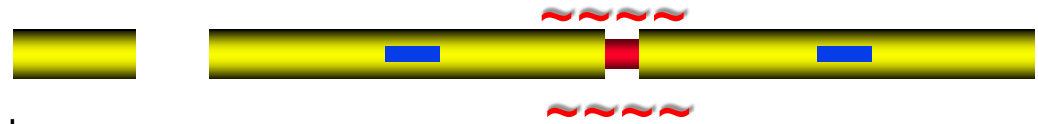


$$\sigma \sim \epsilon$$

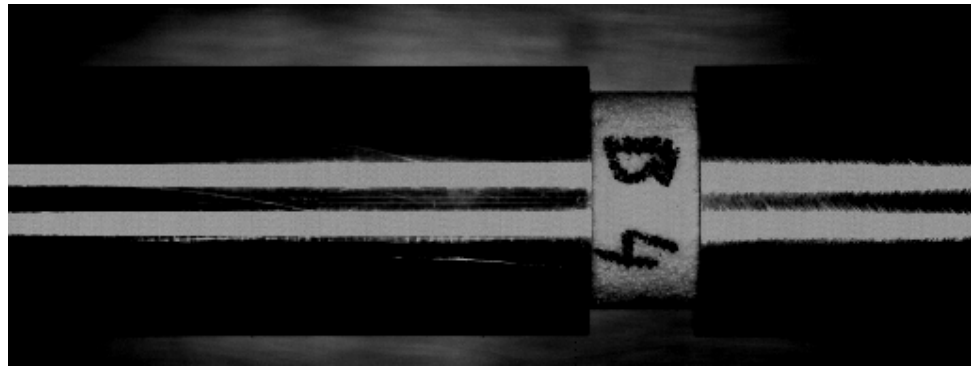


# High-Temperature Kolsky Compression Bar

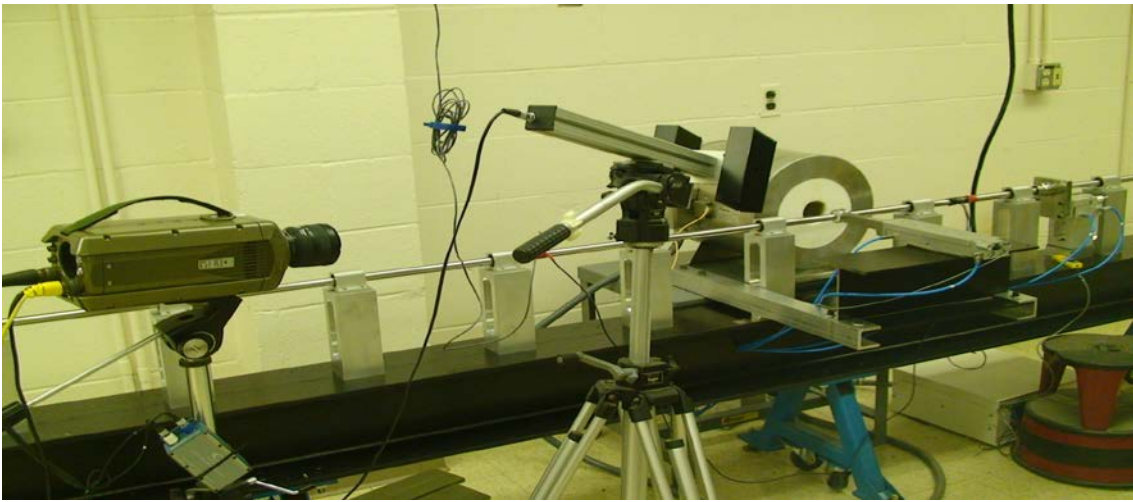
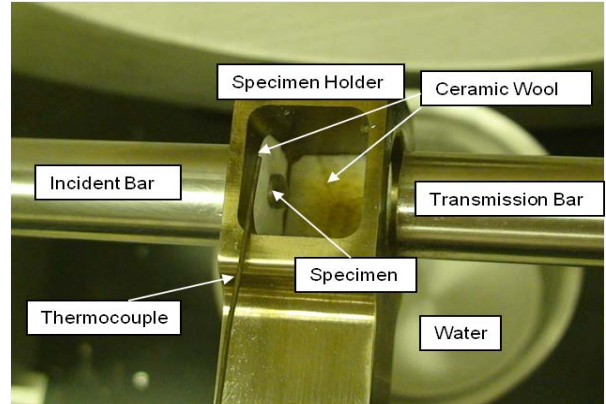
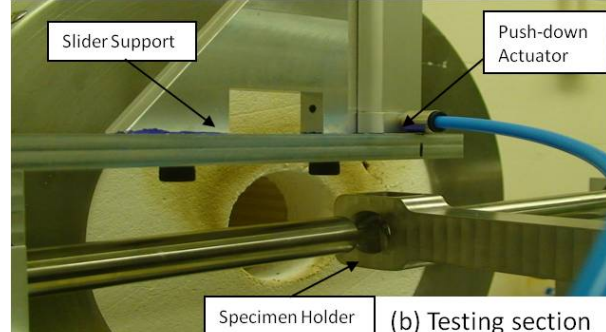
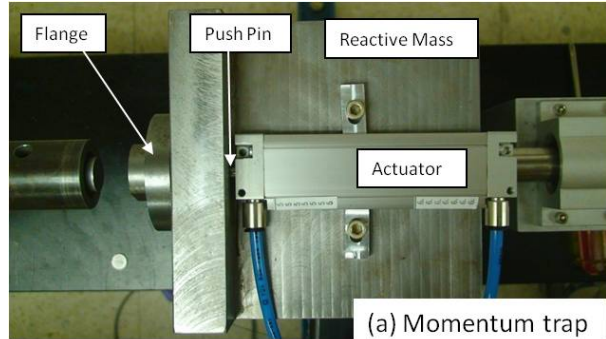
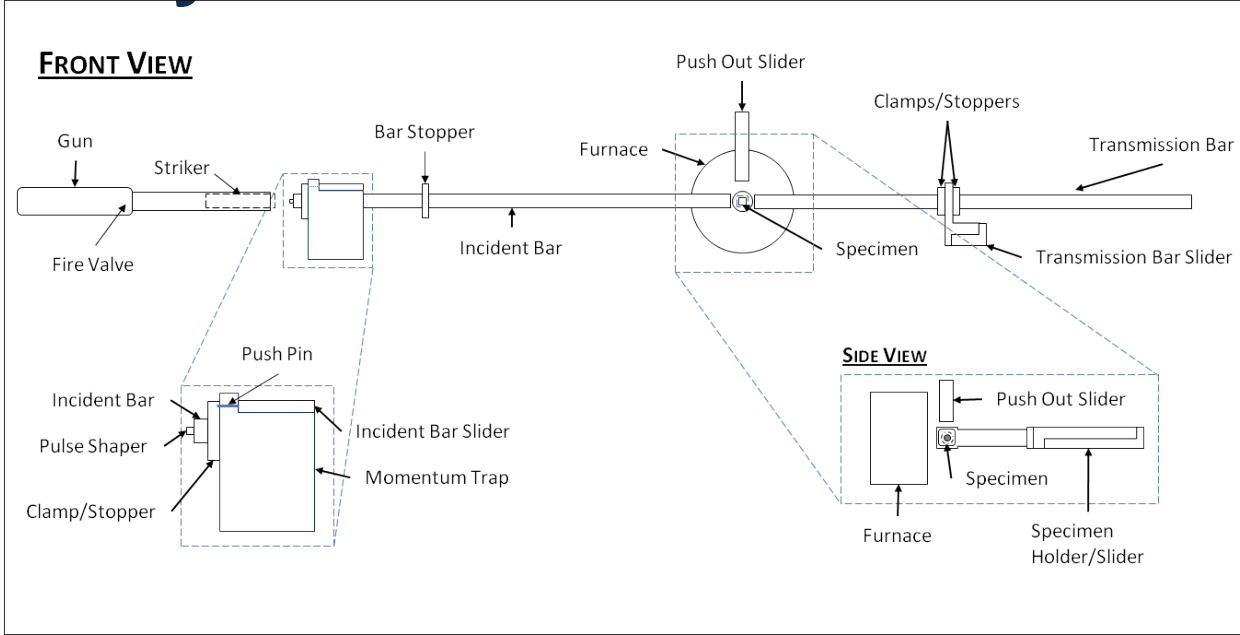
- High-temperature mechanical test
  - Hot Specimen/Cold Bars
    - Heat transfer
      - Specimen temperature drops
      - Bar temperature increases – thermal gradient in the bars
    - Cold Contact Time (CCT)
      - is the time during which the “hot” specimen stays in contact with the “cold” pressure bars until being dynamically loaded
      - should be as short as possible (~ milliseconds)



- Quenching
  - Ensure a single loading on the specimen
  - Maintain the same constant temperature of the specimen before quenched
  - Control the time duration (seconds to minutes) between dynamic testing and quenching

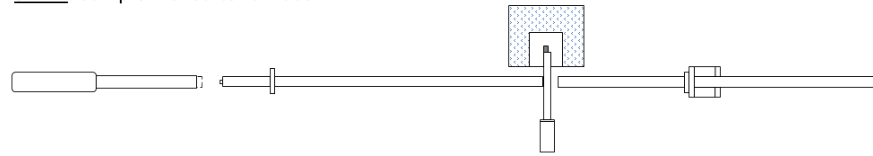


# High-Temperature Kolsky Bar for Recrystallization

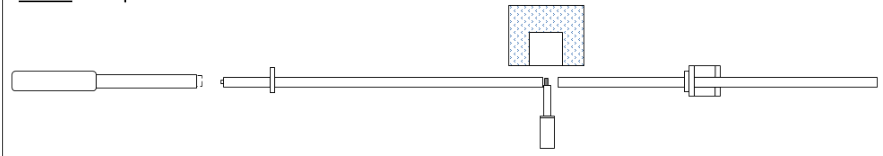


# Operation Procedure

**STEP 1:** Sample moved to furnace



**STEP 2:** Sample removed from furnace



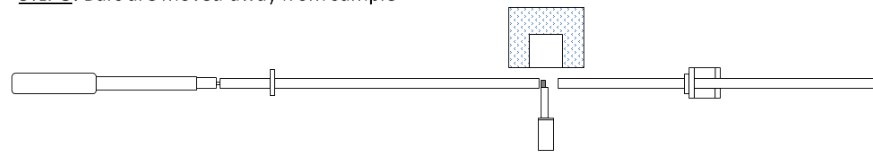
**STEP 3:** Sample is engaged



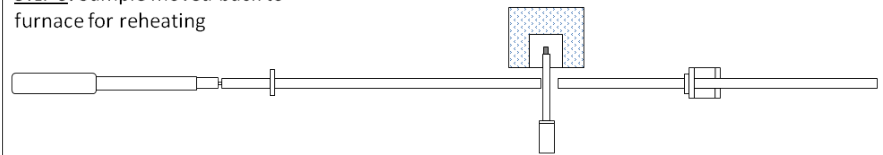
**STEP 4:** Striker is fired



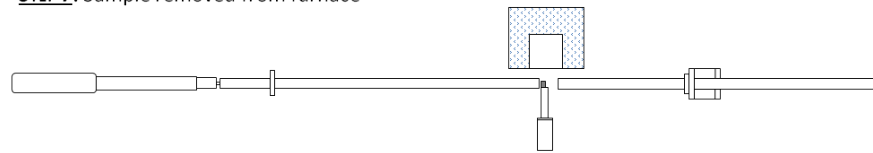
**STEP 5:** Bars are moved away from sample



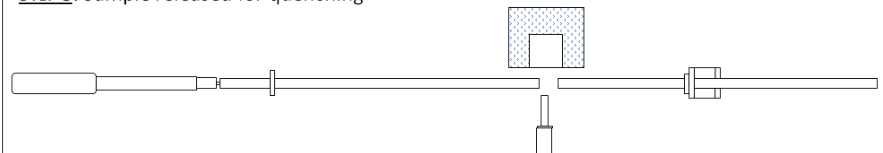
**STEP 6:** Sample moved back to furnace for reheating



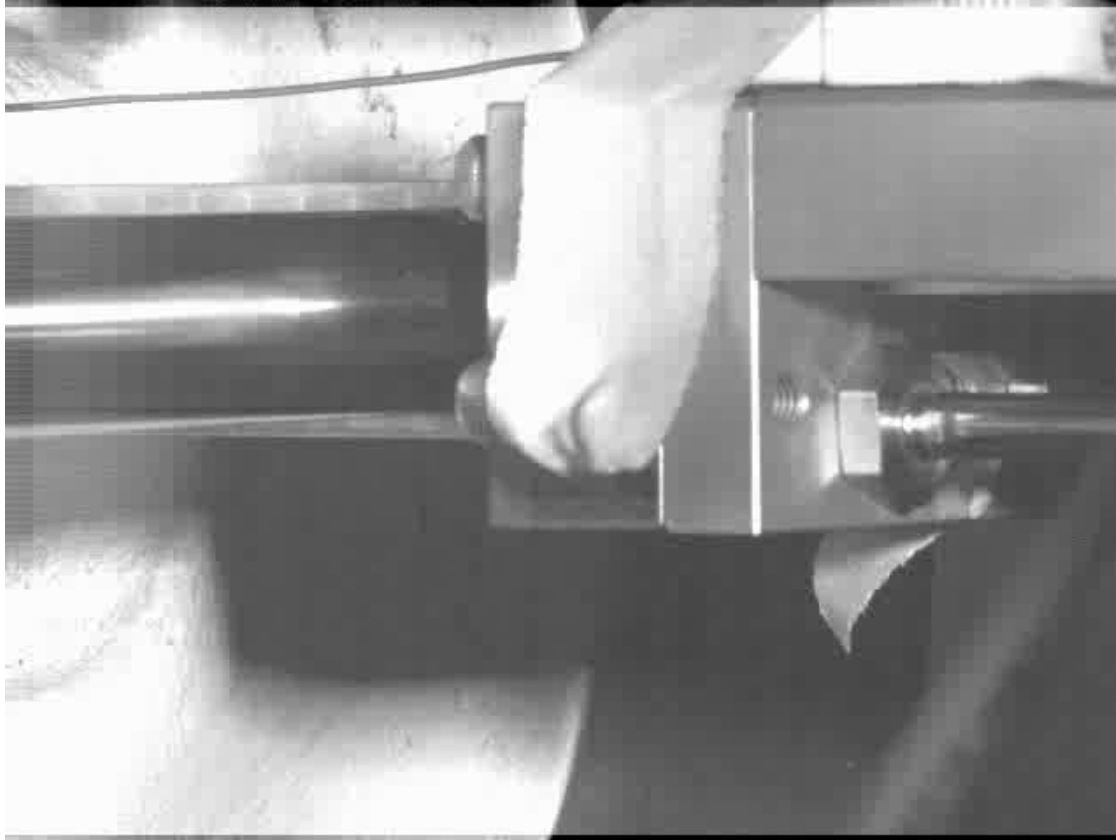
**STEP 7:** Sample removed from furnace



**STEP 8:** Sample released for quenching

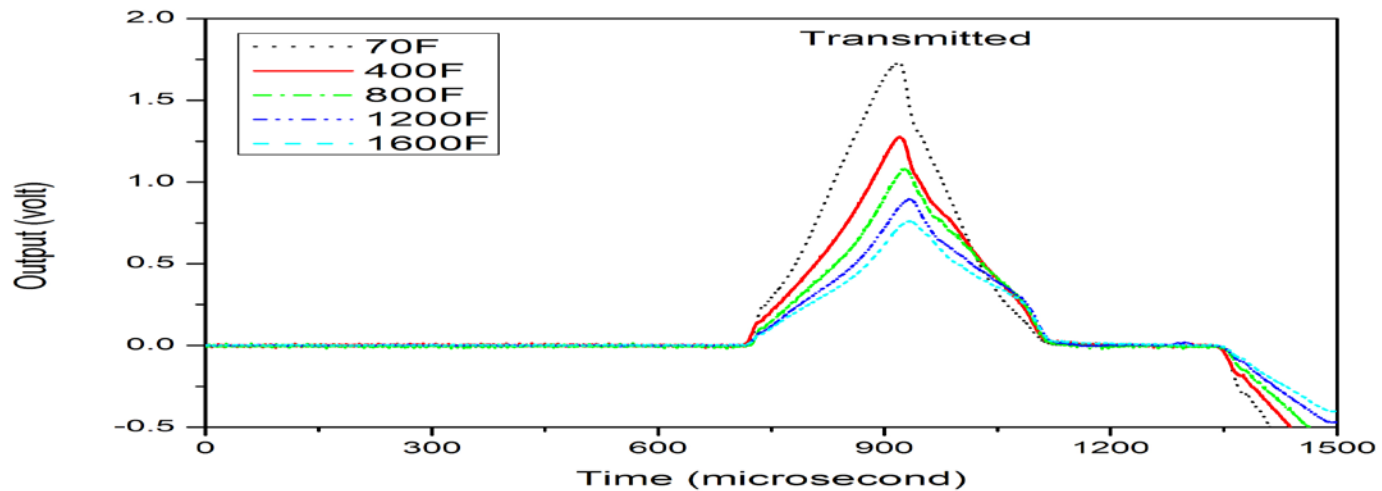
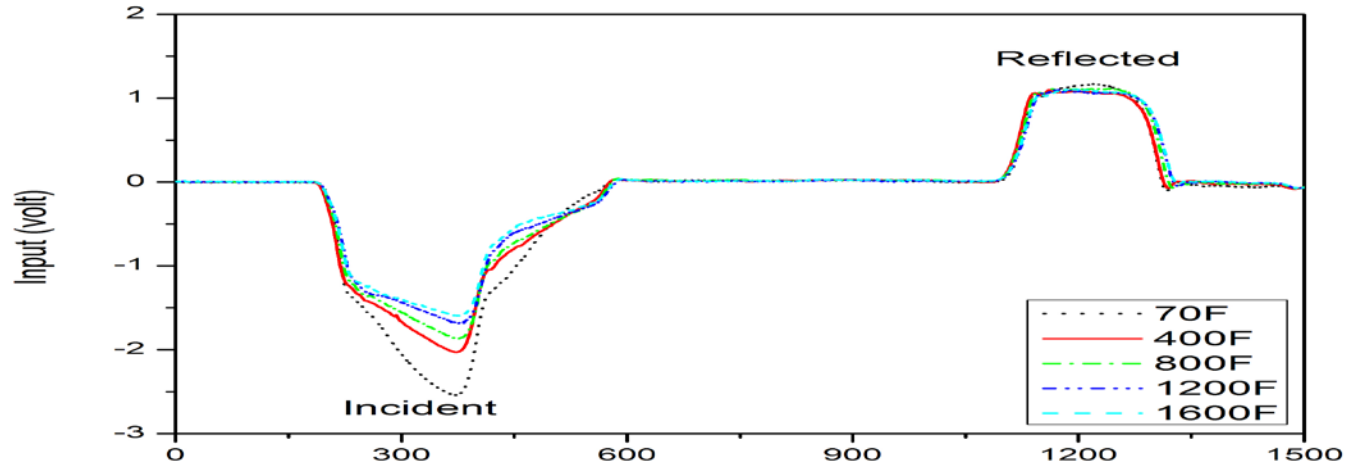


# Experimental Procedure

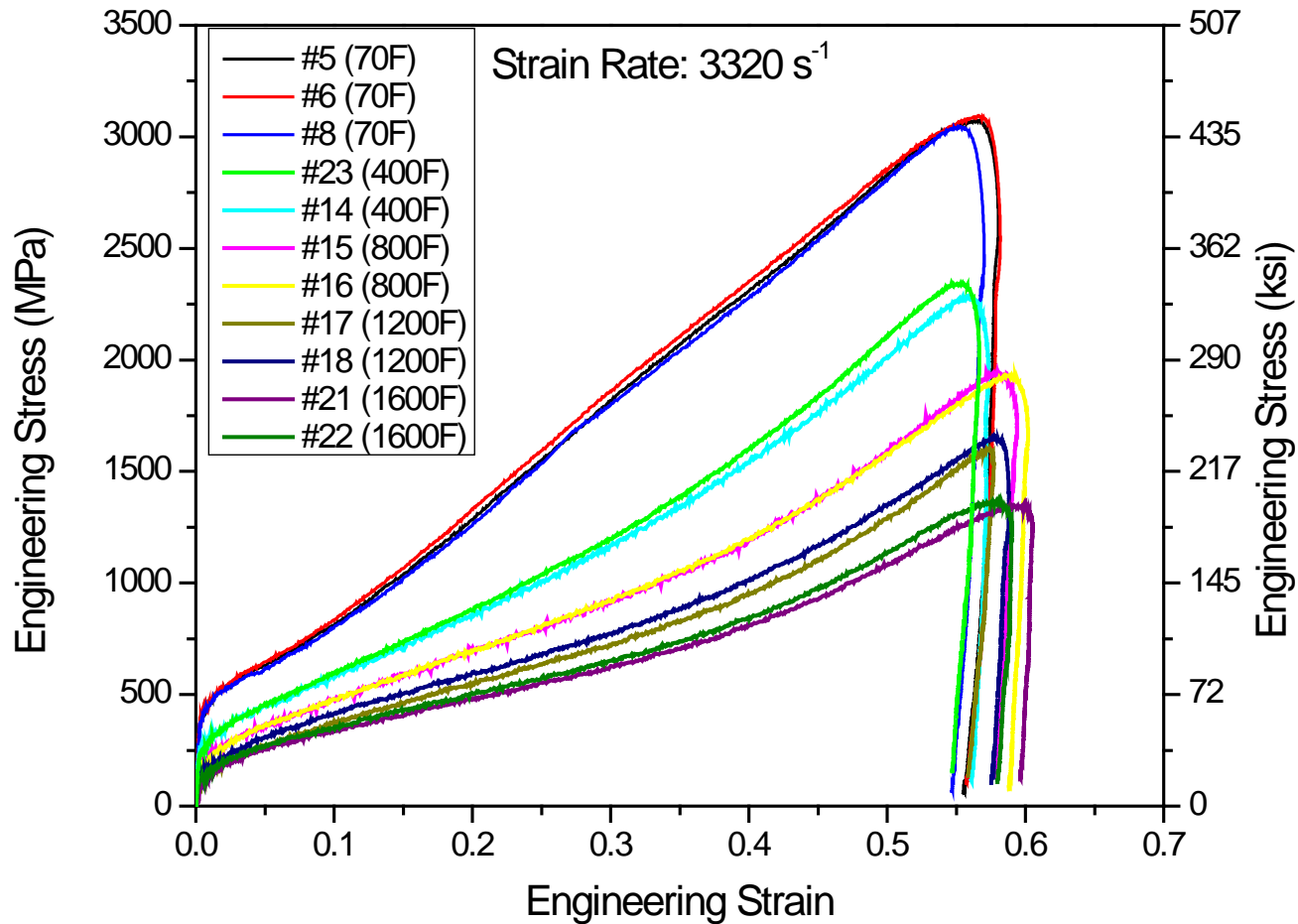


The video has been edited to shorten playing time.

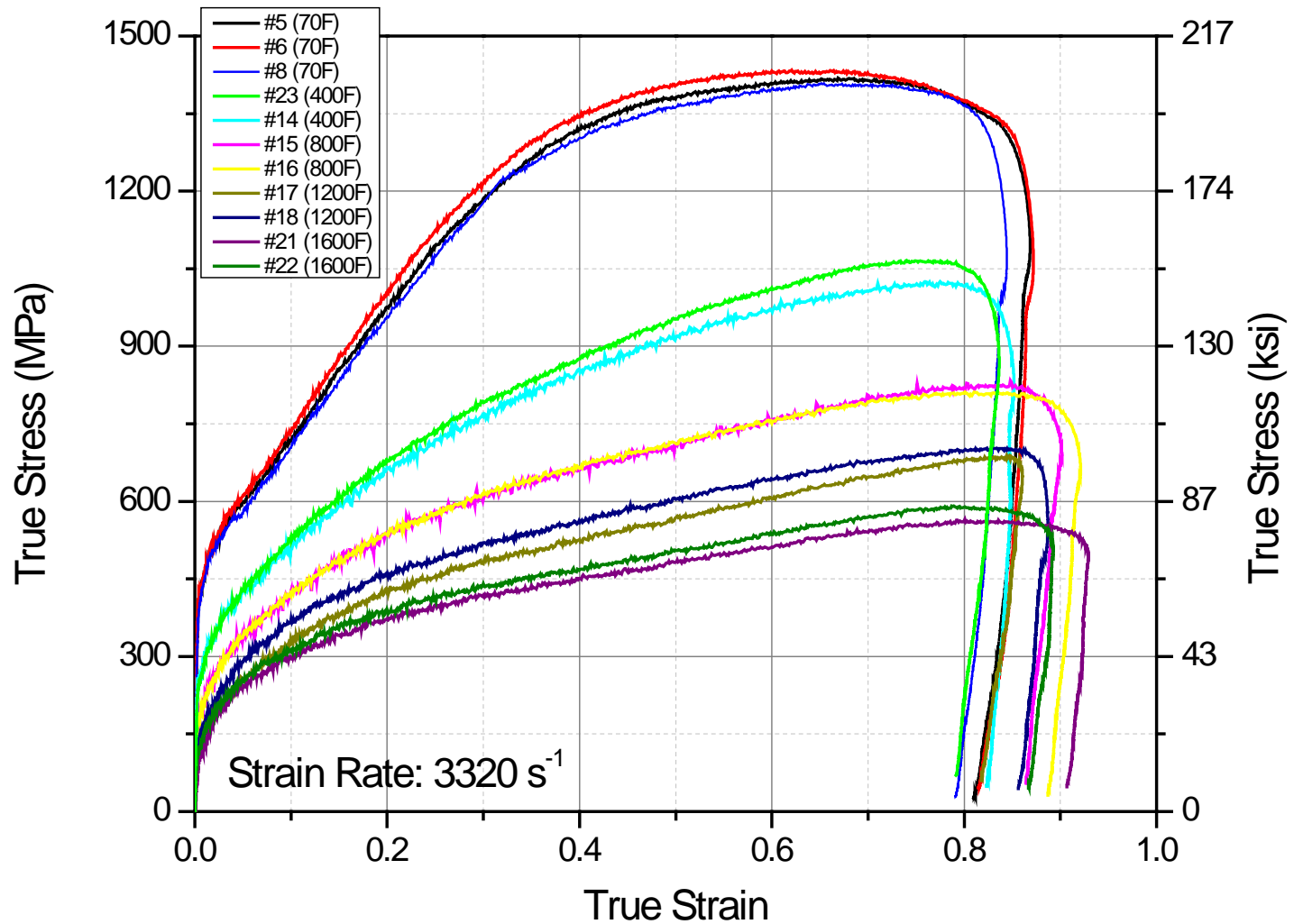
# Original Oscilloscope Records



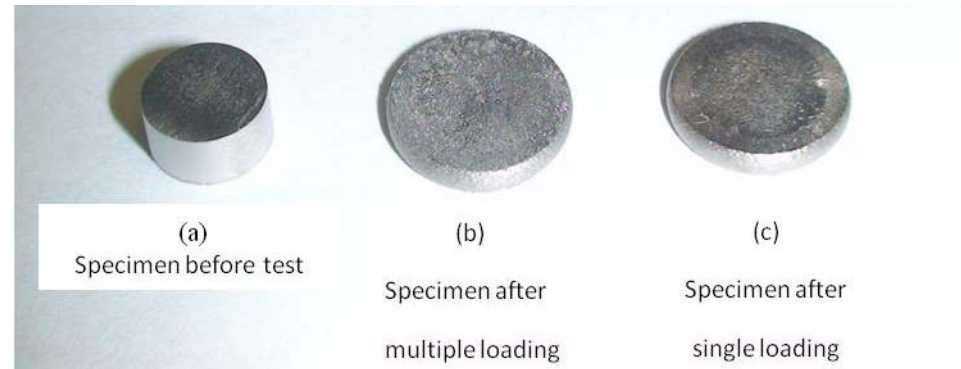
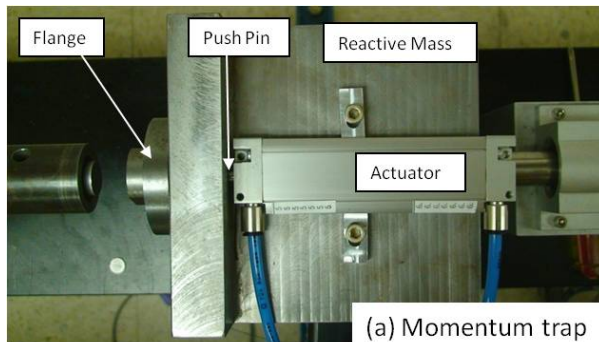
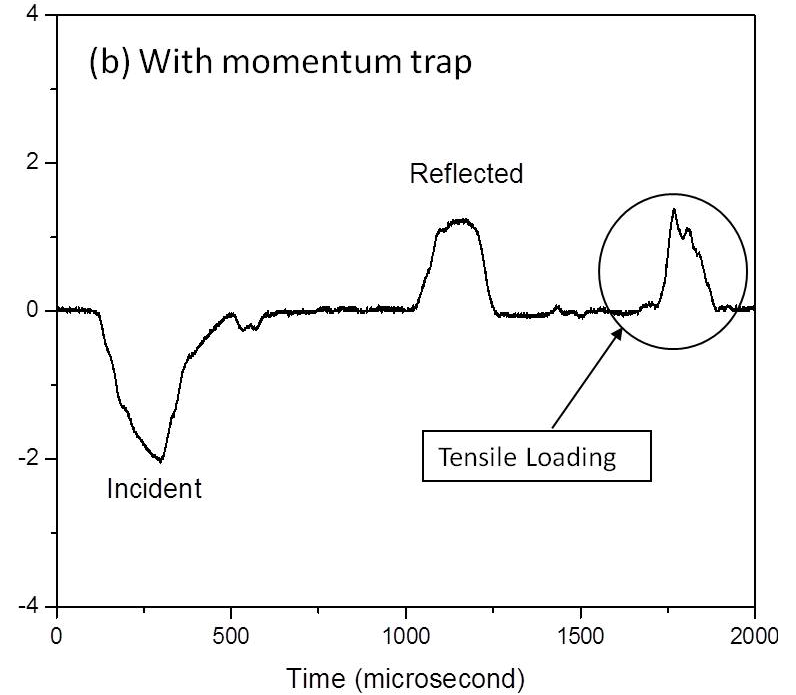
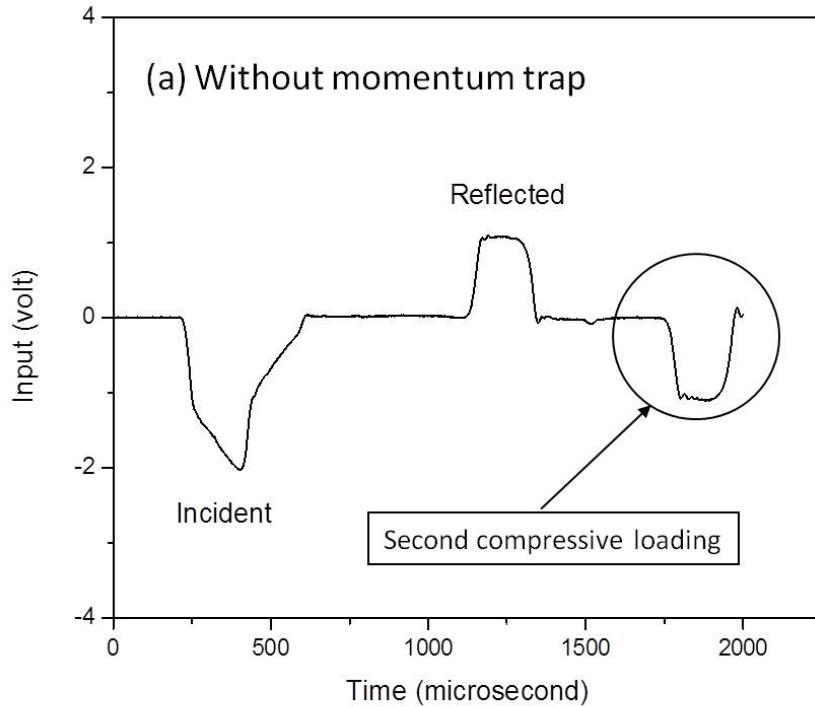
# Dynamic High-Temperature Stress-Strain Curves



# Dynamic High-Temperature Stress-Strain Curves



# Momentum Trap for Single Loading



# “Summary”

## ■ “Who we are?”

- We are mechanical engineers/experimentalists to solve real engineering problems for a variety of applications

## ■ “What do we do?”

- We run experiments/mechanical testing but we are not just simply data factory
- We design experiments, innovate experimental and diagnostic techniques, and advance engineering sciences
- *We are motivated to collaborate with universities on fundamental research and applications*

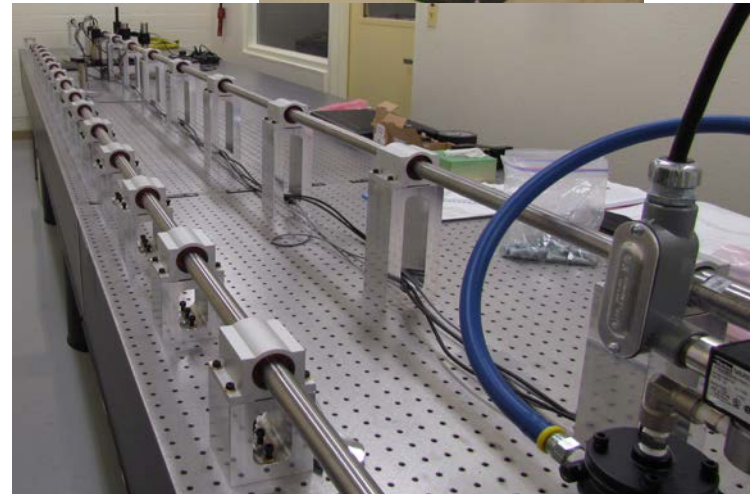
## ■ “What skills do we expect (for recruitment)?”

- Critical thinking (crazy ideas are always welcome!)
- Problem solving
- Challenge loving
- Team work

# What Do We Have?

## Experimental Impact Mechanics Lab. (EIML)

- Facilities:
  - 1"-diameter split Hopkinson compression bar (Kolsky compression bar)
  - 1"-diameter split Hopkinson tension bar (Kolsky tension bar)
  - 1"-diameter "dropkinson" bar for intermediate-rate tensile testing
  - 3"-diameter split Hopkinson compression bar (Kolsky compression bar)
  
- Instrument/Equipment
  - Teledyne LeCroy 4-channel high-speed digital oscilloscope
  - Teledyne LeCroy 8-channel high-speed digital oscilloscope
  - Keyence VHX-5000 digital microscope (20X-5000X)
  - Vishay 4-channel signal conditioner
  - Custom made laser displacement measurement system
  - 1200°C electrical furnace
  - MTI 15kW induction heater
  - Instron environmental chamber (-100 - 350°C)
  - Buehler diamond saw
  - Thermocouple welder
  - Kirana ultra-high speed digital camera
  - NI acquisition and control system
  
- Partnership with:
  - Terminal Ballistic Hopkinson Bar Lab
  - Structure Mechanics Lab (MTS)
  - Shock Mechanics Lab (Drop tables)
  - Mechanical Shock Facility (Gas gun, horizontal actuator)
  - Terminal Ballistic Lab



# What Can We (EIML) Do?

- **Dynamic Characterization of Materials**
  - *Dynamic stress-strain response of materials in compression or tension (shear coming soon)*
  - *Dynamic failure and fracture of materials*
  - *Strain-rate range:  $\sim 100 - 10,000 \text{ s}^{-1}$*
  - *Temperature range:  $-100 - 1200^\circ\text{C}$*
  - *Stress state: uniaxial stress; triaxial stress (in compression only)*
  - *Materials covered: ceramics, alloys, composites, glasses, polymers, foams, biological tissues, concretes, sands, soil, etc*
- **Dynamic Characterization of Component/Small Structures**
  - *Dynamic structural testing with preload capability (compression or tension)*
  - *Wave propagation/interaction*
  - *Shock mitigation*
  - *Dynamic interface problem*
  - *Component/device functionality/survivability in abnormal mechanical environments*
    - *High-g, high-frequency impact and vibration*
  - *Impact Sensor characterization*
- **Rate-dependent Model Validation**
  - *Abnormal mechanical environments (high rate, high frequency, high temperature, etc)*

# EIML POC (Lead/Principal Investigator)

**Bo Song, Ph.D.**

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