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Dynamic Compressive Properties of an Alumina-Filled Epoxy at Various Rates of Loading

Bo Song
Sandia National Laboratories, Livermore, CA

Weinong Chen
Purdue University, West Lafayette, IN

Michael J. Forrestal
Albuquerque, NM

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Outline

- Motivation
- Dynamic Experiments
  - Material and Specimens
  - Experimental Procedure
  - Validation of Testing Conditions
    - Effect of Specimen Size (L/D)
    - Effect of Interfacial Friction
- Experimental Results
- Summary

Motivation

Alumina-Filled Epoxy

- A kind of composite
  - Matrix: epoxy resin
  - Filler: polycrystalline alumina

- Properties and Applications
  - High dielectric strength
    - As a standard encapsulation material for many years
      - Encapsulation of ferroelectric elements for shock depoling in high voltage applications
  - Unique mechanical properties
    - Highly dissimilar mechanical properties between the epoxy resin and the alumina filler
      - Potential applications in light-weight armors where subjected to impact.

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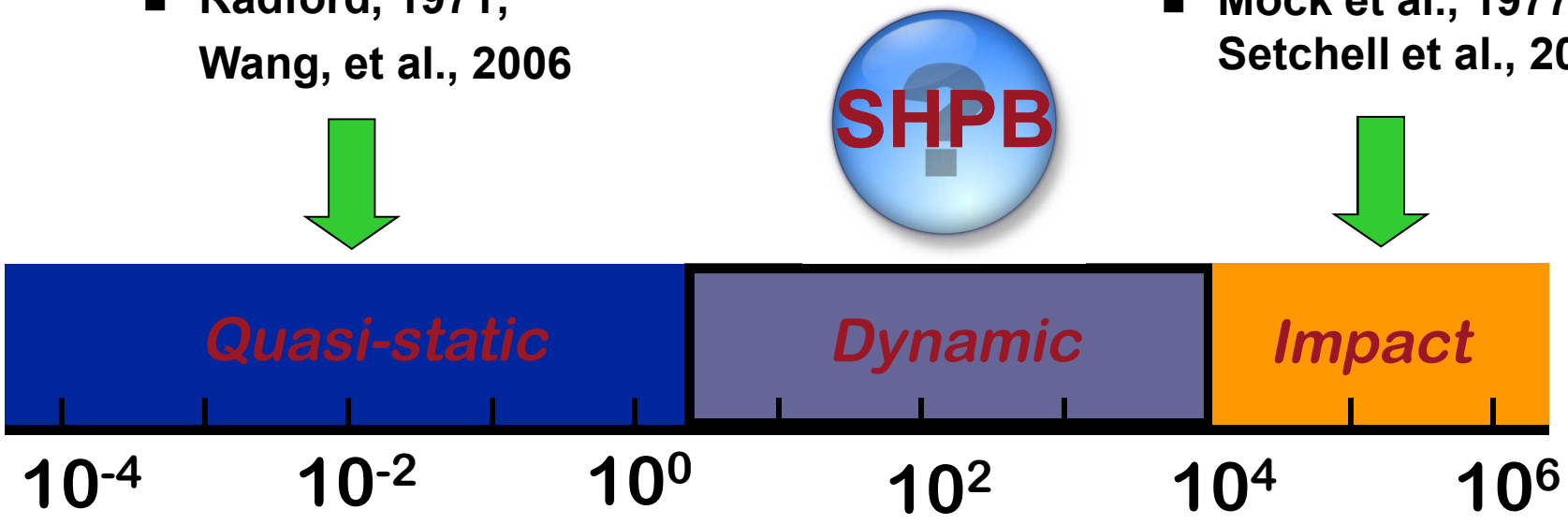
Mechanical Characterization of Alumina-filled Epoxy

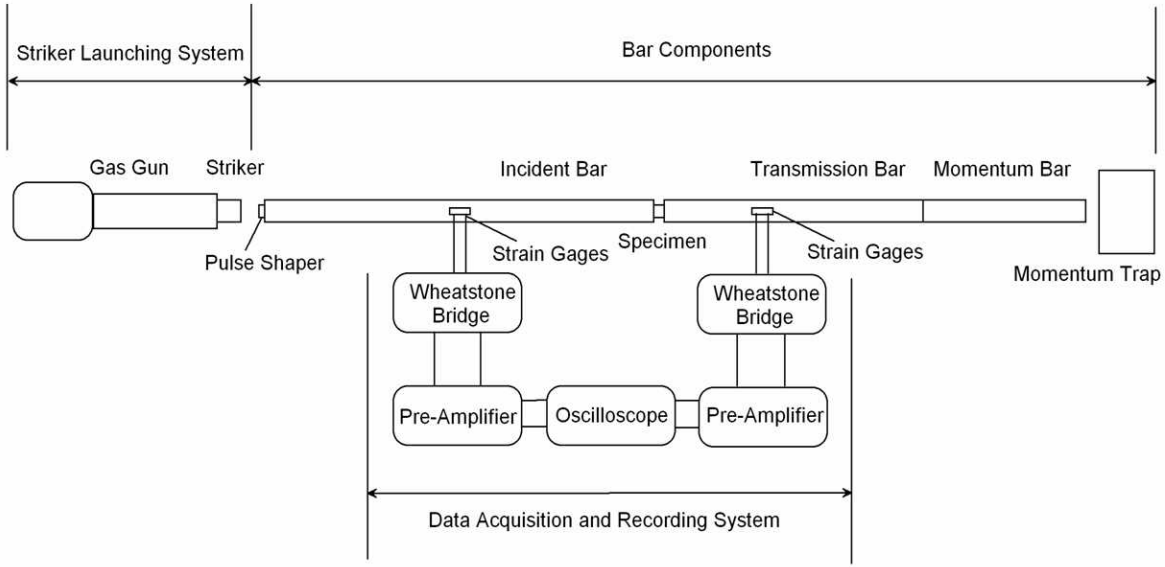
Current Research

- **Quasi-static Experiments**
  - **Conventional Head Cross Devices**
    - **MTS, Instron, etc.**
  - **Strain rate: up to 10^0 s^{-1}**
  - **Radford, 1971; Wang, et al., 2006**
- **Plate-impact Experiments**
  - **Gas Gun**
  - **Strain rate: 10^4 s^{-1} or higher**
  - **1-D strain**
  - **Mock et al., 1977; Setchell et al., 2007**



Split Hopkinson Pressure Bar (SHPB)

- **Strain Rate**
  - **Conventional SHPB (Gary, 2000)**
    - **10^2 – 10^3 s^{-1}**
  - **Miniaturized SHPB (Jia and Ramesh, 2004)**
    - **up to 10^4 s^{-1}**
  - **Long SHPB (Song, et al., 2008); "Slow" SHPB (Zhao, et al., 1997)**
    - **down to 10^1 s^{-1}**
- **Stress/Strain State**
  - **1-D Stress**
  - **3-D Stress/nearly 1-D Strain when applying lateral confinement to the specimen**



We used ¾"-diameter aluminum SHPB for dynamic experiments at Purdue University.

Material and Specimens

- **Material**
  - **Matrix**
    - Epon 828 epoxy resin
    - 23.8% by weight
  - **Filler**
    - Powdered alumina (Al_2O_3)
    - Irregular shape
    - Size varying from ~2-30 μm
    - 4.8% by weight
  - **Curing Agent**
    - Epi-Cure Z
    - 71.4% by weight
  - **Alumina volume fraction: 43%**

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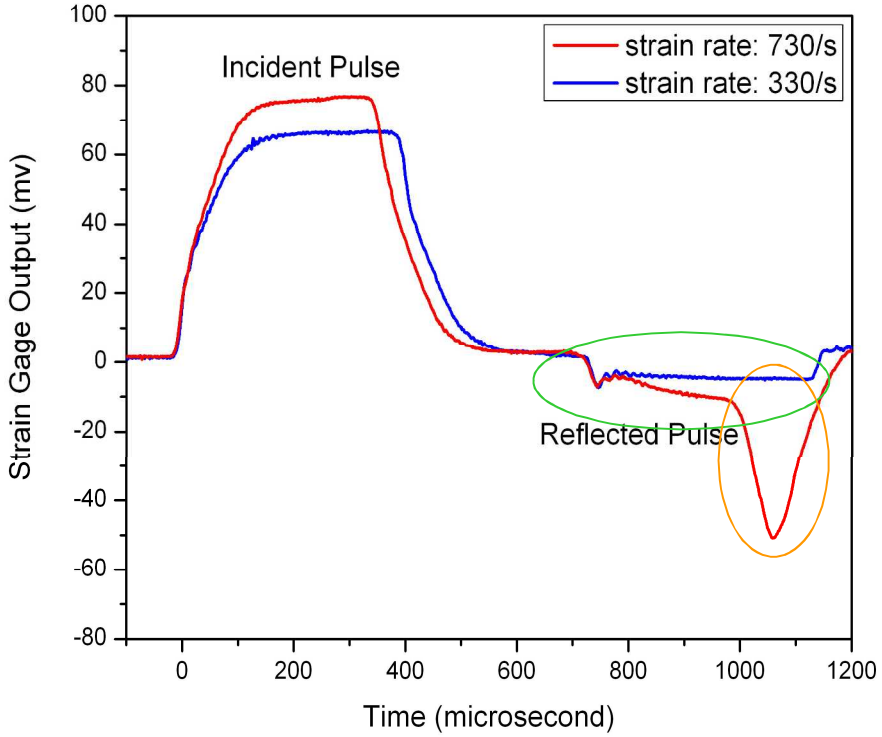
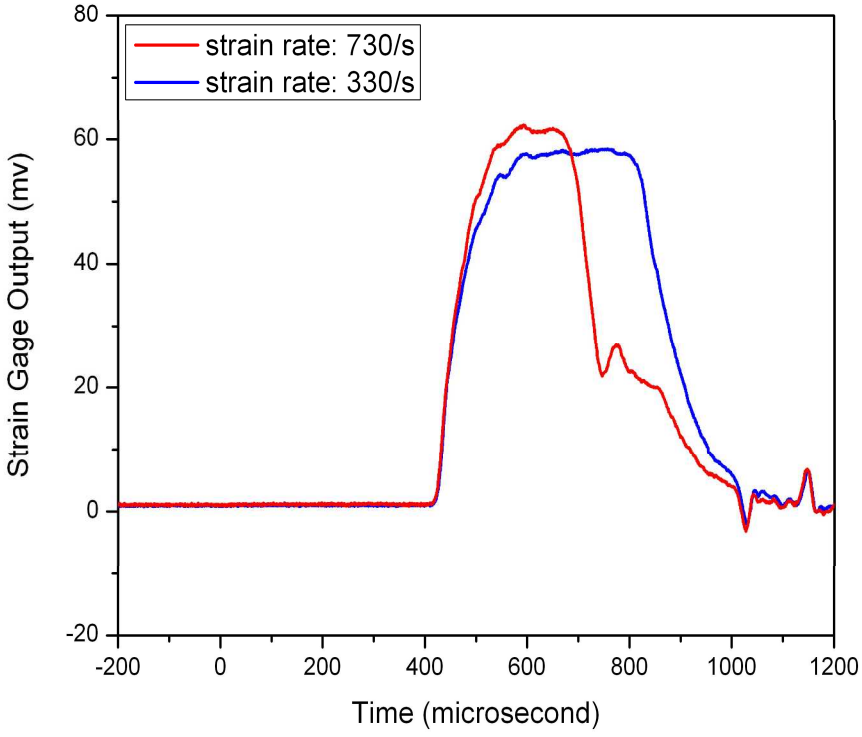
- **Specimens**
  - **Diameter: 12.70 mm**
  - **Thickness: 6.35 mm**

Typical Oscilloscope Records



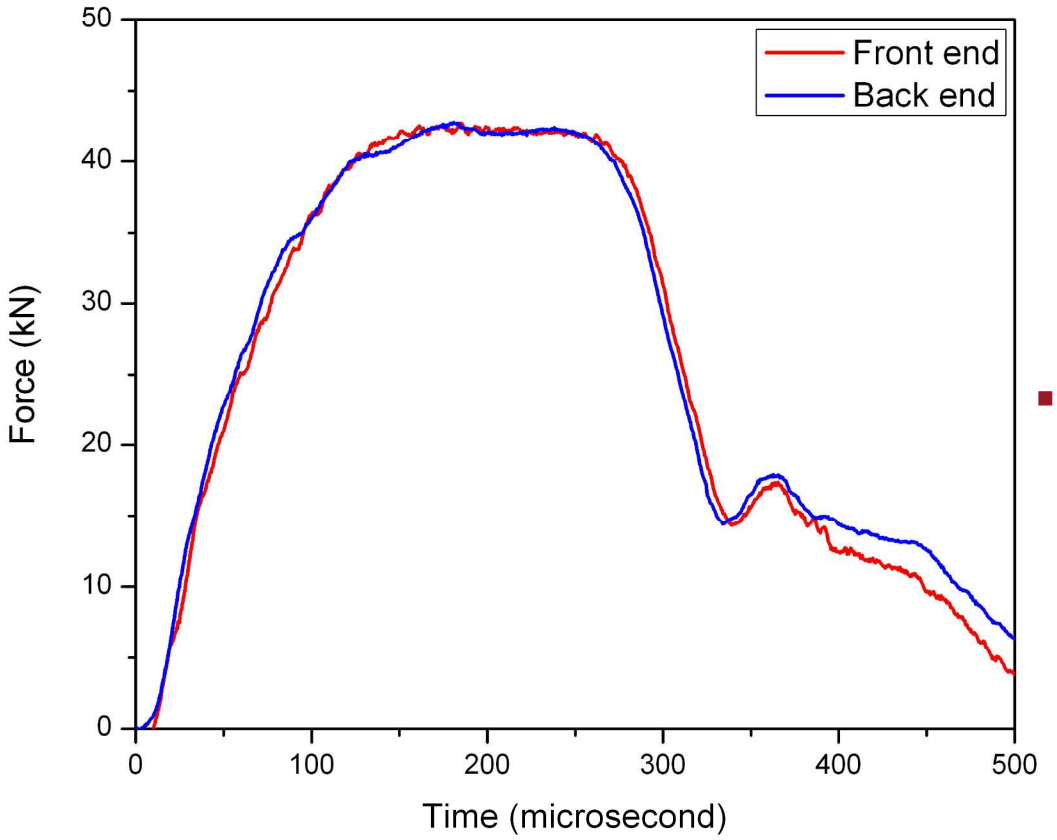
Incident and Reflected Pulses



Transmitted Pulses

Validation of Testing Conditions

Dynamic Stress Equilibrium



- **2-wave, 1-wave method**

$$F_1 = E_0 A_0 (\varepsilon_i + \varepsilon_r)$$
$$F_2 = E_0 A_0 \varepsilon_t$$

$F_1 = F_2$ ⇓ *verification*

$$\varepsilon_i + \varepsilon_r = \varepsilon_t$$

- **Calculation of stress-strain curve**

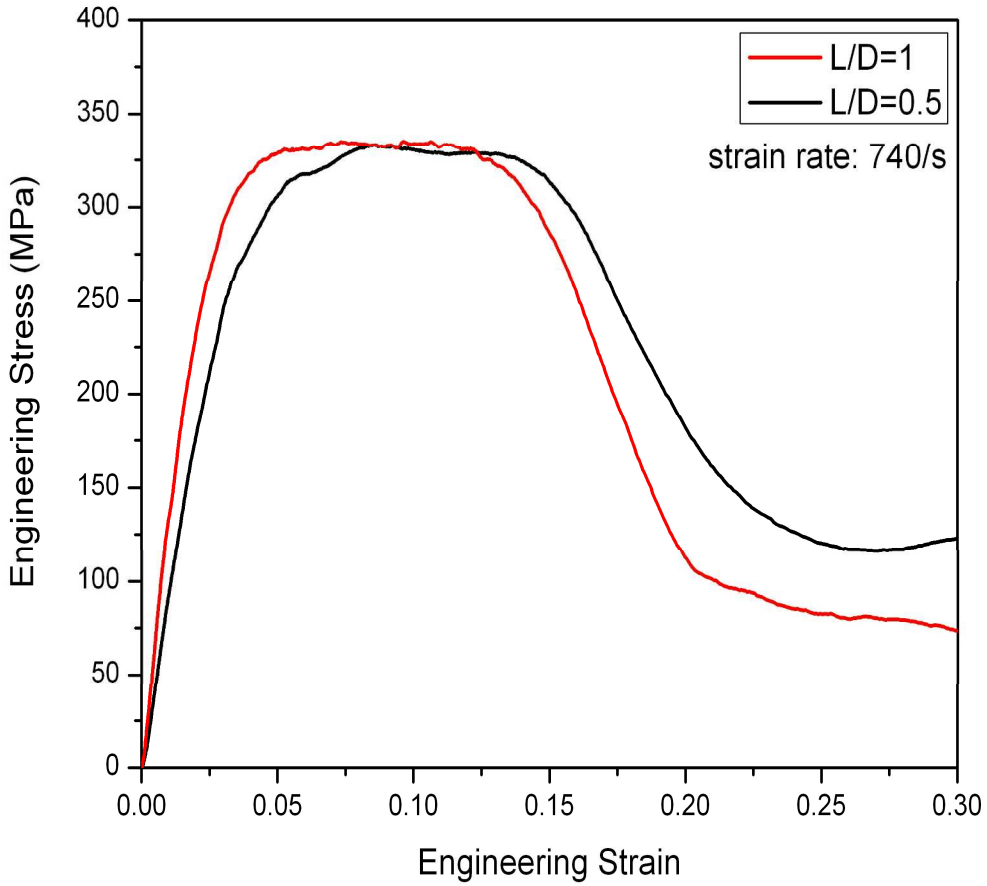
$$\dot{\varepsilon} = \frac{C_0}{L_s}(\varepsilon_i - \varepsilon_r - \varepsilon_t) = -\frac{2C_0}{L_s}\varepsilon_r$$

$$\varepsilon = -\frac{2C_0}{L_s}\int_0^t \varepsilon_r dt$$

$$\sigma = \frac{A_0}{A_s} E_0 (\varepsilon_i + \varepsilon_r) = \frac{A_0}{A_s} E_0 \varepsilon_t$$

Validation of Testing Conditions

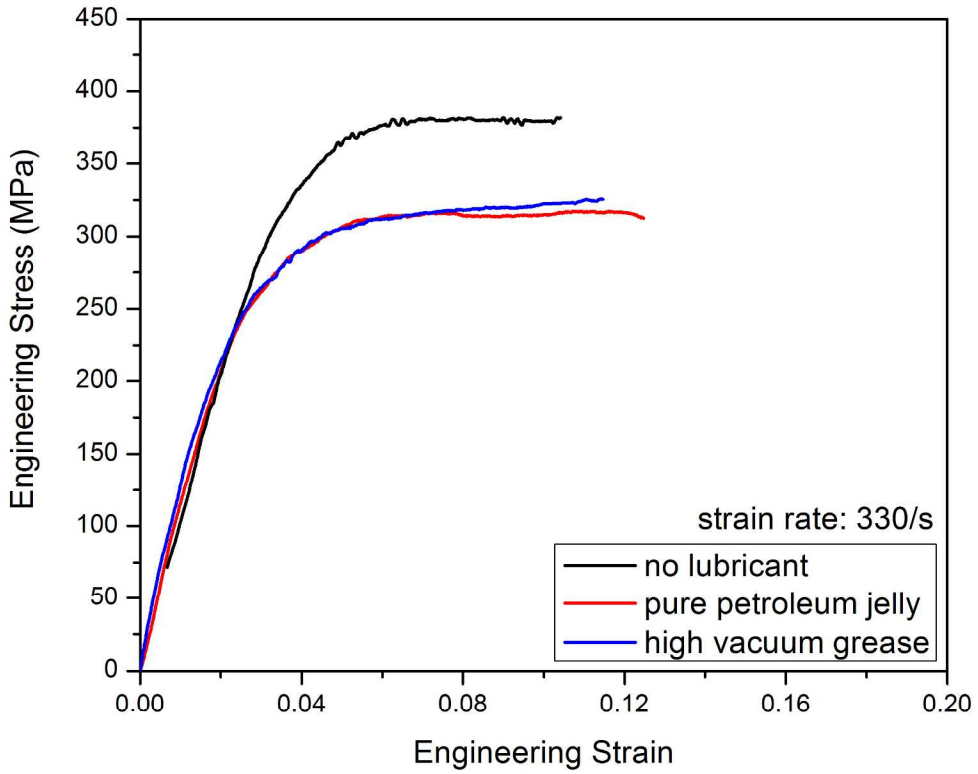
Specimen Size Effect



- **Same strain rate**
  - **Strain rate: 740 s^{-1}**
- **Same lubricant**
  - **Pure petroleum jelly**
- **Different L/Ds**
  - **L/D=1**
  - **L/D=1/2**

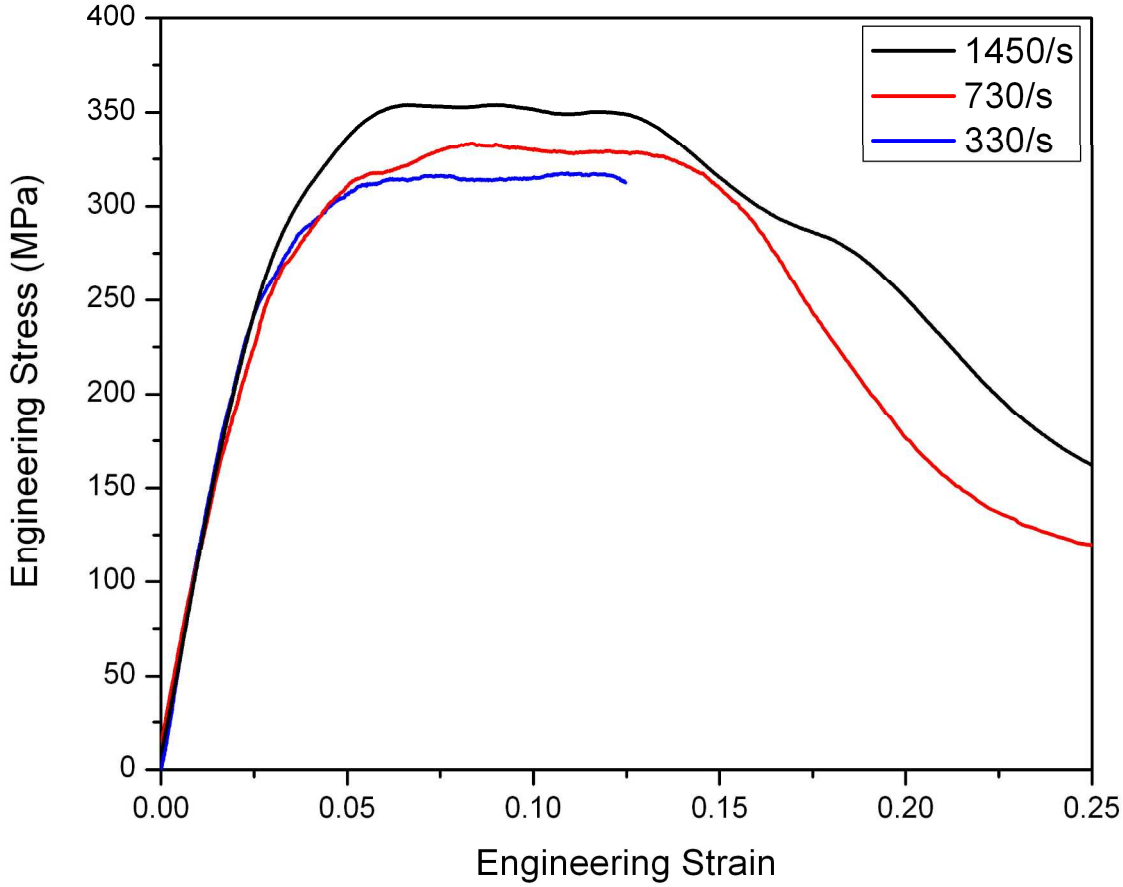
Validation of Testing Conditions

Interfacial Friction Effect



- Same specimen L/D
  - L/D=1/2
- Same strain rate
  - Strain rate: 330 s^{-1}
- Different lubricants
  - No Lubricant
  - Pure Petroleum Jelly
  - High Vacuum Grease

Dynamic Stress-strain Curves



Summary

- The SHPB was modified to characterize compressive response of alumina-filled epoxy at three dynamic strain rates;
- Validation of the testing conditions in the SHPB experiments has been examined:
  - Stress in the specimen was dynamically equilibrated;
  - Constant strain rate is achieved;
  - Effect of specimen L/D is studied:
    - The L/D influences the elastic response
    - An L/D of ½ was selected
  - Effect of interfacial friction is investigated:
    - The strength significantly increases without using lubricant
    - No significant difference was discovered between using petroleum jelly and high vacuum grease
- Dynamic compressive stress-strain curves were obtained at three high strain rates, showing significant strain-rate effect on flow stress.