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Title: COMPRESSIVE PROPERTIES OF LOW RELATIVE DENSITY MATERIALS, BOTH ENGINEERED AND RANDOM STRUCTURES.

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COMPRESSIVE PROPERTIES OF LOW RELATIVE DENSITY MATERIALS, BOTH ENGINEERED AND RANDOM STRUCTURES.

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The compressive constitutive behavior of low relative density materials bas been characterized for various materials. It has been seen that engineered structures have a better strength for relative density. These materials have been evaluated under static and dynamic loading conditions as a function of temperature. High-strain-rate tests (1000–2000 s^{-1}) were conducted using a split-Hopkinson pressure bar (SHPB). Quasi-static and intermediate-strain-rate tests were conducted on a hydraulic load frame. Localized deformation and stress state instability during testing of foams and structured materials is discussed in detail since the mechanical behavior over the entire range of strain rates indicates non-uniform deformation. Additionally, investigation of the effect of processing conditions on the mechanical behavior was investigated.

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COMPRESSIVE PROPERTIES OF LOW RELATIVE DENSITY MATERIALS, BOTH ENGINEERED AND RANDOM STRUCTURES

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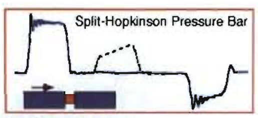

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Outline

- Types of Foams
- Uses of Foams
- Loading Behavior of Foams
- Mechanisms of of failure

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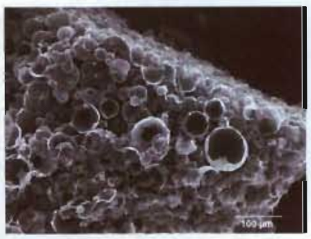
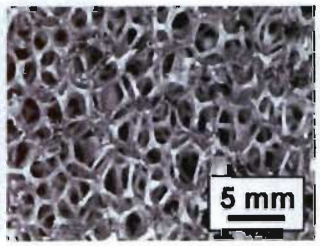
Types of Foams

- Stochastic
  - Syntactic Foam – Hollow particle in a matrix – High strength to weight
  - Open Cell – polyurethane(soft), metals, ceramic
  - Closed Cell – polyethylene, polyurethane(rigid), neoprene, polystyrene, expanded metals, ceramic

➤ Metal foams – cast and dissolve, gas injection, chemical reaction



APO/BMI Syntactic carbon foam



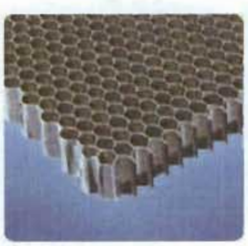
Duocel Open cell metal foam

Closed cell polyurethane foam

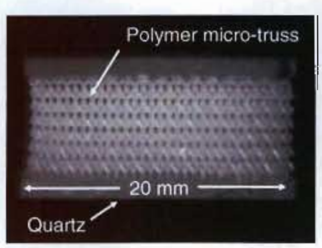
Types of Foams

- Periodic
  - Corrugated – Mechanically deformed and bonded layers
  - Slotted – connecting by slotting each piece
  - Investment casting – wax mold
  - Rapid prototyping – laser sintering, stereo lithography

➤ Metal foams – cast and dissolve, gas injection, chemical reaction



Honeycomb structure



"photo lithography" formed structure

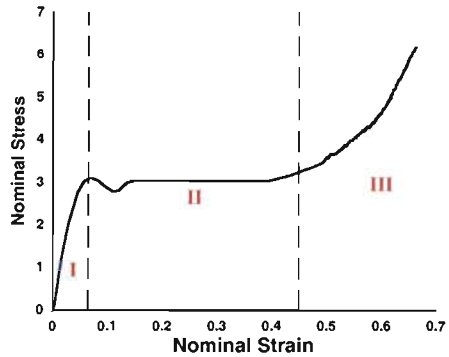
Closed cell polyurethane foam

Uses

- **Stochastic**
  - **Polymeric – Cushions, insulation, Structural support & floatation**
  - **Ceramic – insulation, filters, high temperature applications,**
  - **Metal – filters, sound & energy absorption, catalitic converters, structural support, reduce weight**
    - **Cheap, Easy to make, Effective**
- **Periodic**
  - **Polymeric – Precursor for metal forms, energy absorption**
  - **Ceramic - insulation, armor, structural support at temperatures**
  - **Metal – Heat transfer, filters, sound & energy absorption, structural support, armor**
    - **Lower density, Stiffer, engineered for specific purpose**

Both stochastic and periodic foams are useful. There will always be a cost/benefit question to be answered.

Characteristic Behavior of Low Density structures

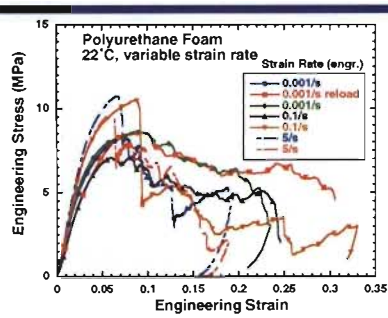


I. Linear elastic "bending" of ligaments

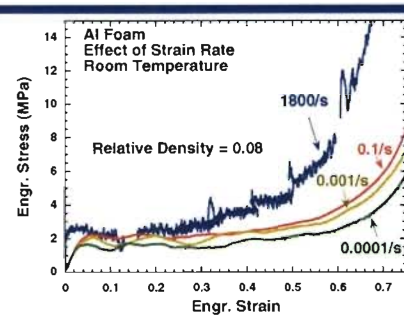
II. Pore collapse, buckling, and cell wall failure

III. Densification

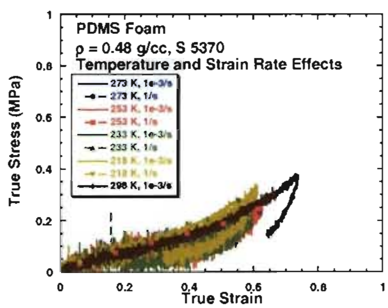
Mechanical Behavior - Stochastic



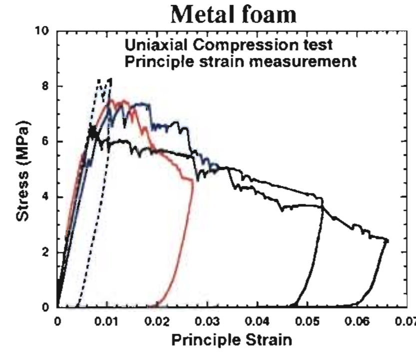
Rigid polymeric foam



Metal foam



Visco-elastic polymeric foam



Syntactic carbon foam

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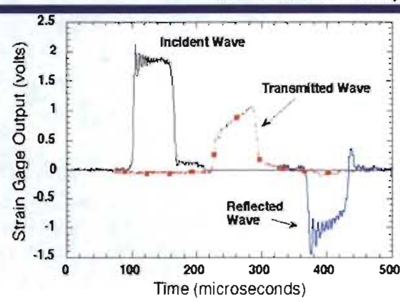
SHPB - Traditional Data Analysis (Assumptions), Data Reduction, to yield "Valid" SHPB-data



"1-wave" analysis uses only the reflected wave for strain rate and strain and only the transmitted wave for stress.

"2-wave" analysis calculates the stress in the sample at the incident bar-sample interface using a momentum balance of the incident and reflected wave pulses.

- 1) After initial "ring-up"- specimen achieves force equilibrium along its length -
  - Uniaxial stress state achieved and maintained,
  - Time dependent on sample sound speed and geometry,
- 2) specimen is deforming uniformly, (no non-homogeneous, localized plastic flow, fracture)
- 3) sample unconstrained laterally (uniaxial stress) - friction is minimized,
- 4) volume of sample remains constant, [no foams, etc.]
- 5) bar elastic properties invariant [no temperature gradients]

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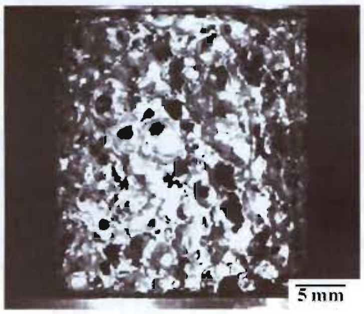
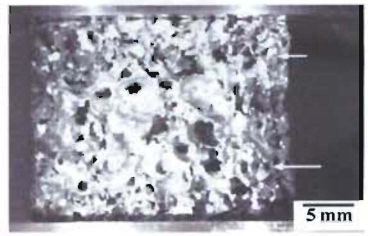
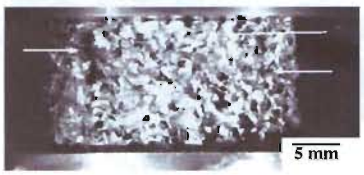
Conservation of Volume?



As Received



30% Engr. Strain

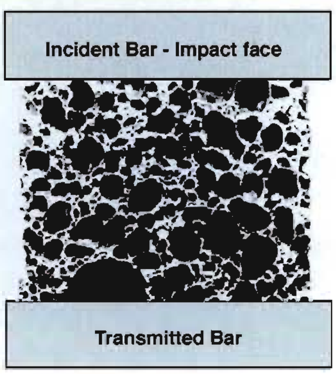


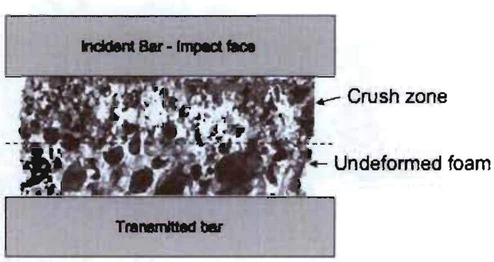
50% Engr. Strain

40% Engr. Strain

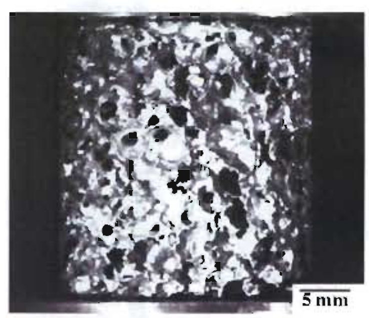
Uniform Deformation?

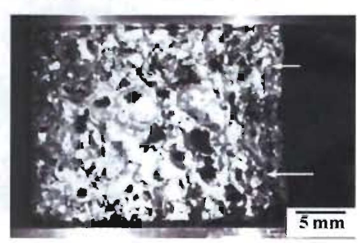
High Rate Test



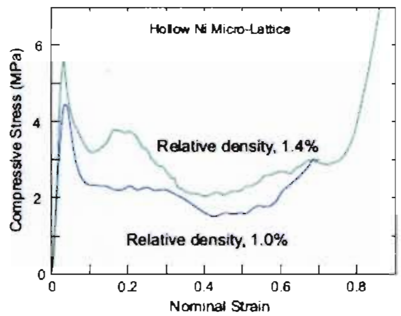


Low Rate Test

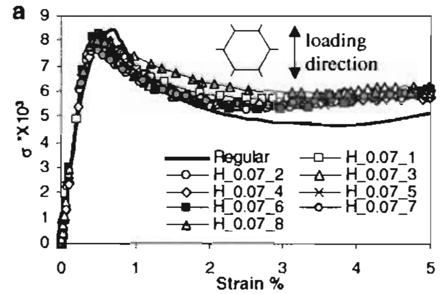




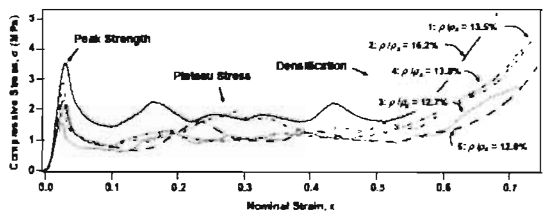
Mechanical Behavior - Periodic



Hollow micro lattice structure

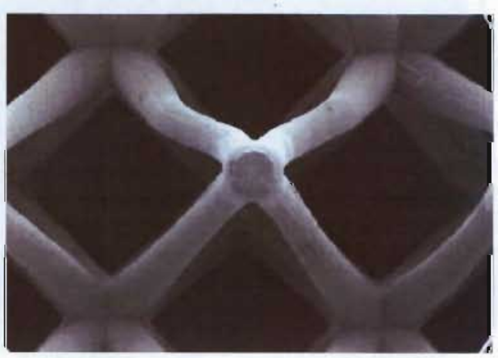


Metal honeycomb structure



Cured polymeric micro-truss structure
A.J.Jacobsen, HRL laboratories

Deformation behavior

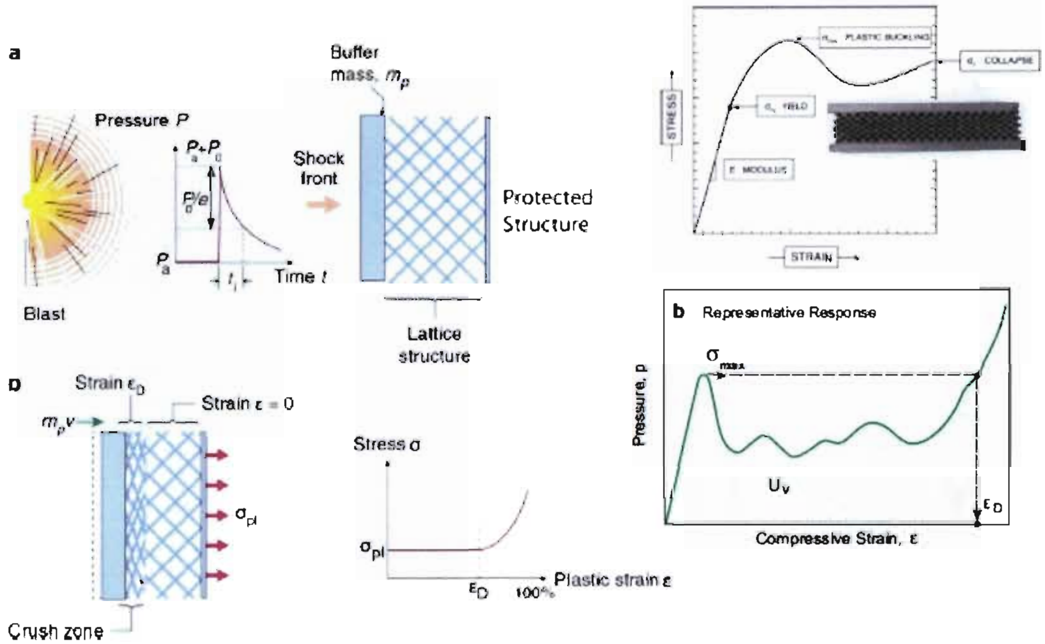


Buckling in polymer micro lattice structure

Buckling in hollow tube micro lattice structure

Evans, He, et. al., IJIE (2010)pp947-959

Deformation behavior



Evans, He, et. al., IJIE (2010)pp947-959

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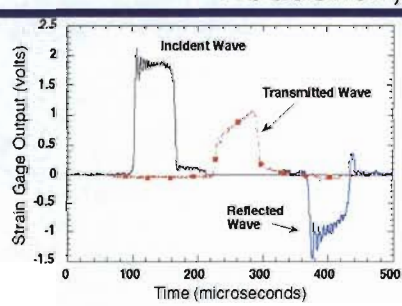

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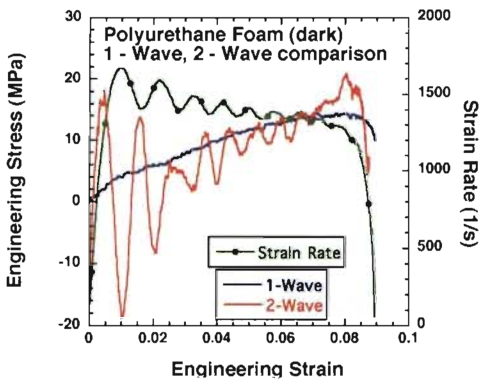
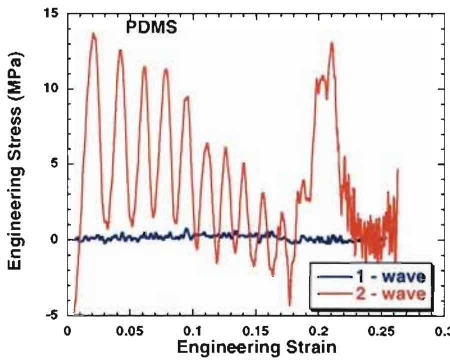
Challenges with Polymer SHPB Testing - Use of Mg Pressure Bars

- SHPB testing of Polymeric materials is complicated by their low wave speeds and the dispersive constitutive response of these materials
- Two chief technical problems
  - Low sound speed (restricts attainment of stress-state equilibrium) -- thinner sample thickness can reduce this problem to a limit
  - Low signal to noise on SHPB data
    - Maraging 350 Steel (E ~220 GPa) - elastic to ~ 2400 MPa
    - Mg (E ~45 GPa) - elastic to ~ 100 MPa - improves response





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Strain Rate and Temperature Properties - Stochastic

Soft foams (rubbery, "shape memory")
- visco-elastic for temperatures of interest.
- There are aspects like Mullins effects and aging that change material response with cyclic loading and time
- Not strain rate sensitive

Brittle Foam (rigid polyurethane, ceramic)
- Properties are determined by processing
- Does not appear to be strain rate sensitive
- The foam has a temperature sensitivity
- Sample dimensions can lead to different failure modes.
- Peak load carrying at initial failure

Metal foams
- Collapse from impact face at high strain rates, randomly at low rates
- Little strain rate sensitivity
- Failure by pore collapse

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Strain Rate and Temperature Properties - Periodic

Polymer
- Permanent softening of structure due to local bending of struts.
- Fracture of struts may occur depending on material condition (curing)
- Not strain rate sensitive

Metal
- Collapse from impact face at high strain rates, randomly at low rates
- Little strain rate sensitivity
- Failure by ligament bending
- Initial "bending" may be strain rate sensitive but subsequent deformation is strain rate insensitive

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Summary

- The failure behavior of both stochastic and periodic structures is strain rate dependent – but the mechanisms differ.
- The stress-strain behavior of the structures is similar in nature.
- Characterization of soft materials at high strain rates presents many challenges
- Periodic structures should have a higher stiffness to weight and can be made for specific applications

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