Numerical simulation of the dynamic compression of a 6061-T6 aluminum metallic foam

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University of Utah

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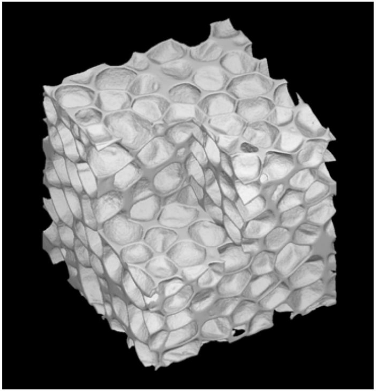
Outline

1. Motivation
   - Previous Work
2. Approach
3. The Plasticity Model
4. Creation of Foam Microstructures
5. Crushing of Foam Microstructures

Why Aluminum Foams?



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- High weight to specific mechanical stiffness.
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  - High-capacity impact absorption.
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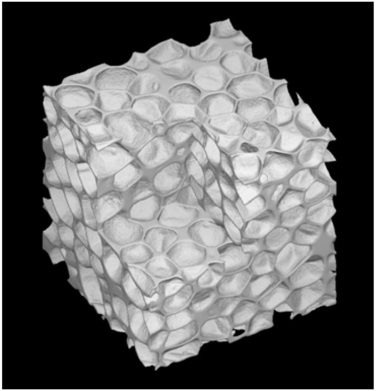

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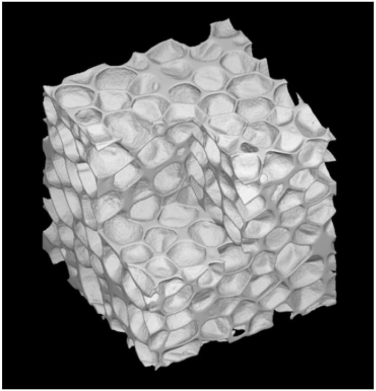

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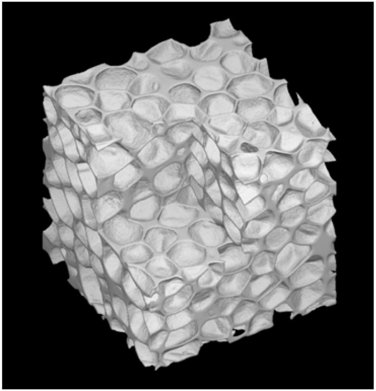

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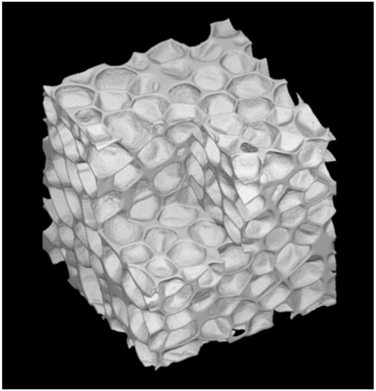

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- Uintah Computational Framework.
  - Parallel multiphysics framework.
  - Large deformation solid mechanics with the Material Point Method (MPM).
    (Sulsky et al., 1995,1996).
  - Fluid dynamics with the multimaterial Implicit Continuous Eulerian (ICE) algorithm.
    (Kashiwa et al., 2000).
  - Fluid-structure interaction on a common grid. (Kashiwa et al., 2000; Guilkey et al., 2006).
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- The flow stress is given by (Follansbee and Kocks, 1988; Goto et al., 2000)

$$\sigma_y(\epsilon_p, \dot{\epsilon}, T, p) = (\sigma_a + S_i\sigma_i + S_e\sigma_e)\,\frac{\mu(T,p)}{\mu_0} \tag{1}$$

- The athermal part contains the effect of grain size.
- The scaling factors depend on strain-rate, temperature, and pressure.
- Uses an empirical strain hardening model (modified Voce model)

$$\frac{d\sigma_e}{d\epsilon_p} = \theta_0(T)\,[1 - f(\sigma_e)] \tag{2}$$

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Shear Modulus Model

- We use a temperature and pressure dependent shear modulus model (Nadal and Le Poac, 2003; Guinan and Steinberg, 1974)

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- We use a pressure dependent melting temperature model (Burakovsky et al., 2000)

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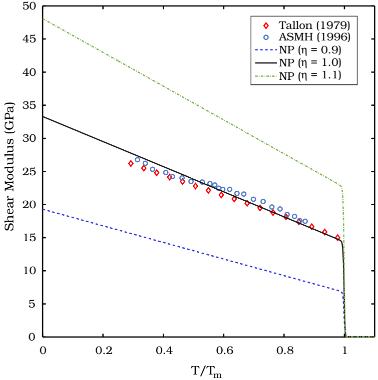
Model Validation: Shear and Melt Models



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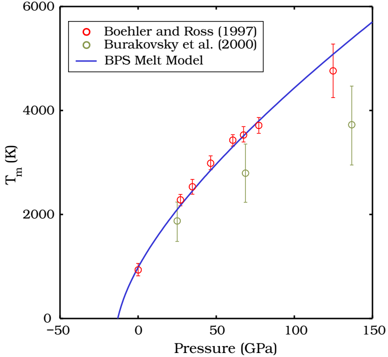
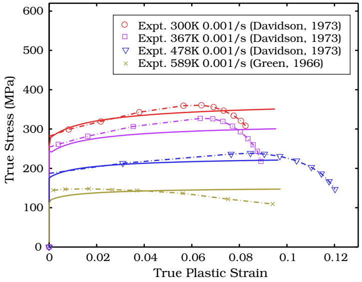
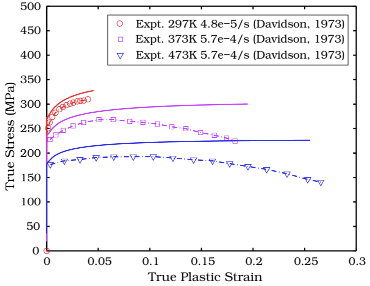


Melt Temperature.

Model Validation: Flow Stress Model



Strain rate = 0.0001/s.



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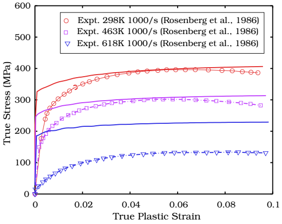
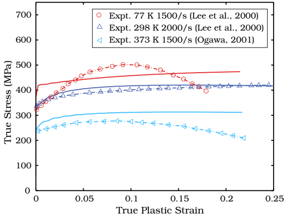
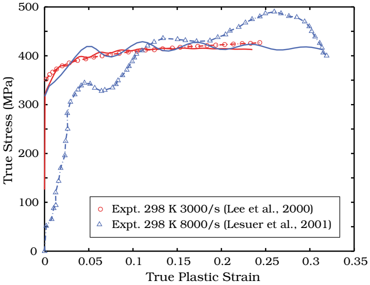


Strain rate = 1000/s.

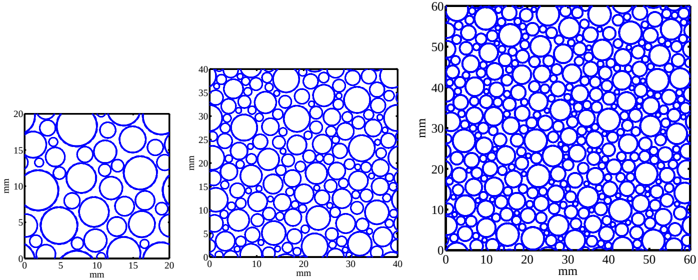


Strain rate = 1500-2000/s.



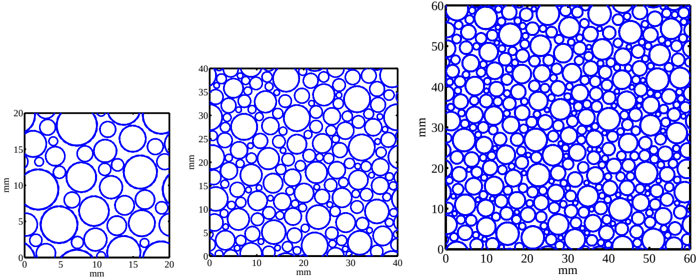
Strain rate = 3000-8000/s.

Bubble Creation



- Use a Poisson process to create bubble distribution.
- Periodic RVE.
- Uses input size distribution and volume fraction.

Bubble Creation



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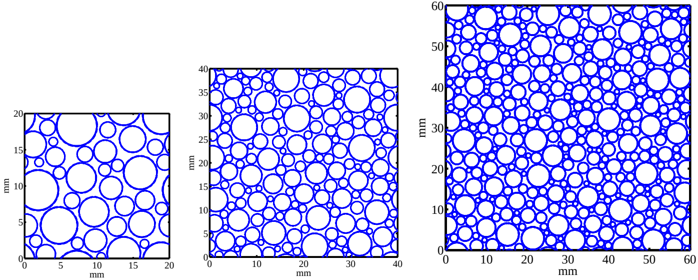
Bubble Creation



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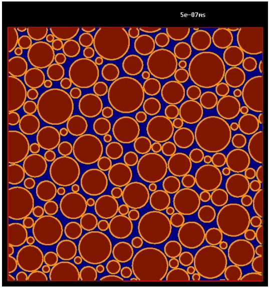
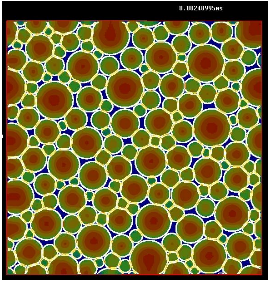
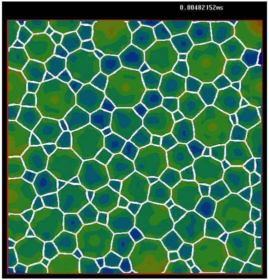
Bubble Pressurization

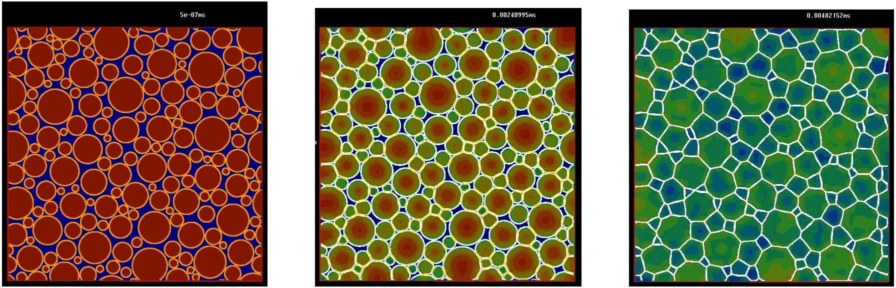






- Use fluid-structure interaction to expand bubbles.
- Compressible Neo-Hookean solid with $K = 0.6$ MPa and $\mu = 0.3$ MPa.
- Gas inside bubbles is pressurized by adding heat.
- Gas between bubbles has low pressure and temperature.

Bubble Pressurization



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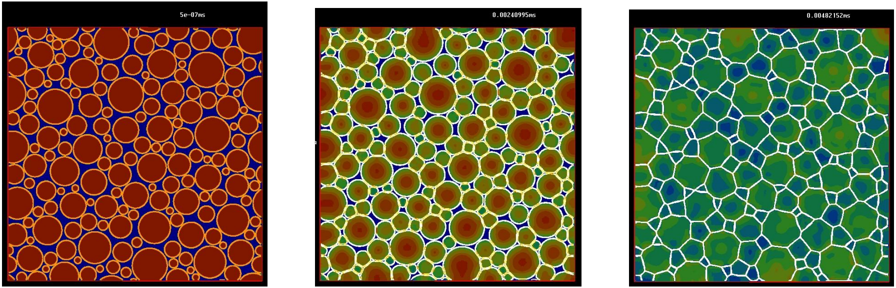

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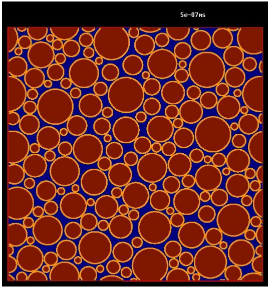

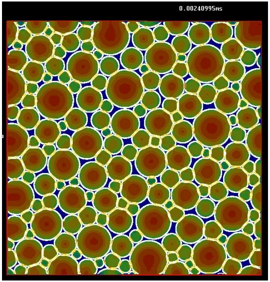

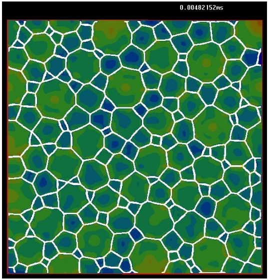

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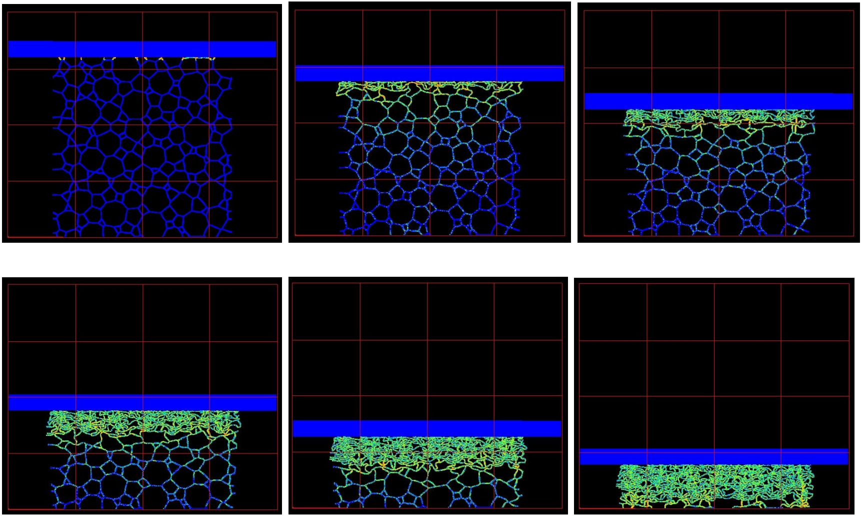
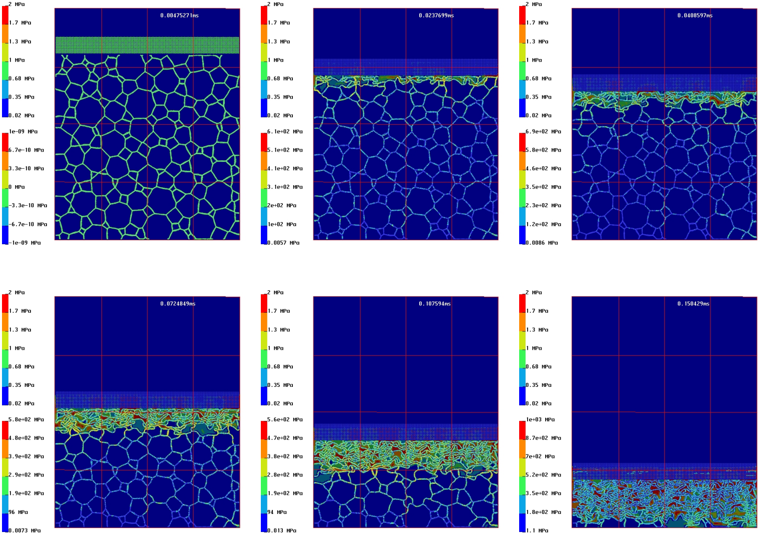
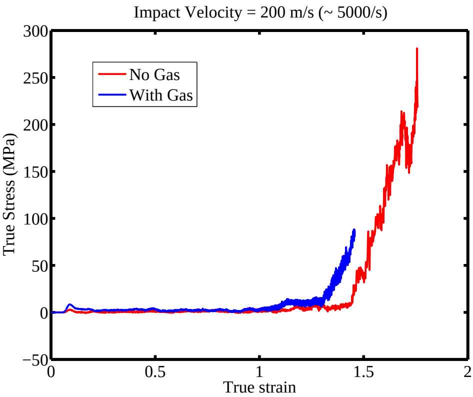
Crushing Without Interior Gas



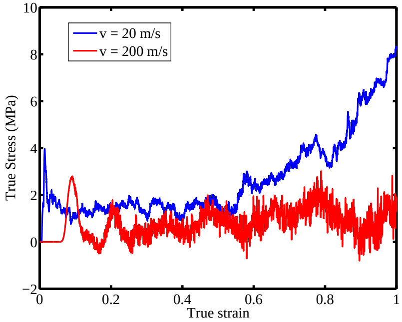
Crushing With Interior Gas



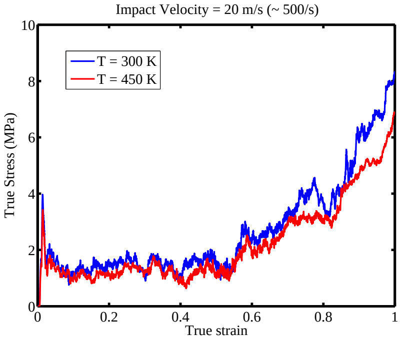
Stress-Strain Curves



Effect of Strain-Rate and Temperature



Effect of Strain Rate

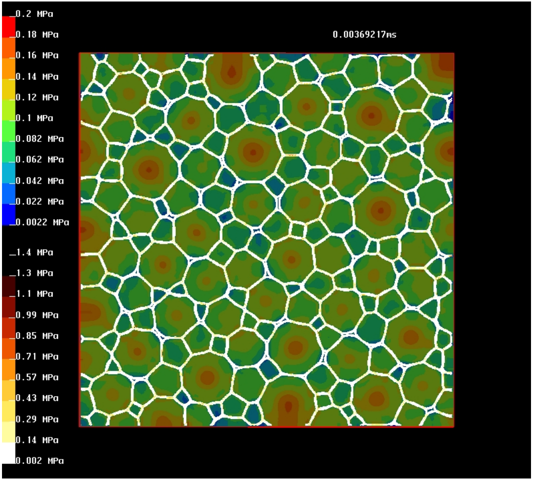


Effect of Temperature

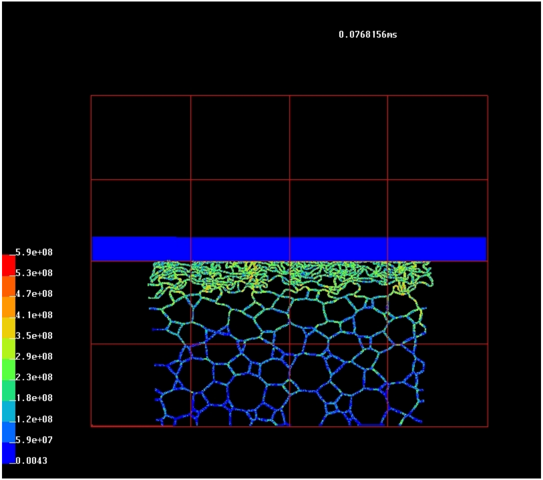
Summary

- MTS plasticity model of 6061-T6 Al.
- A novel way of creating a foam microstructure.
- There is a clear effect of including gas in the stress-strain curves.
- Crushing of foam shows no shear banding.
- Further work is needed to create a macroscopic model of the dynamic response of Al foam.

Creation of Foam Microstructure



Crushing of Empty Foam



Crushing of Gas-Filled Foam