SAND2016-8052PE

Probing the Shock Loading of Porous and Granular Materials

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Kinetic Response of Materials at Extreme Conditions
August 22-24, 2016
Lawrence Livermore National Laboratory
Livermore, CA

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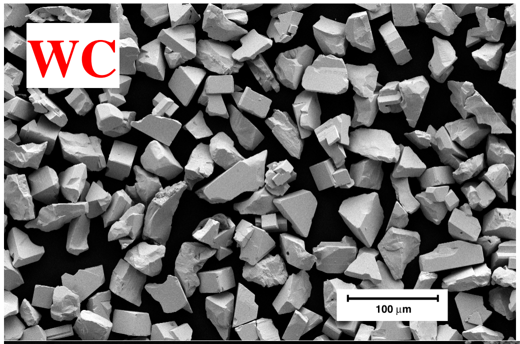
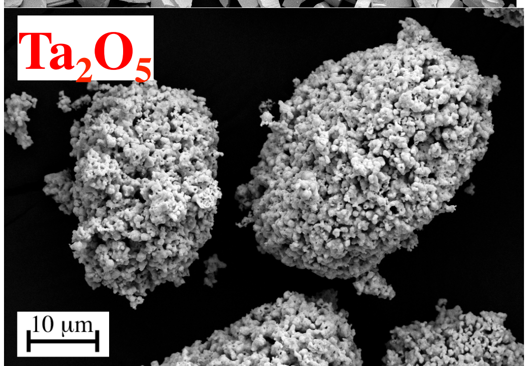
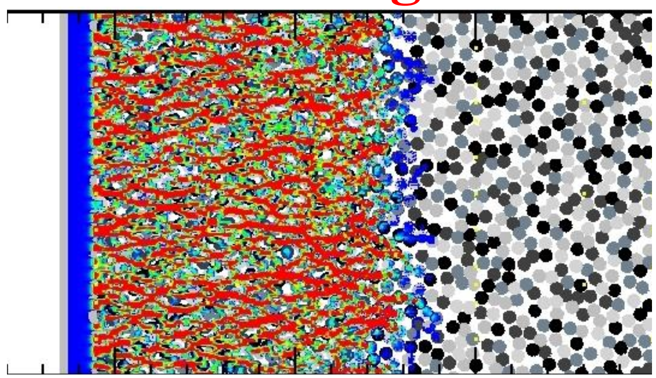
Granular Materials Investigations

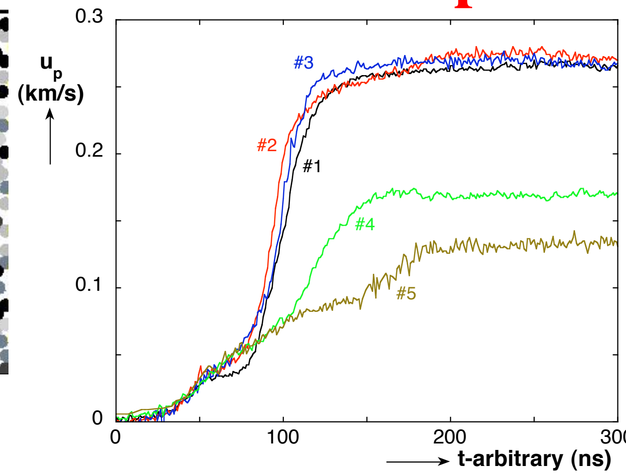


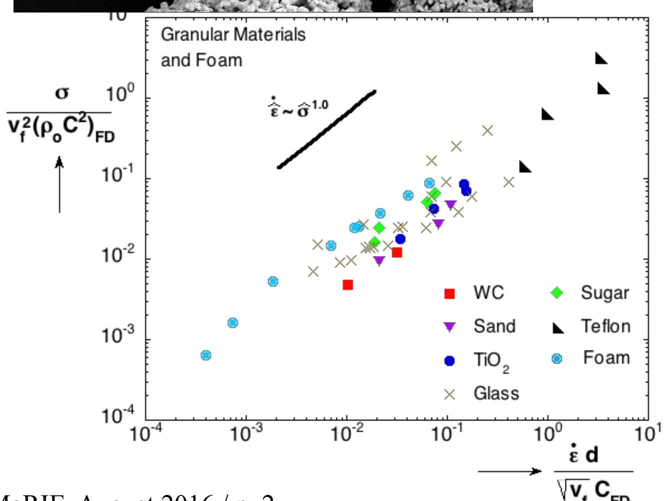


Mesoscale Modeling

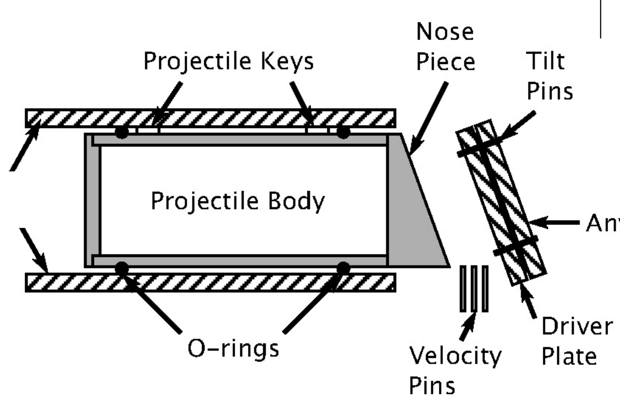


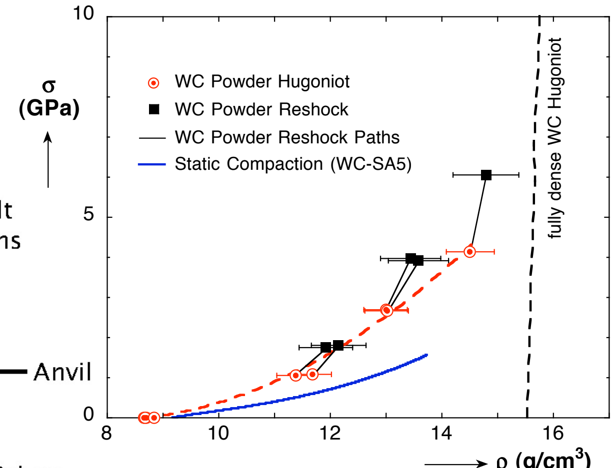
Planar Impact



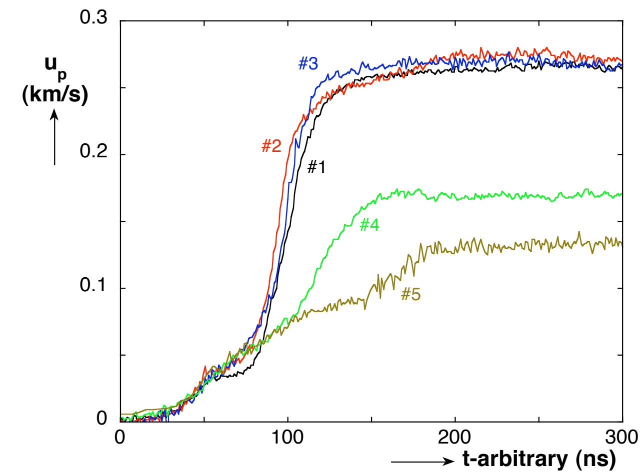


Pressure-Shear





Average (Bulk) Behavior



conservation of

mass: $\rho\,(U_s - u_p) = \rho_o\, U_s$

momentum: $\sigma_x = \rho_o\, U_s\, u_p$

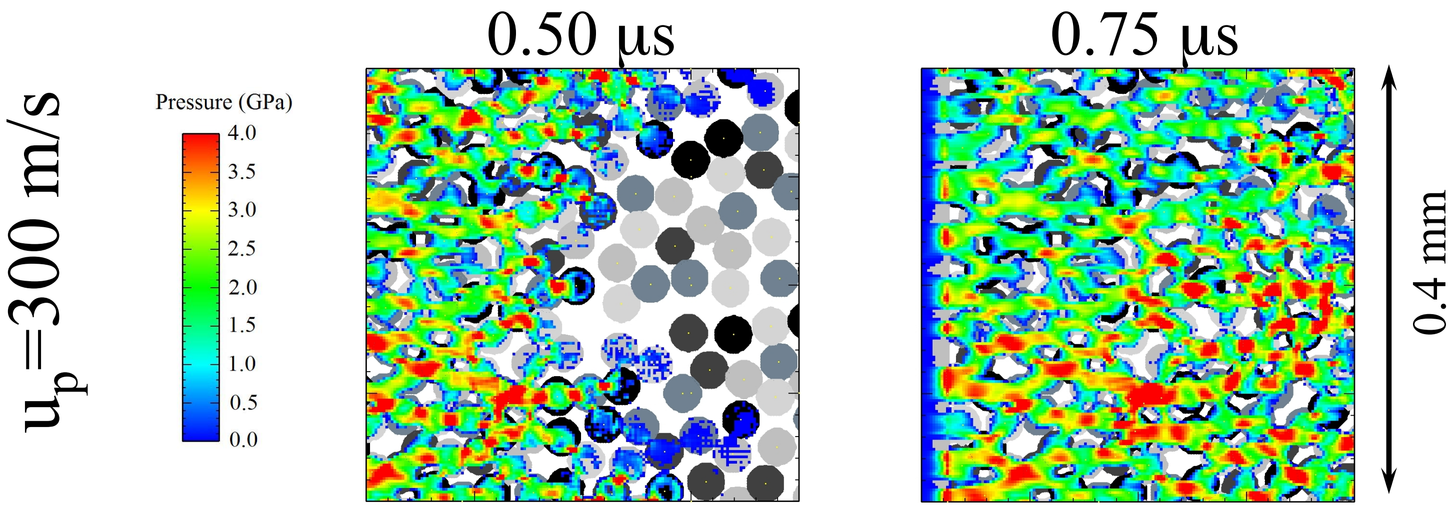
energy: $E - E_o = 0.5\sigma_x\,(V_o - V)$

Rankine-Hugoniot relations apply for steady waves. Are waves in granular materials steady?

Describe average behavior of sample, but distributions of states exist.

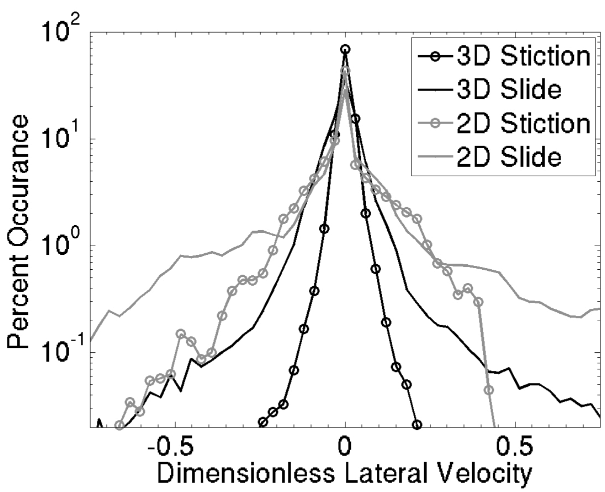
Tails of distributions can be important (e.g. energetics)

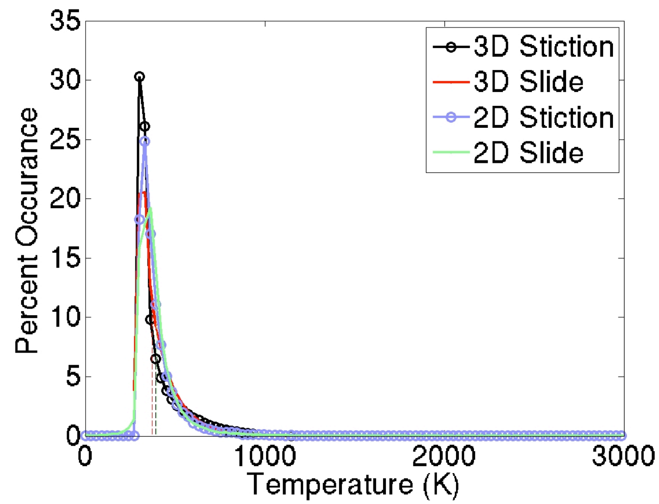
Mesoscale Simulations of the Compaction Process



Borg & Vogler, 2008, 2009, 2013

States (pressure, temperature, shear, etc.) are spatially non-uniform

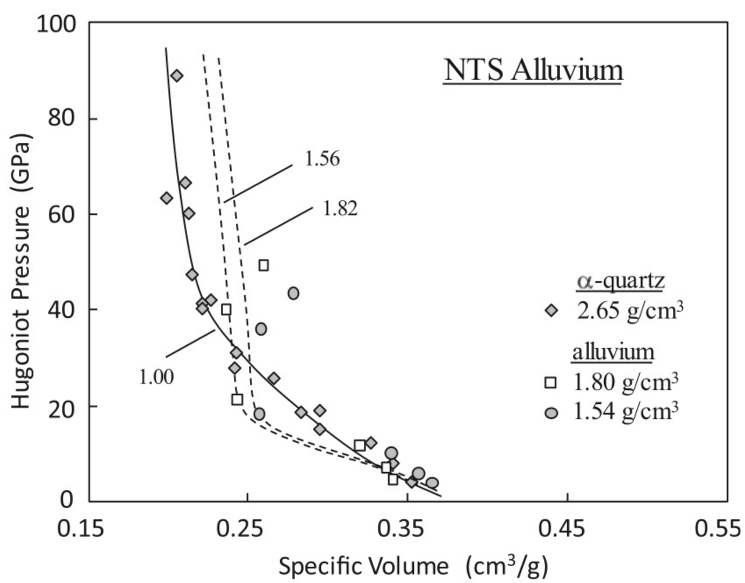


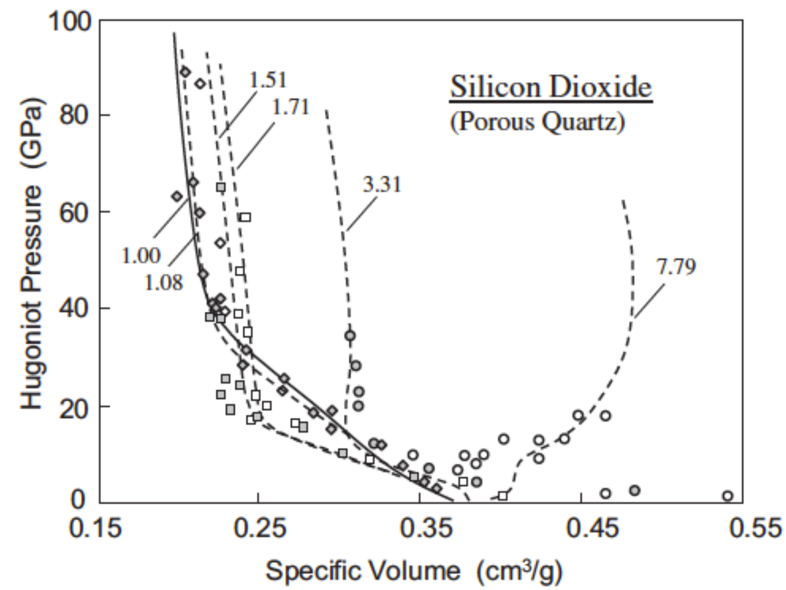


Porosity Enhanced Densification Occurs in Some Porous Ceramics

Some porous material can reach higher densities than the fully-dense form shocked to the same pressure

Grady et al. proposed that void collapse can cause phase transformations to occur at lower pressure due to enhanced shear stresses. Pressures that are locally higher could also be responsible.



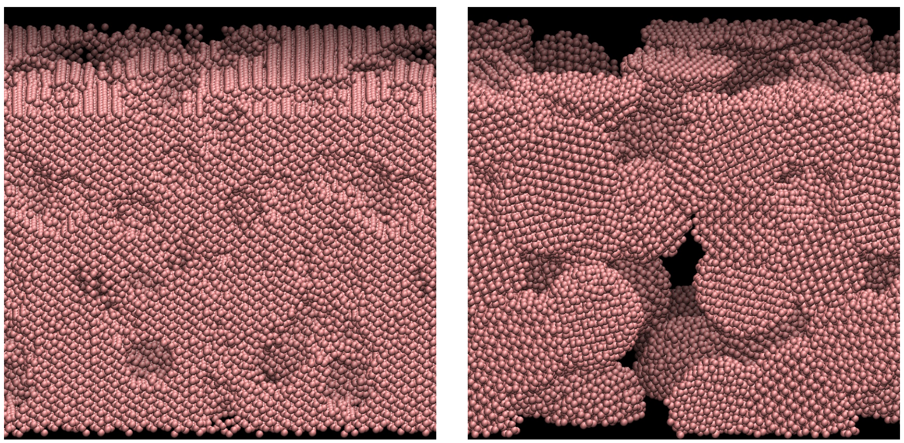


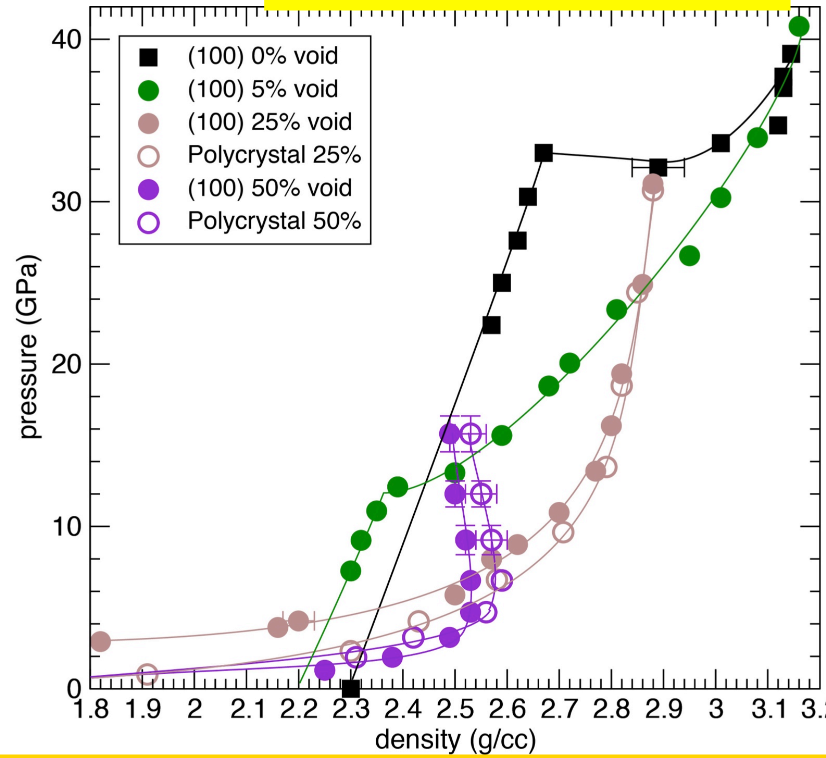
High Porosity Silicon Displays Porosity Enhanced Densification

Lane et. al, PRB, 2014

Classical MD simulations of porous silicon demonstrate phenomenon, though interpretation remains difficult

50% porosity: (l) cut voids, (r) polycrystal spheres





Can we detect emergence of phases that are not expected at a given average state? May be possible at DCS for low Z materials; MaRIE would allow extension to higher density materials (e.g. Ta_2O_5).

Direct Density Measurements for Highly Porous Systems

$$\rho = \rho_o \frac{U_s}{U_s - u_p}$$

For solids at moderate compressions (e.g. 25%), 2% uncertainties in Us and up give density uncertainties of $0.009\rho_o$ (0.007ρ)

Very distended solids (e.g. 75% porous) can have high compression ratios at modest pressures. Density uncertainties are $0.34\rho_o$ (0.085ρ)

Rigg et al. (PRB, 2008) reported density errors of order 1% for shock compression of aluminum and copper at pRad. This should be relatively independent of compression ratio.

Cu was near limit for pRad at 40 mm

Additional Thoughts on MaRIE

For optimum usage, MaRIE should provide
- reliable, well-characterized launch system
- synchronization of launch system and diagnostics

Some Static Applications
- static characterize mixture of powders when densities are comparable
- in-situ monitoring of compaction process to >1 GPa

Some Dynamic Applications
- porosity-assisted densification
- direct measurement of density in shock loading
- detection of localized melting during shock loading