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Scaling of Waves in Heterogeneous Materials

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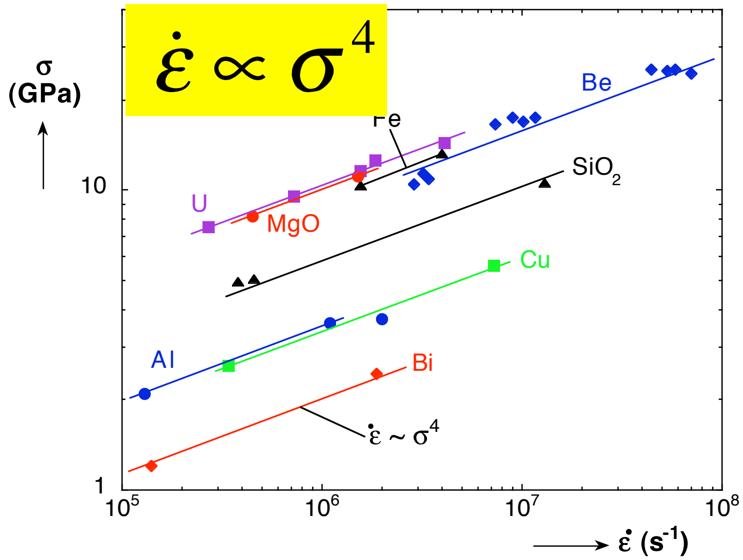
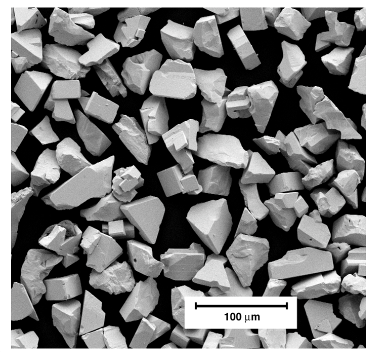
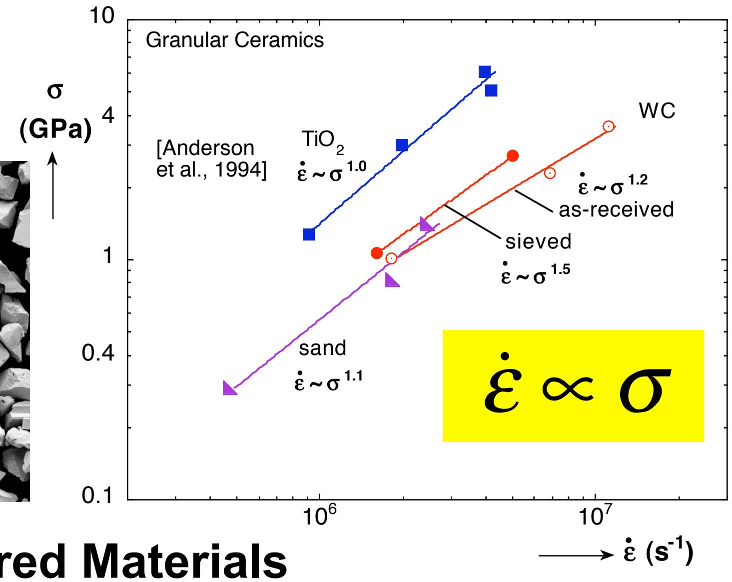
Scaling of Waves in Homogeneous Materials

"Homogeneous" Materials

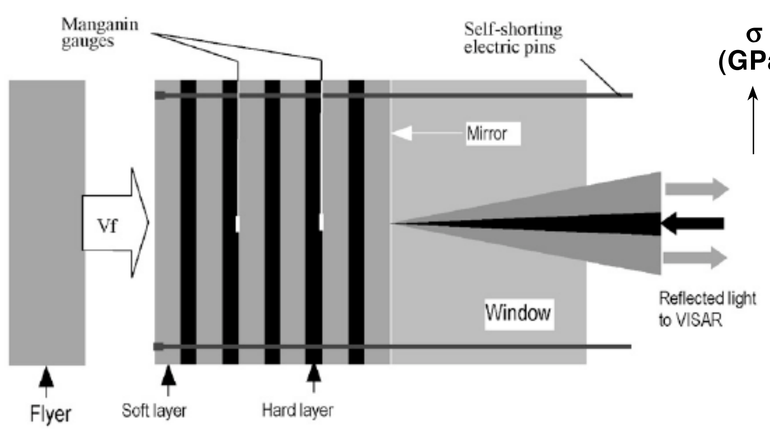


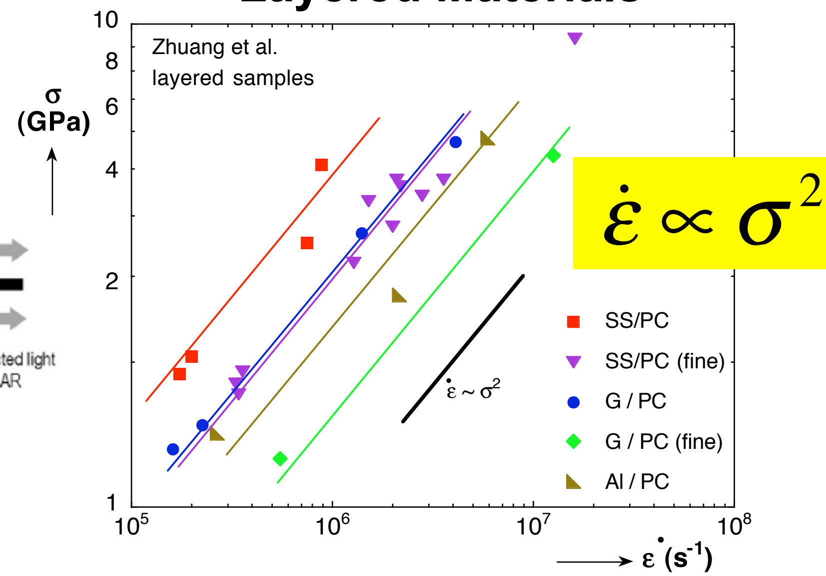


Granular Materials



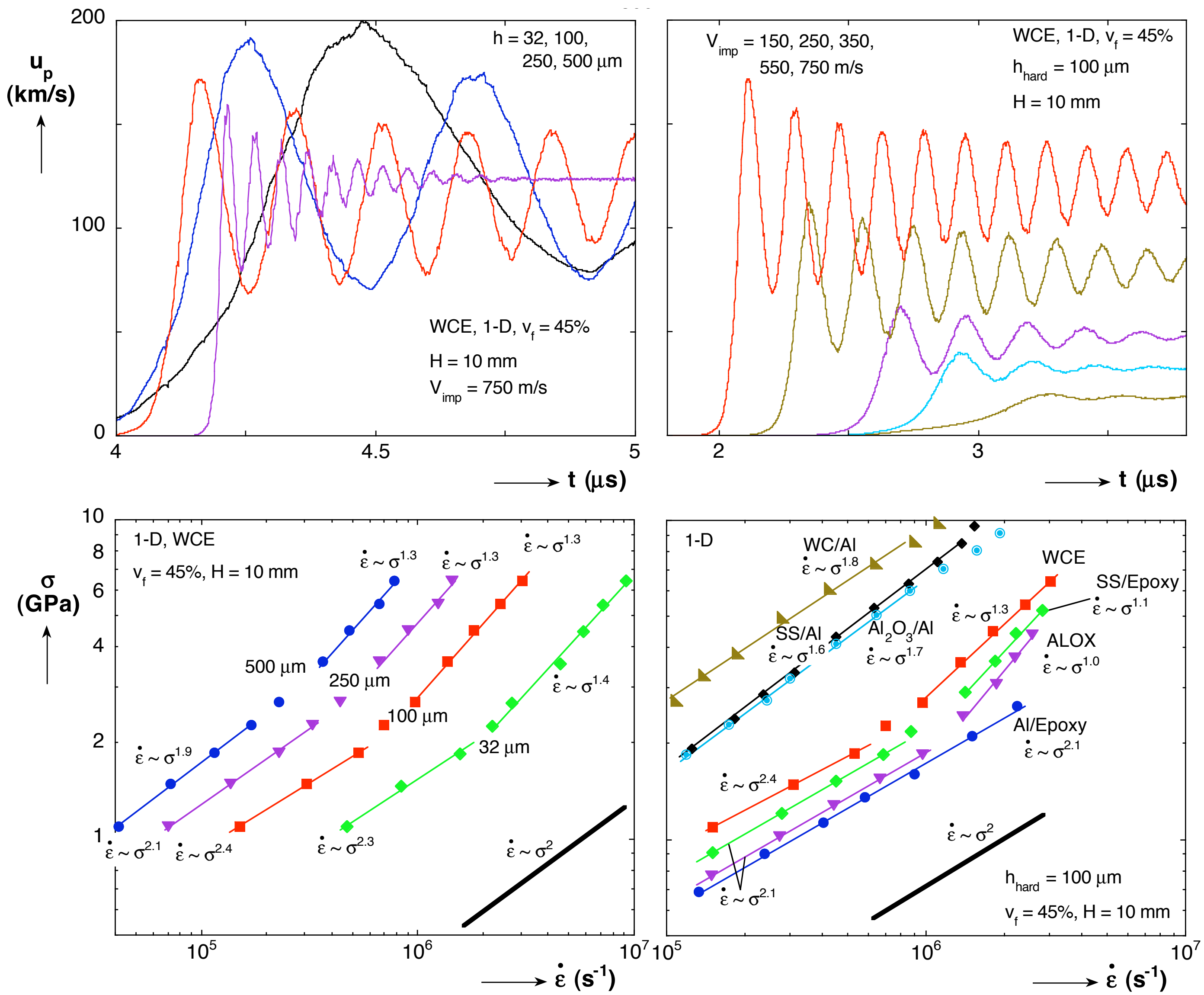
Layered Materials





Simulations for Layered Materials

1-D CTH Calculations



h ↑ $\dot{\varepsilon}$ ↓

V,σ ↑ $\dot{\varepsilon}$ ↑

also a function of material parameters of layers

Dimensional Analysis for Layered Materials

variables of problem:

$\sigma, \dot{\varepsilon}, h, v_f, C, (\rho_s,\rho_h)$ or (z_s,z_h)

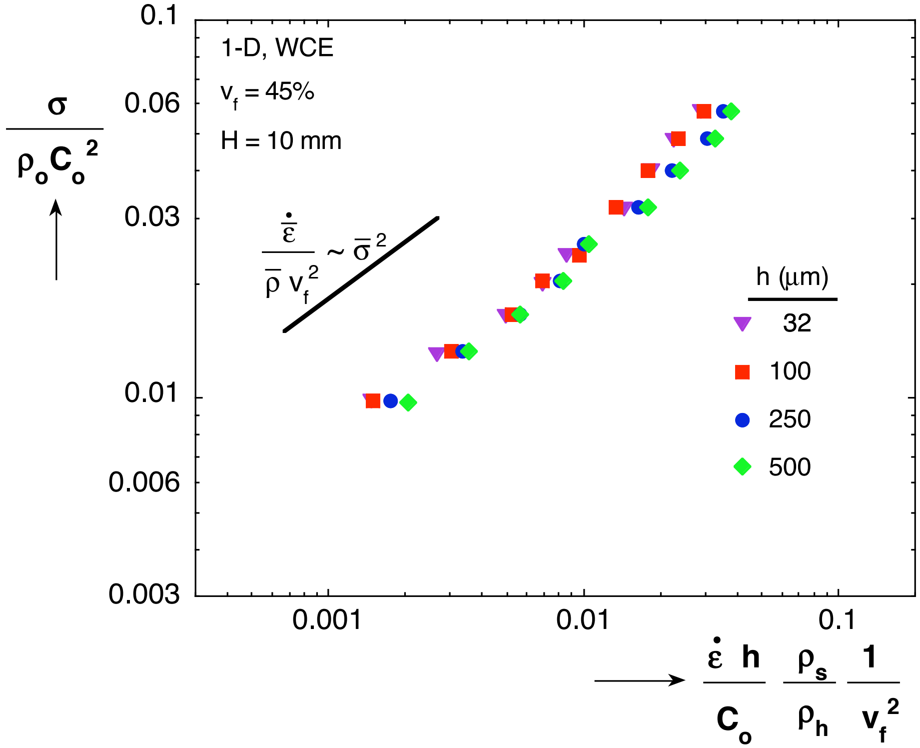
construct non-dimensional groups:

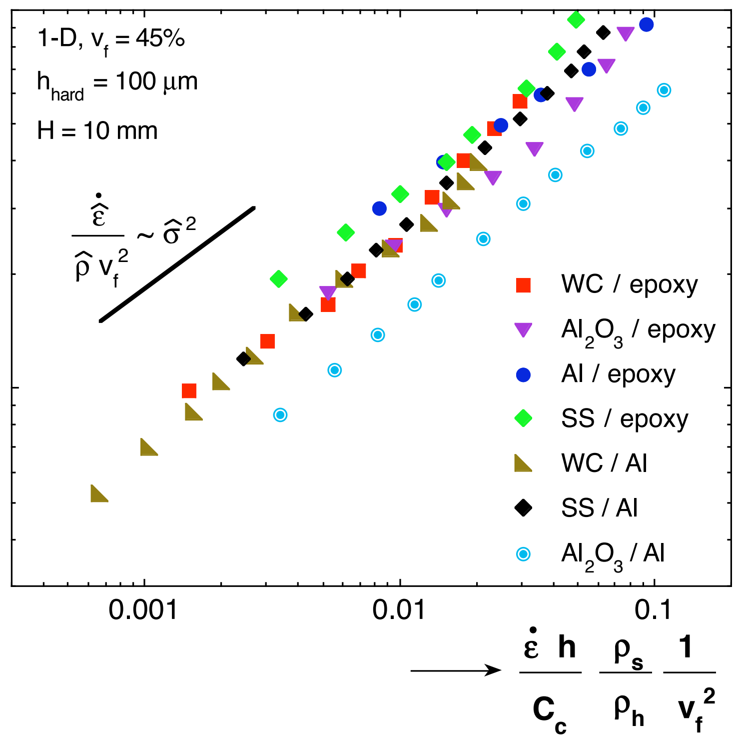
$$\bar{\dot{\varepsilon}} = \left(\frac{\dot{\varepsilon}\, h}{C_o}\right) \qquad \bar{\sigma} = \left(\frac{\sigma}{\rho_o\, C_o^2}\right) \qquad \left(v_f\right) \qquad \bar{\rho} = \left(\frac{\rho_s}{\rho_h}\right)$$

$$C_o = \left(\frac{v_f}{C_h} + \frac{1-v_f}{C_s}\right)^{-1} \qquad C_h, C_s = \begin{cases} C_B \;\; for\;\; polymers\; and\; metals \\ C_L \;\; for\; ceramics \end{cases}$$

$$\rho_o = v_f \rho_h + (1-v_f)\rho_s$$

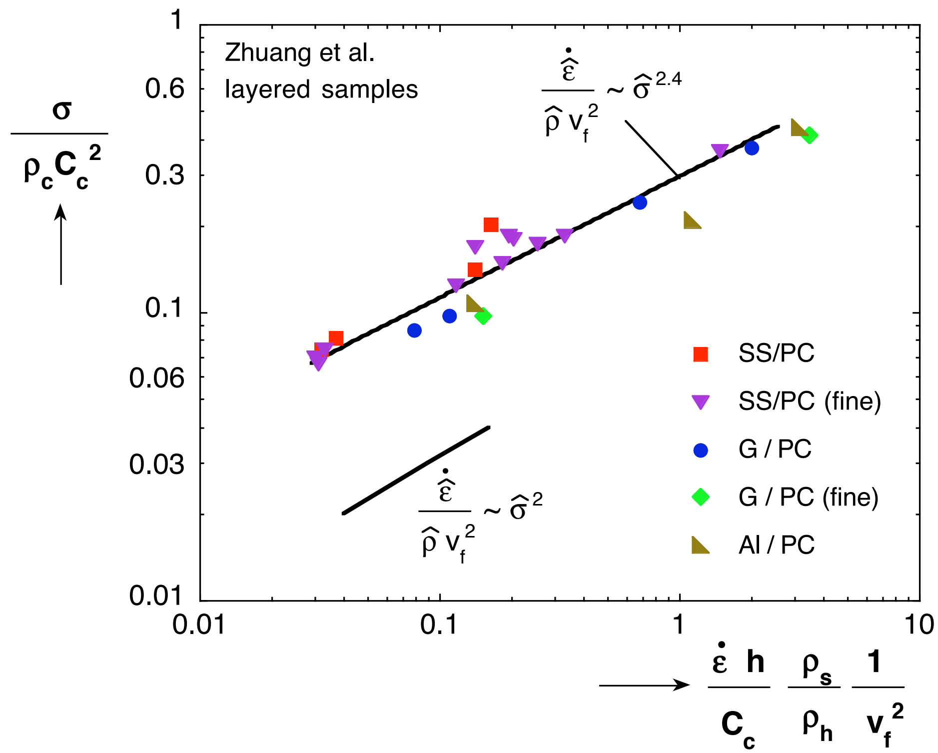
Non-Dimensional Simulation Results





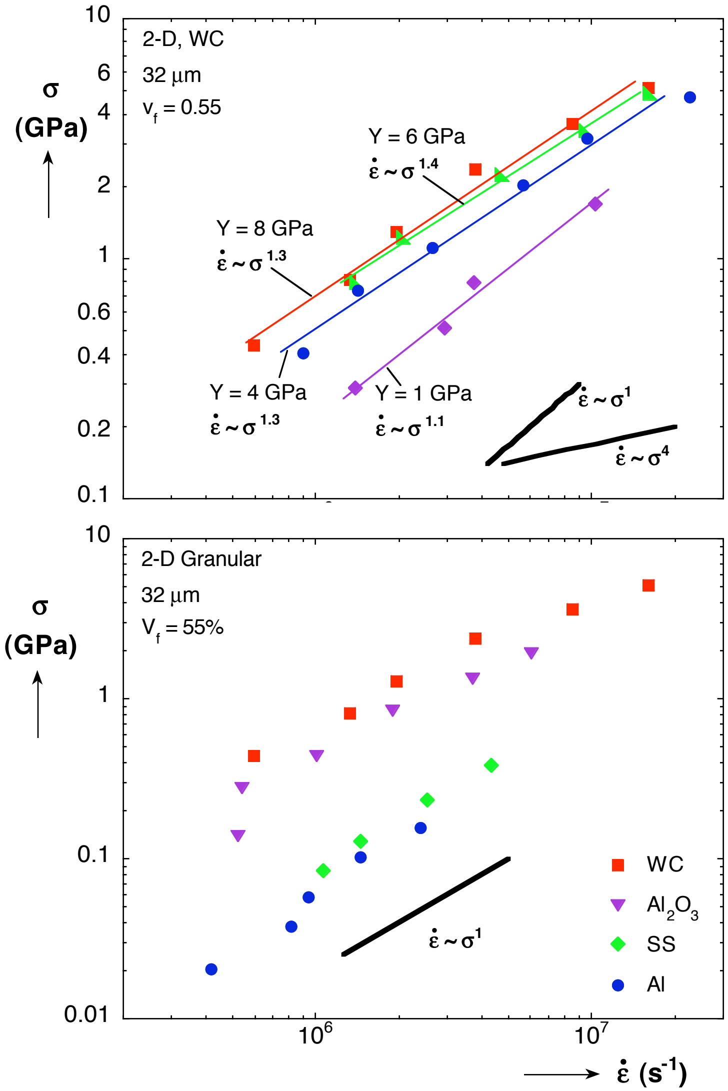
- non-dimensionalization collapses data for different layer thicknesses
- data for different material combinations collapse well using density ratio (with one exception)

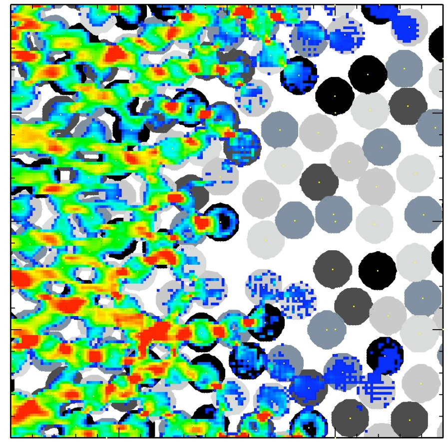
Non-Dimensionalized Experimental Results



- non-dimensional experimental results also collapse to a single curve (approximately to second power)

2-D CTH Simulations of Granular Materials

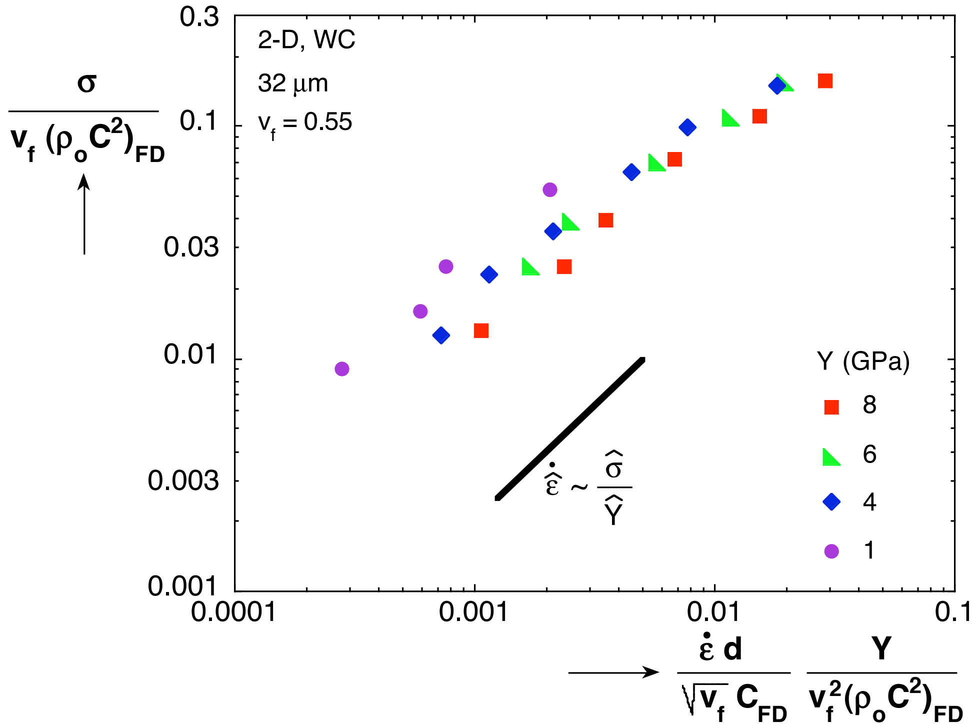


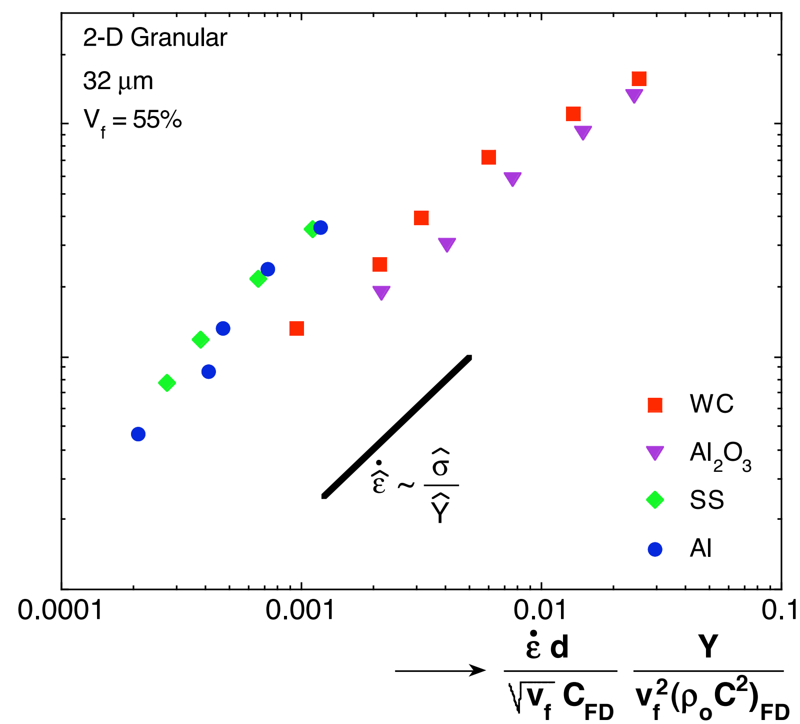


- non-planar shock structure
- CTH simulations reproduce first power scaling
- some dependence on Y, strong material dependence
- non-dimensionalization suggested by Grady (2010):

$$\frac{\sigma}{\dot{\varepsilon}} \propto \left(\frac{\rho_o}{\rho_s}\right)^m \sqrt{\rho_o\, d^2\, \sigma_c}$$

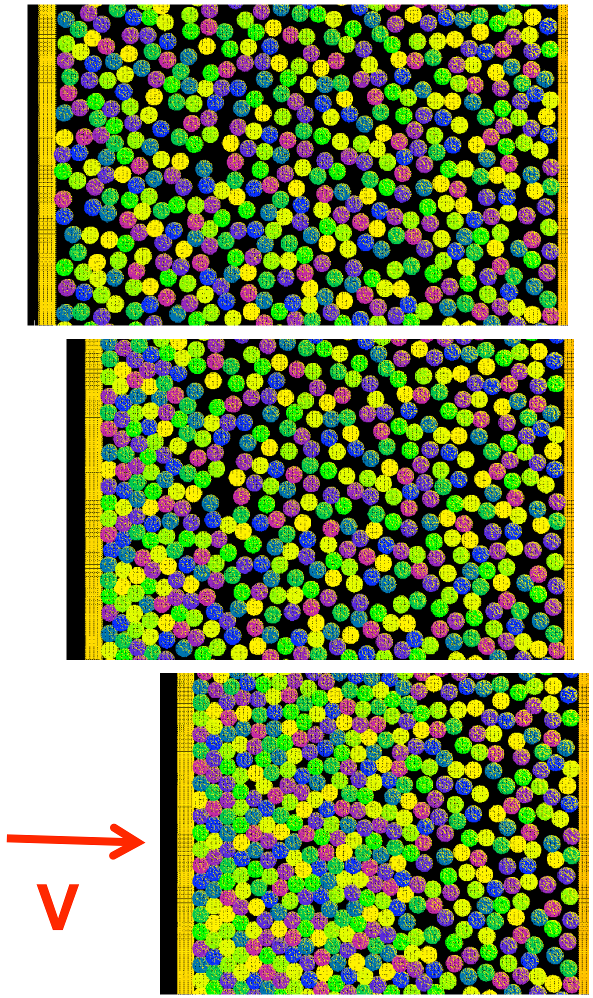
Non-Dimensionalization of CTH Results



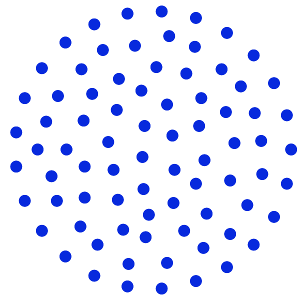


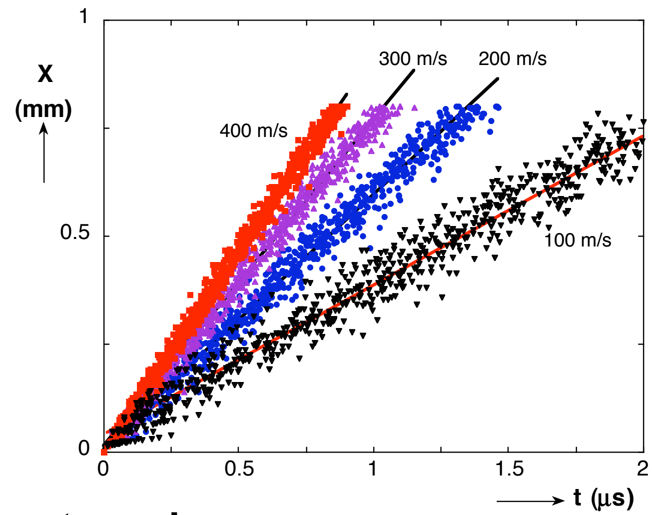
- scale wave speeds by square root of volume fraction (suggested by Steinberg, some validation by Bless)
- Y needed to collapse data, though metals and ceramics separated somewhat

Results from a Particle-Based Code



EMU - Parallel, particle-based implementation of peridynamics (Silling, S. A. (2000). *J. Mech. Phys. Solids 48, 175-209*

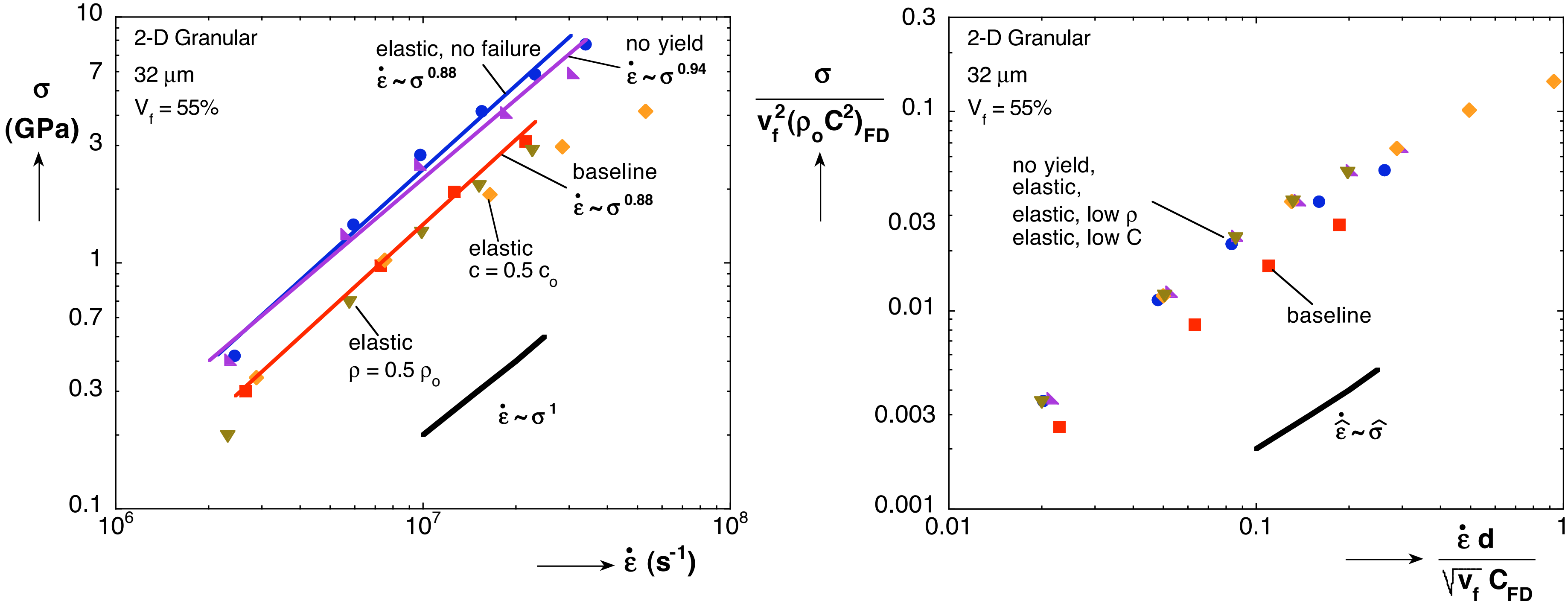




- waves appear steady
- wave speed increases with V
- width of band decreases with V
- elastic simulations yield same scaling - Grady's scaling doesn't work

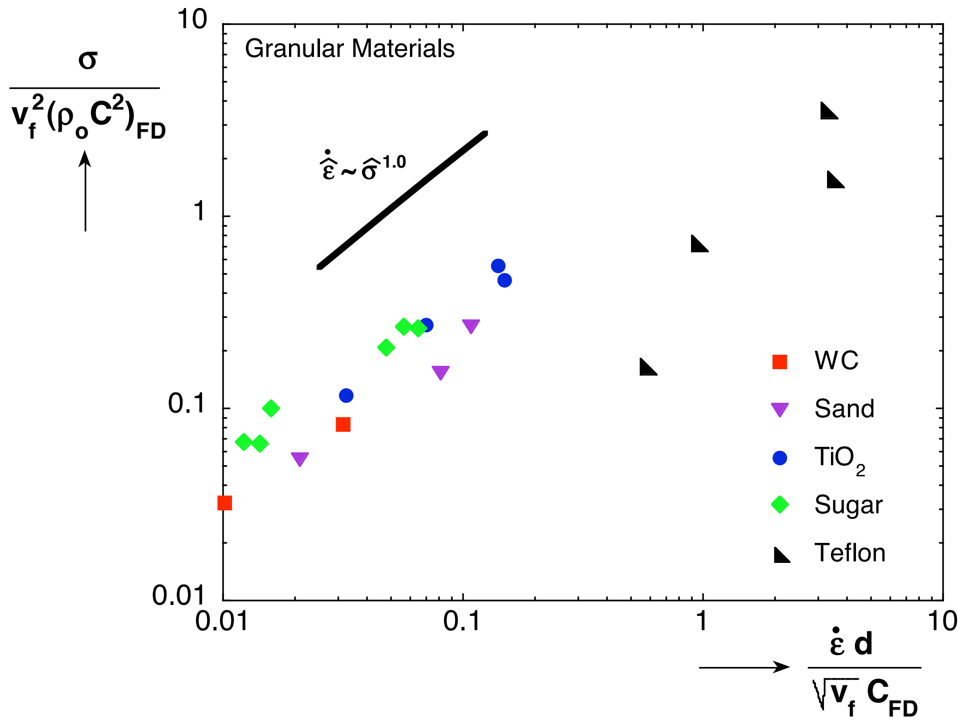
10:00 AM–10:15 AM Friday, Renaissance Ballroom AB
Chris Lammi - Mesoscale Simulations of Granular Materials with Peridynamics

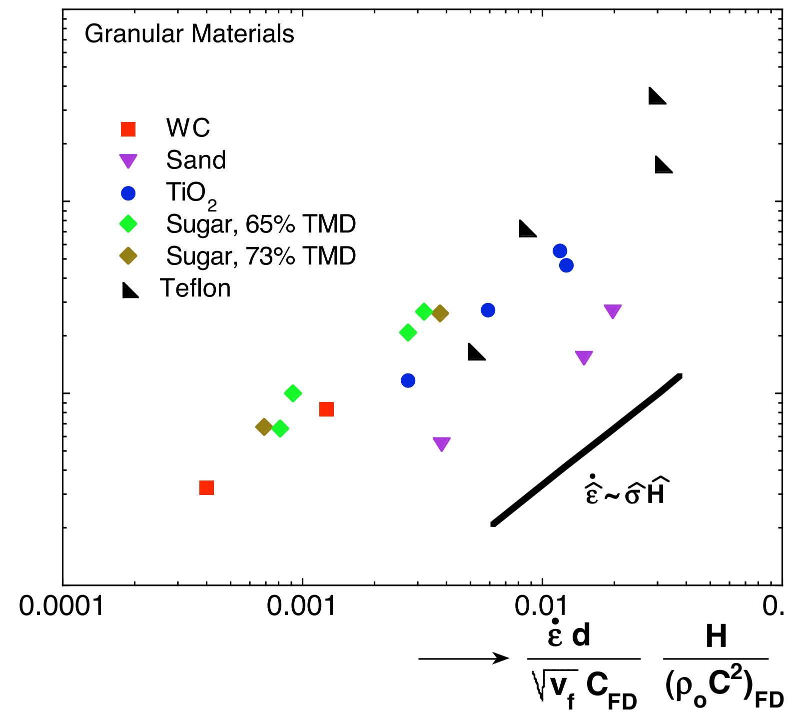
Non-Dimensionalization for EMU Results



- no strength in problem is material elastic
- fracture does not seem to affect scaling
- elastic-plastic material (baseline) has lower characteristic wave speed → will shift data upward

Non-Dimensionalization of Experimental Results

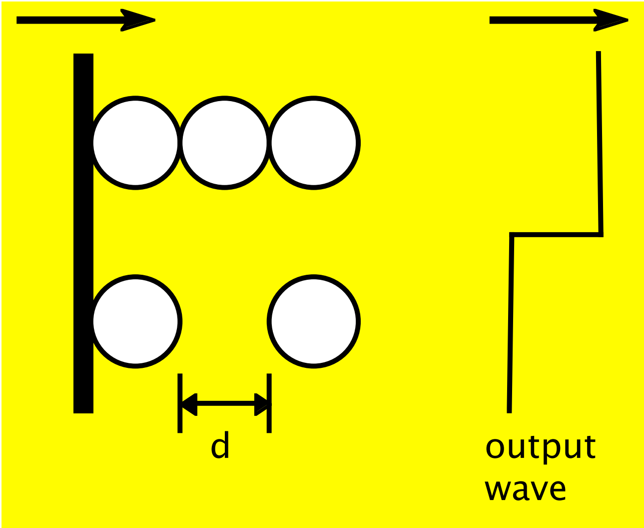




- use hardness (H) as characteristic strength
- does volume fraction enter in separately?
- ceramics collapsed better without H, teflon collapsed better with H → additional data needed to distinguish two possibilities

A Simple Scaling Argument for Granular Materials (1)

$$\varepsilon = \frac{u_p}{U_s}$$



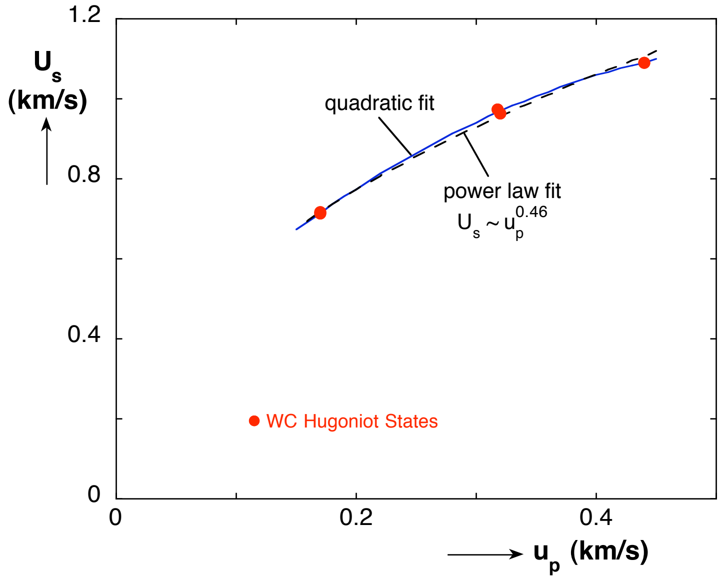
$$\dot{\varepsilon} \propto \frac{\varepsilon}{\Delta t} \propto \frac{u_p / U_s}{d / u_p}$$

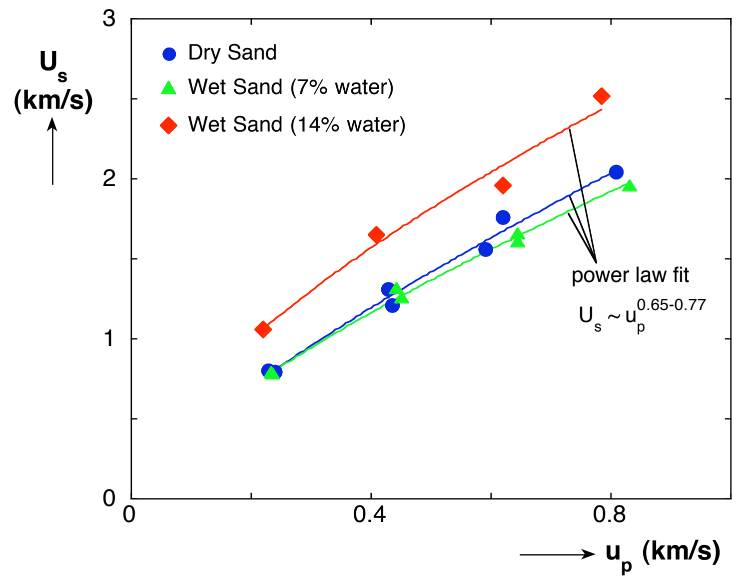
mass traversing pores controls width of shock front

$$\dot{\varepsilon} \propto \frac{u_p^2}{d\,U_s}$$

A Simple Scaling Argument for Granular Materials (2)

$$\sigma = \rho_{oo} U_s u_p \qquad \dot{\varepsilon} \propto \frac{u_p^2}{dU_s}$$





$if \ \ U_s \propto u_p^{0.5}$

$\sigma \propto u_p^{3/2}$ $\dot{\varepsilon} \propto u_p^{3/2}$ ➡ $\dot{\varepsilon} \propto \sigma$

$if \ \ U_s \propto u_p^{0.75}$

$\dot{\varepsilon} \propto \sigma^{0.7}$

mass transfer across void is critical aspect, thus granular WC and WC/epoxy behave very differently

Conclusions

- power law dependence of strain rate with stress occurs in materials with microstructure:
  - 2nd - layered materials - wave reverberation due to density differences
  - 1st - granular materials - mass transport
- non-dimensionalization collapse both experimental and simulated data for layered materials
- a simple argument based on mass transport yields first power scaling for granular materials
- non-dimensionalization for granular materials can be done (at least) two ways
- how to apply to mixtures of granular materials?