



Some Considerations on Yield Stress:
A Modeler's Perspective



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Why study the rheology of concrete?

- # Concrete is the most widely used building material.
 - # Ease of flow and placement can significantly reduce costs.
 - # Architectural benefits: Improving workability and mechanical properties allows for more flexibility in design.
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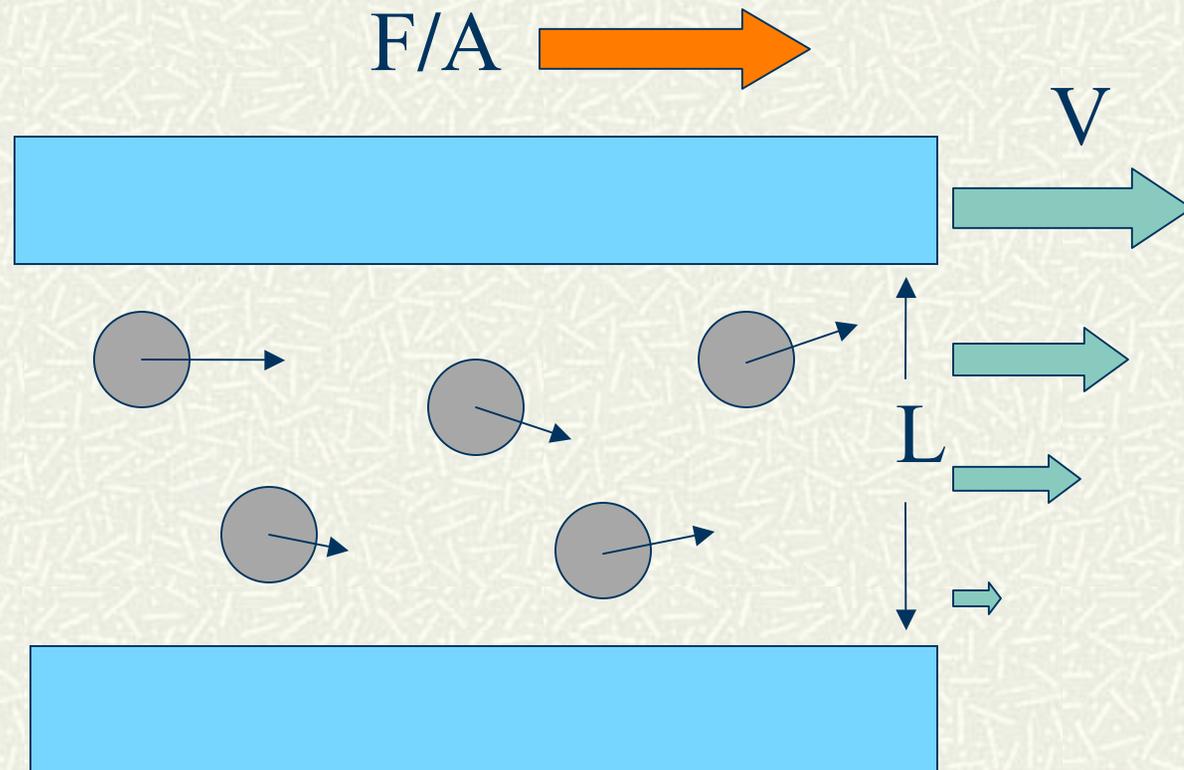
$$\text{Viscosity} = \frac{F/A}{V/L}$$

F = applied force

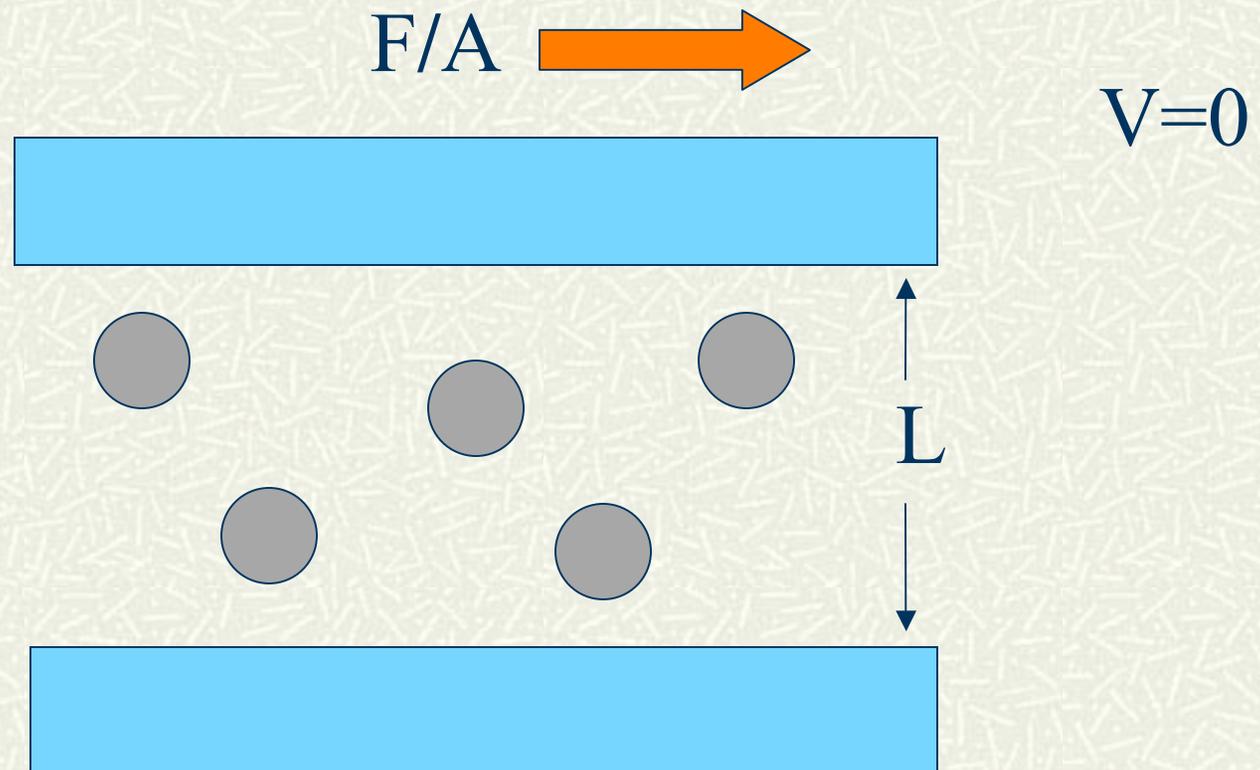
A = area

V = velocity

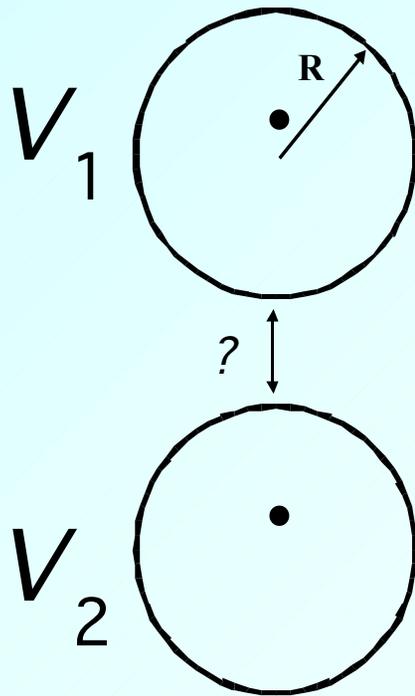
L = gap width



Yield Stress



Lubrication Forces

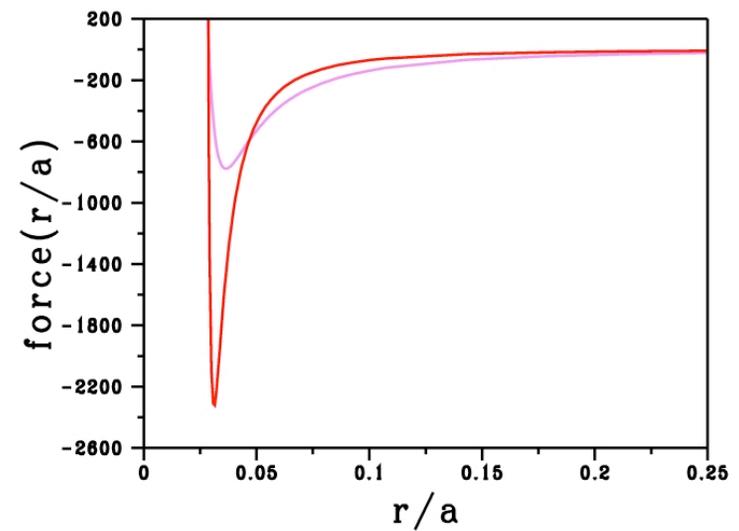
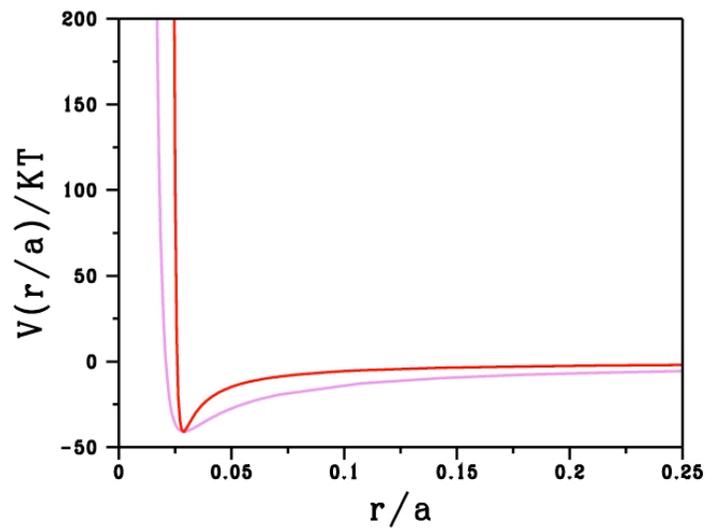


$$F \sim \frac{V_1 - V_2}{?}$$

$$\text{High } Pe = \frac{6\pi \eta R^3 \dot{\gamma}}{kT}$$

$$\text{Probe Distances} \sim \frac{1}{Pe}$$

Interaction potential



Model: Measurement

- # Bingham model

$$\dot{\gamma} = \dot{\gamma}_0 + \gamma$$

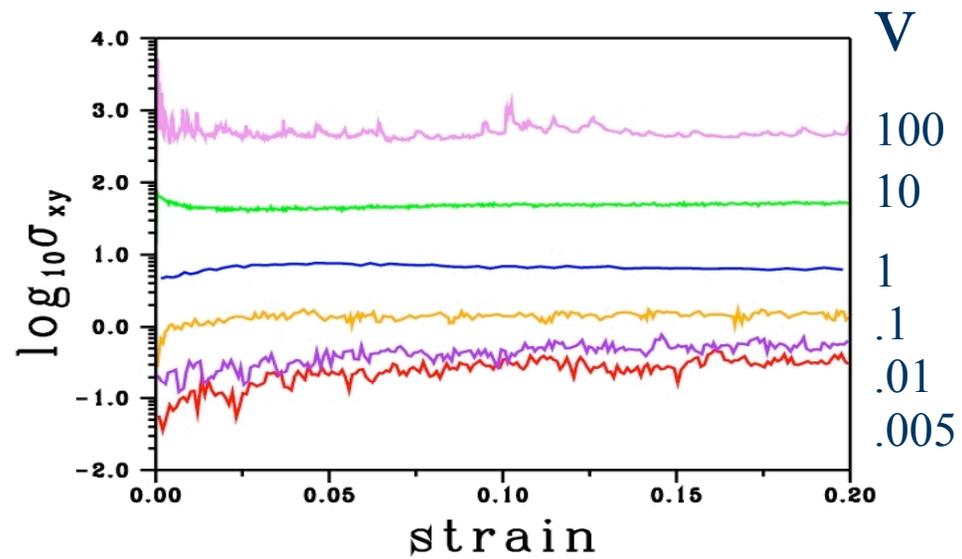
- # Hershel Buckley:

$$\dot{\gamma} = a \dot{\gamma}^n + \gamma$$

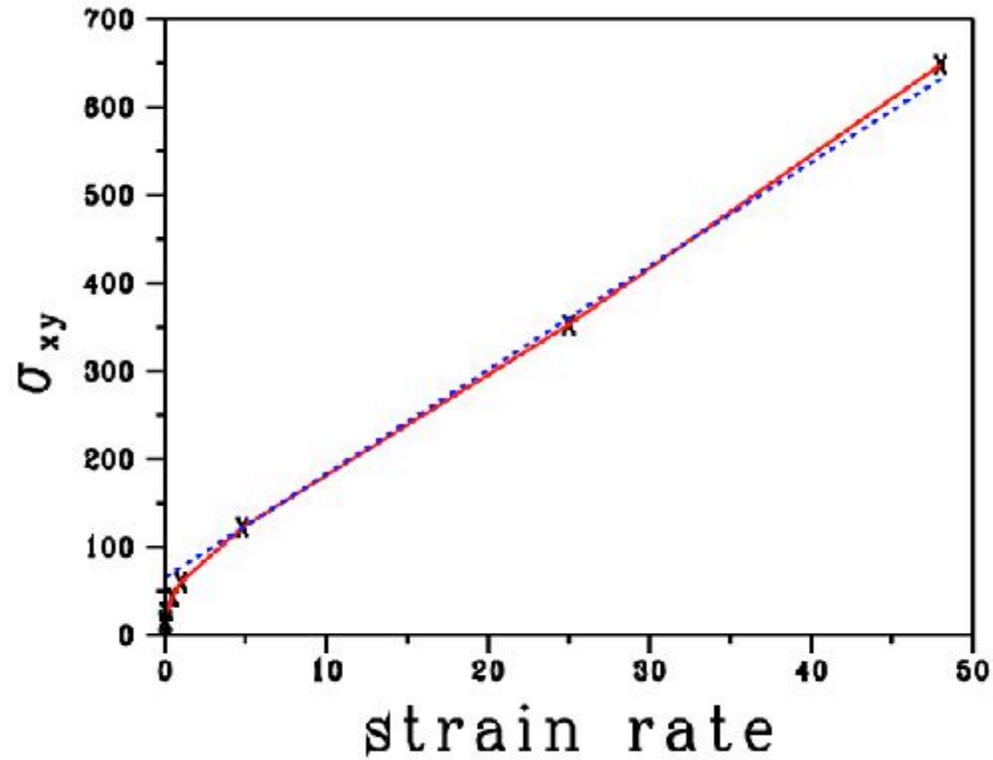
- # Modified Casson Equation:

$$\dot{\gamma} = \left(a \dot{\gamma}^{1/p} + \gamma^{1/q} \right)^q$$

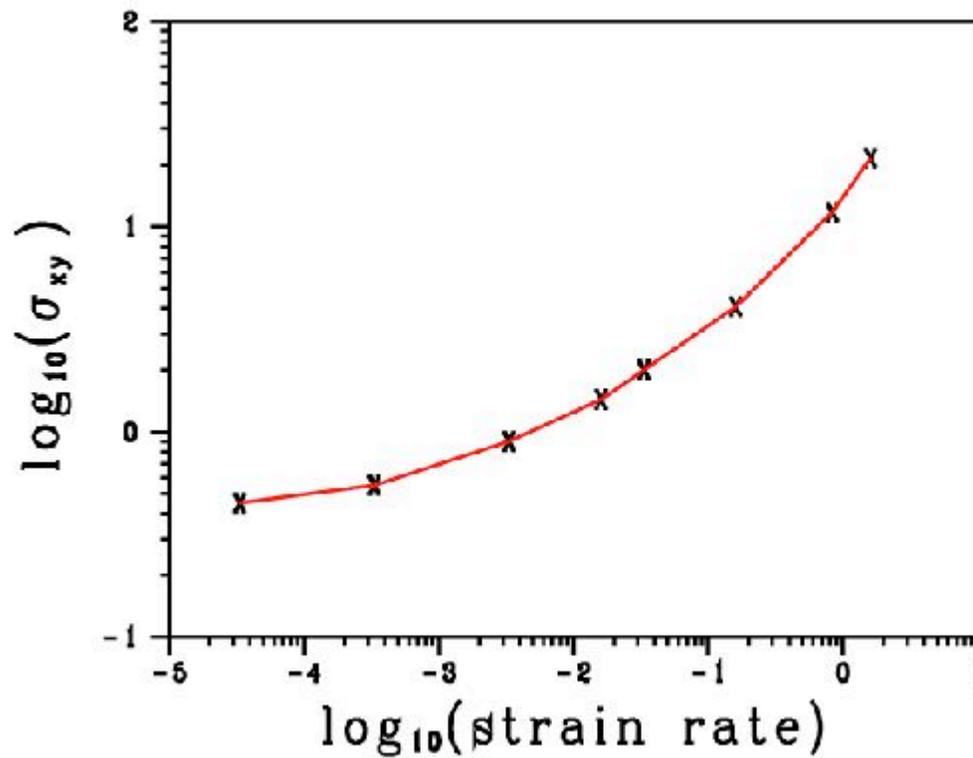
Stress Growth



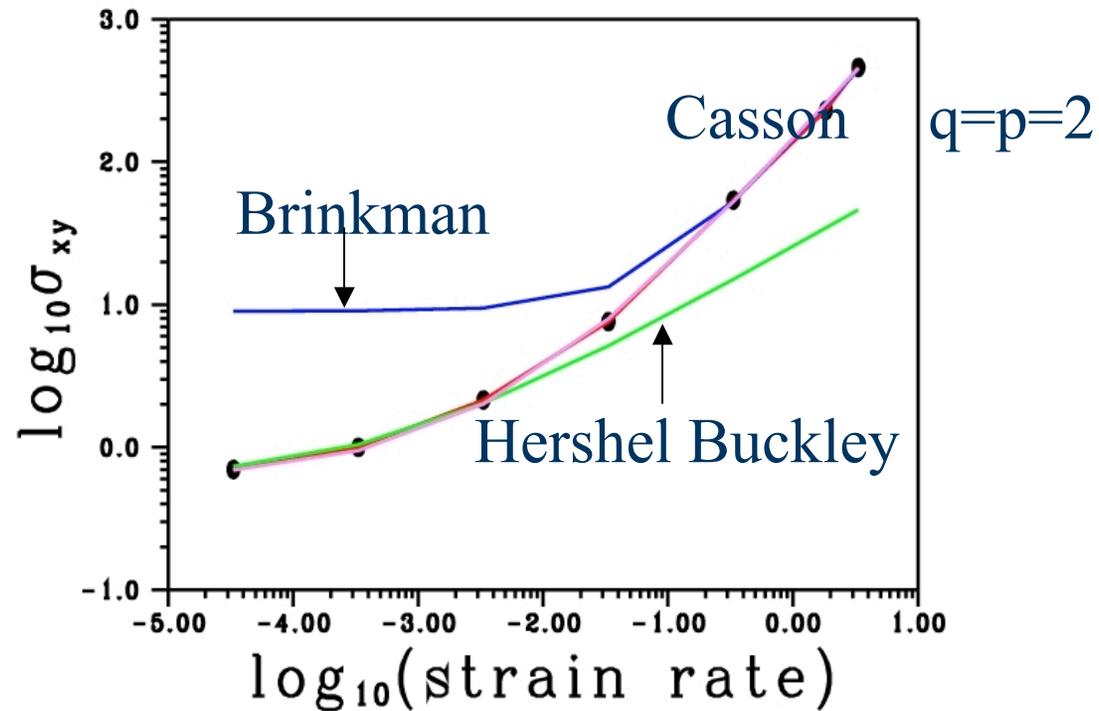
Bingham Model



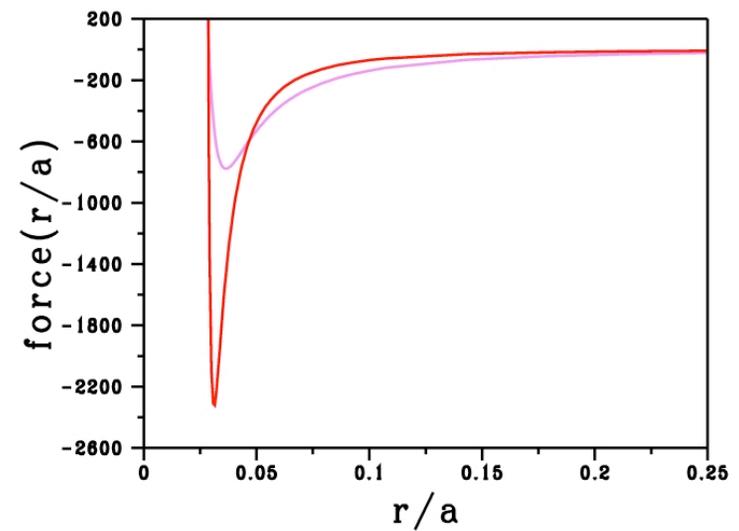
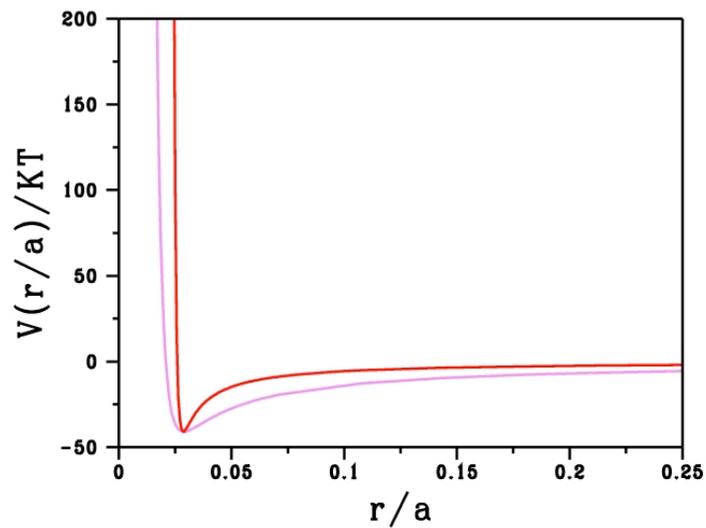
Low Shear Rate Limit



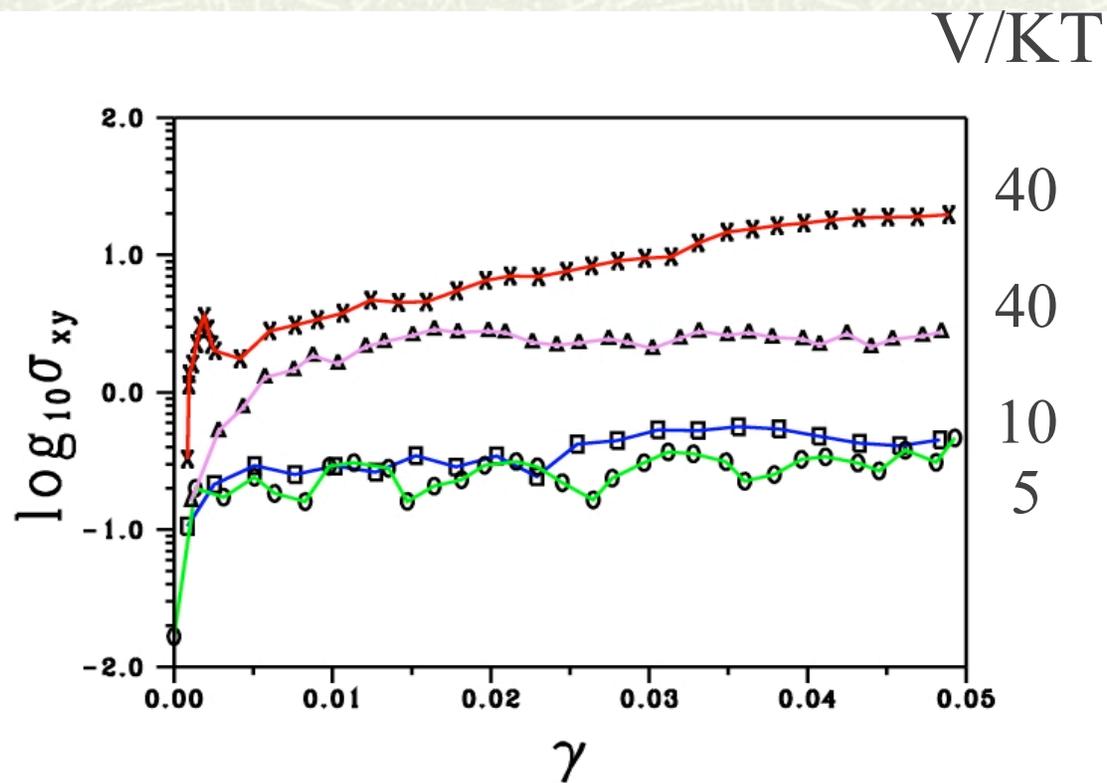
Comparison of models



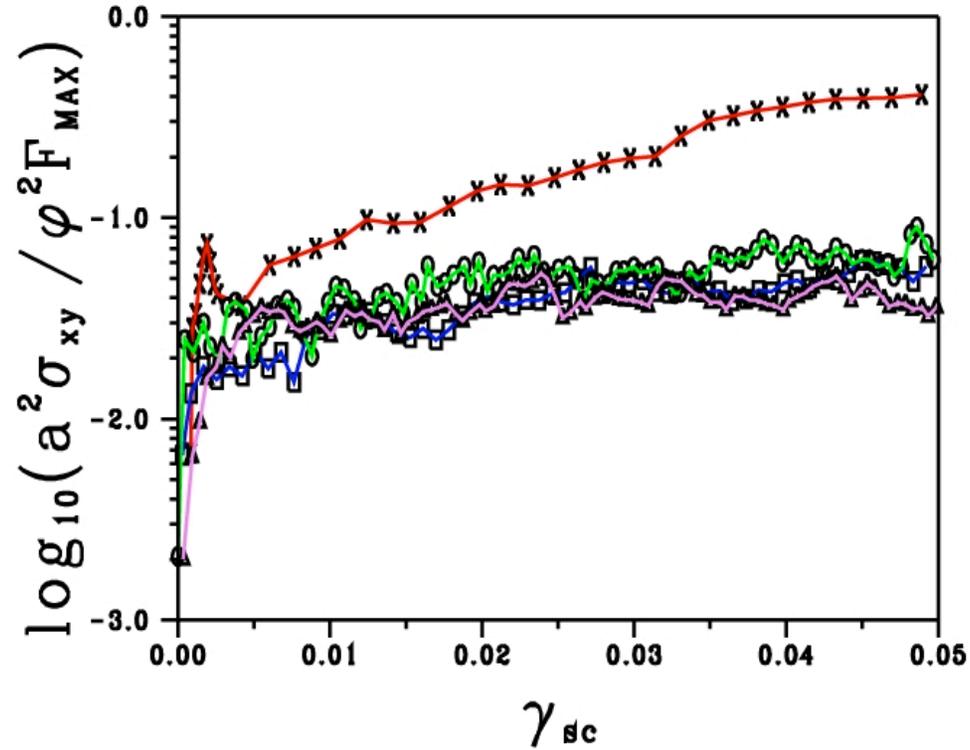
Role of force vs. potential



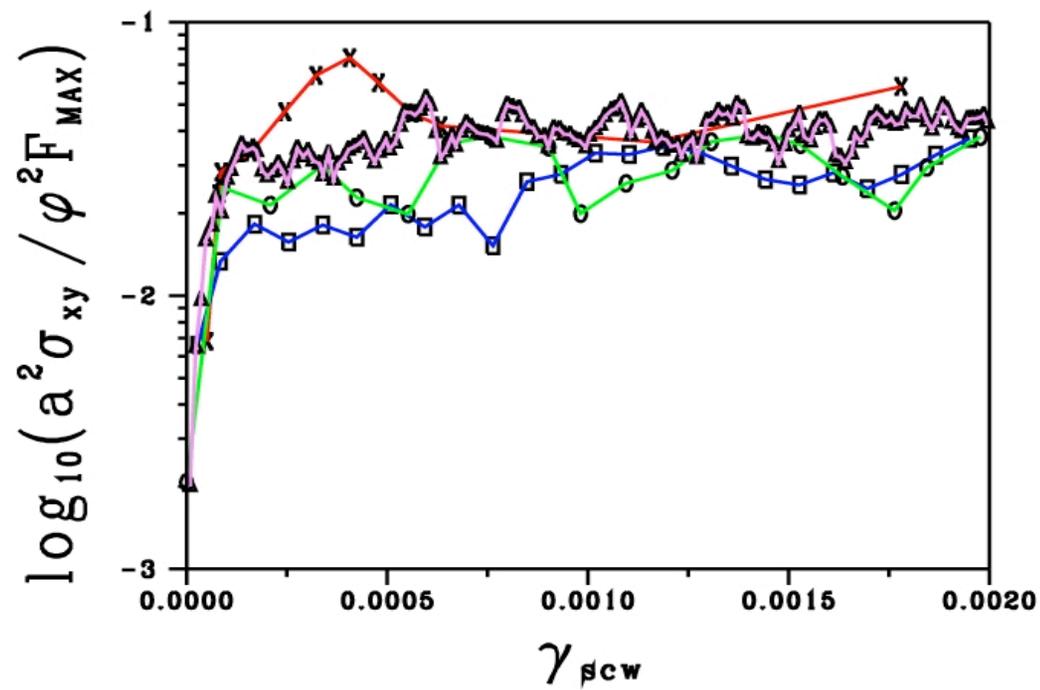
Stress Growth-Raw Data



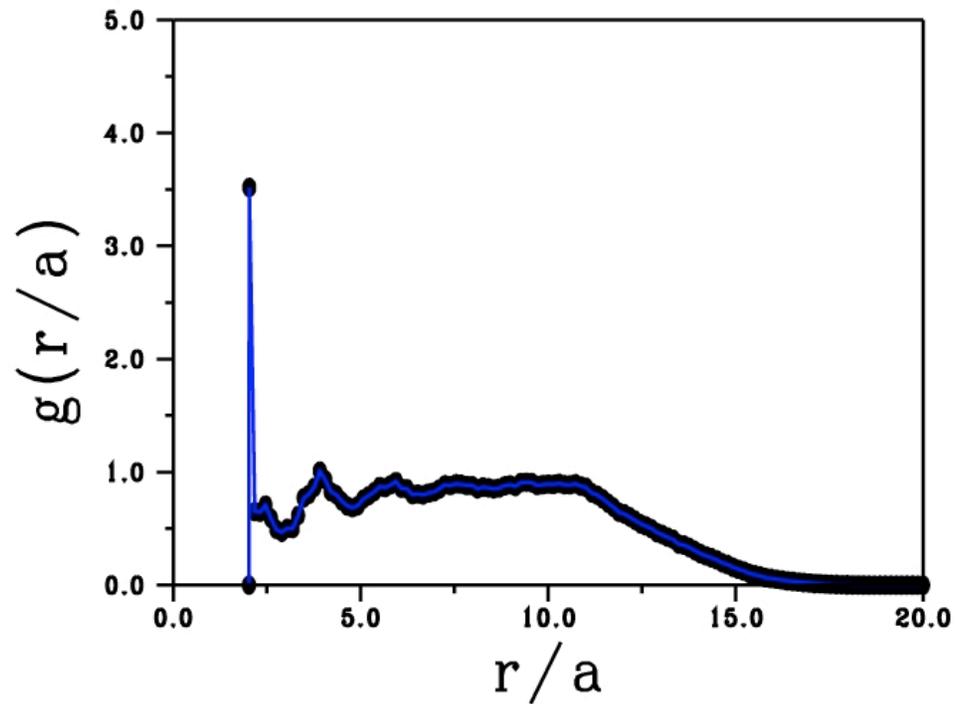
Scaled Data (I)



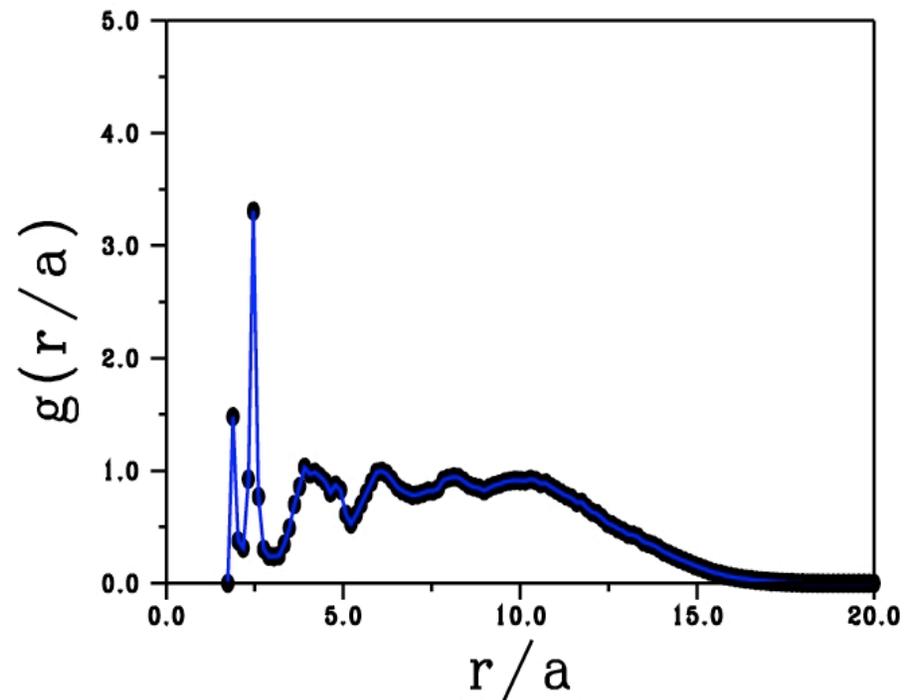
Scale Data (II)



Radial distribution function: $V(r)$



Radial distribution function for scaled potential: $V(3r)$

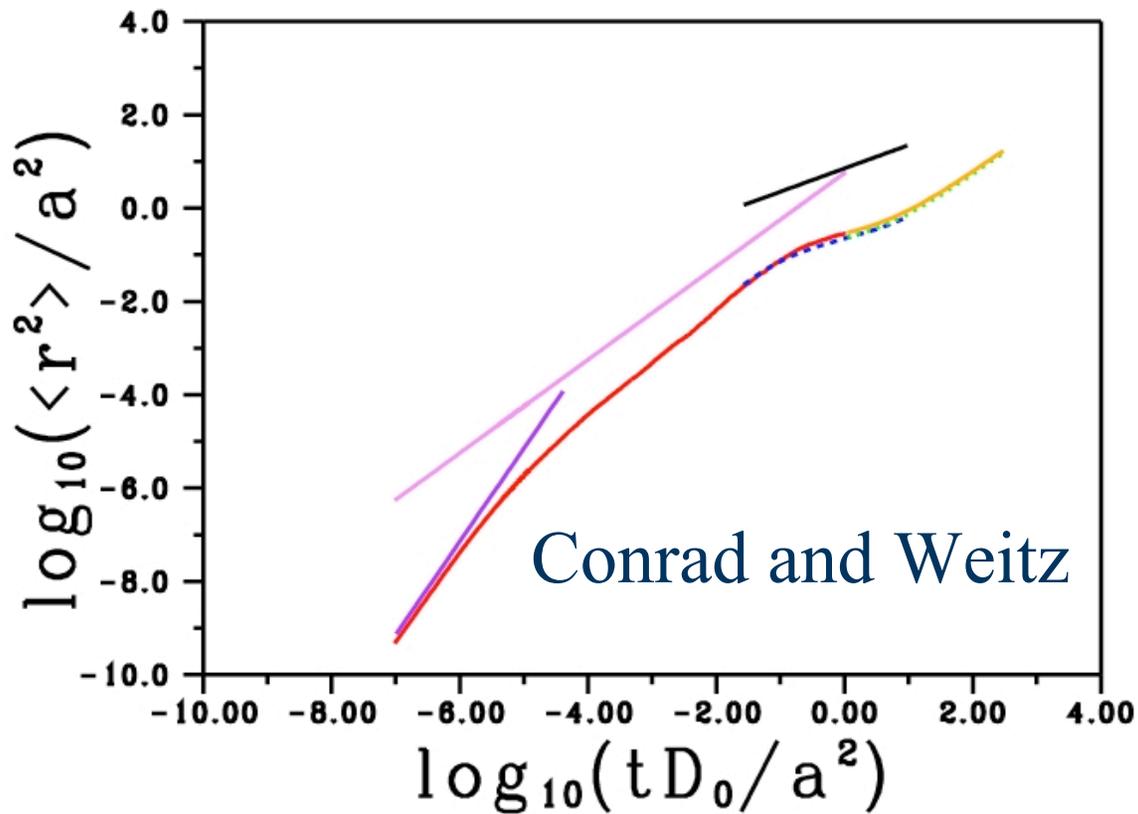


Observations on Yield Stress

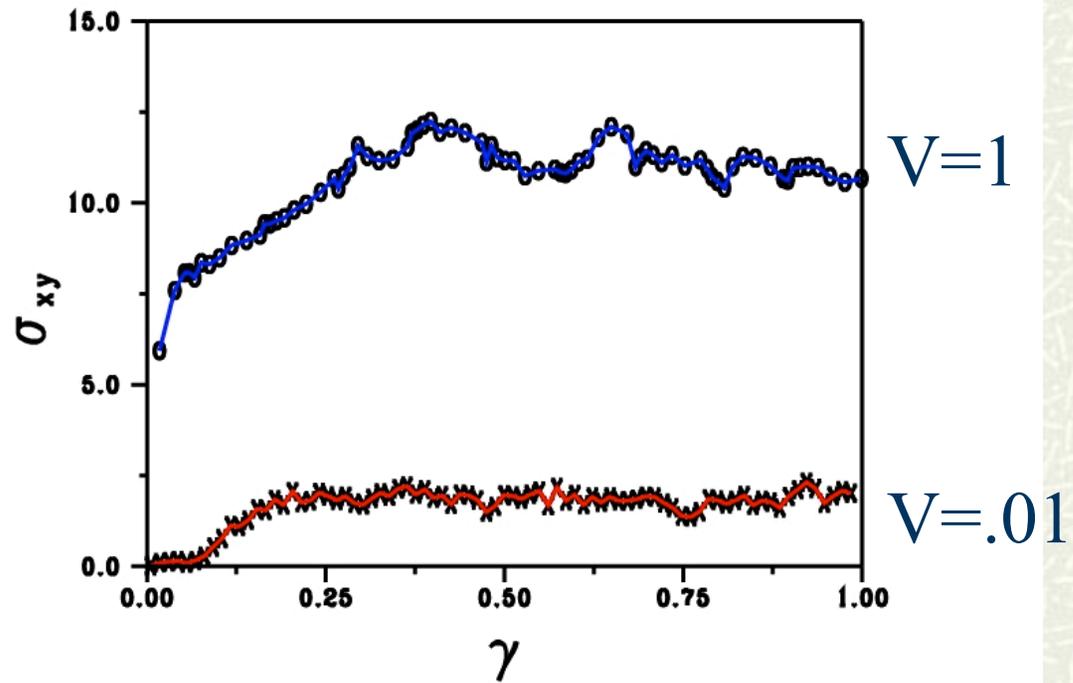
- 1) Over small strains ($\ll 1$) stress growth simulation data can be collapsed using maximum force and interaction potential width as scaling parameters (at fixed concentration).
 - 2) Over larger strains (~ 0.1) entropic barriers begin to complicate analysis.
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Mean Squared Displacements

Volume fraction=0.52



Yield Stress?



Some possible questions...

- 1) Further validation steps?
 - 2) What are the most reliable measurements to compare to?
 - 3) Other improvements?
 - 4) Potential use of AFM or other methods to determine inter-particle forces.
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Realistic interaction forces

Nonat et al.

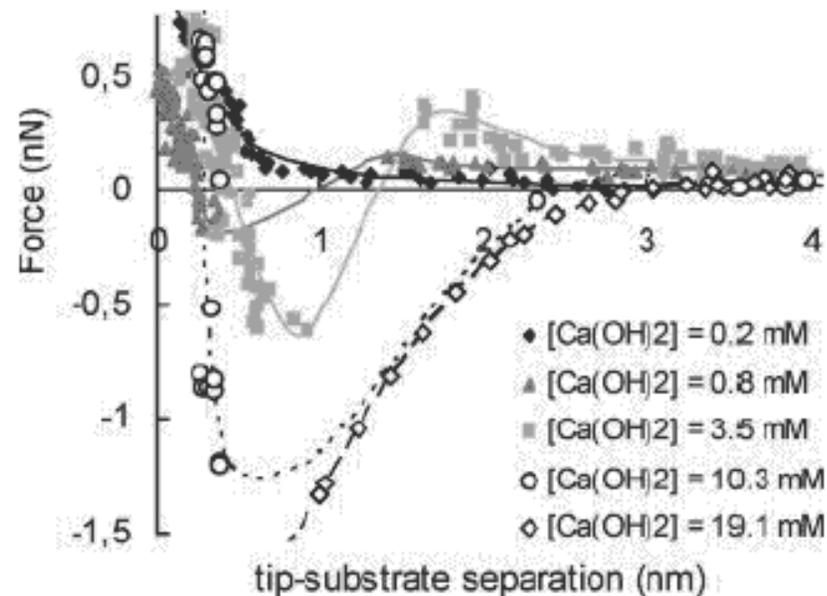
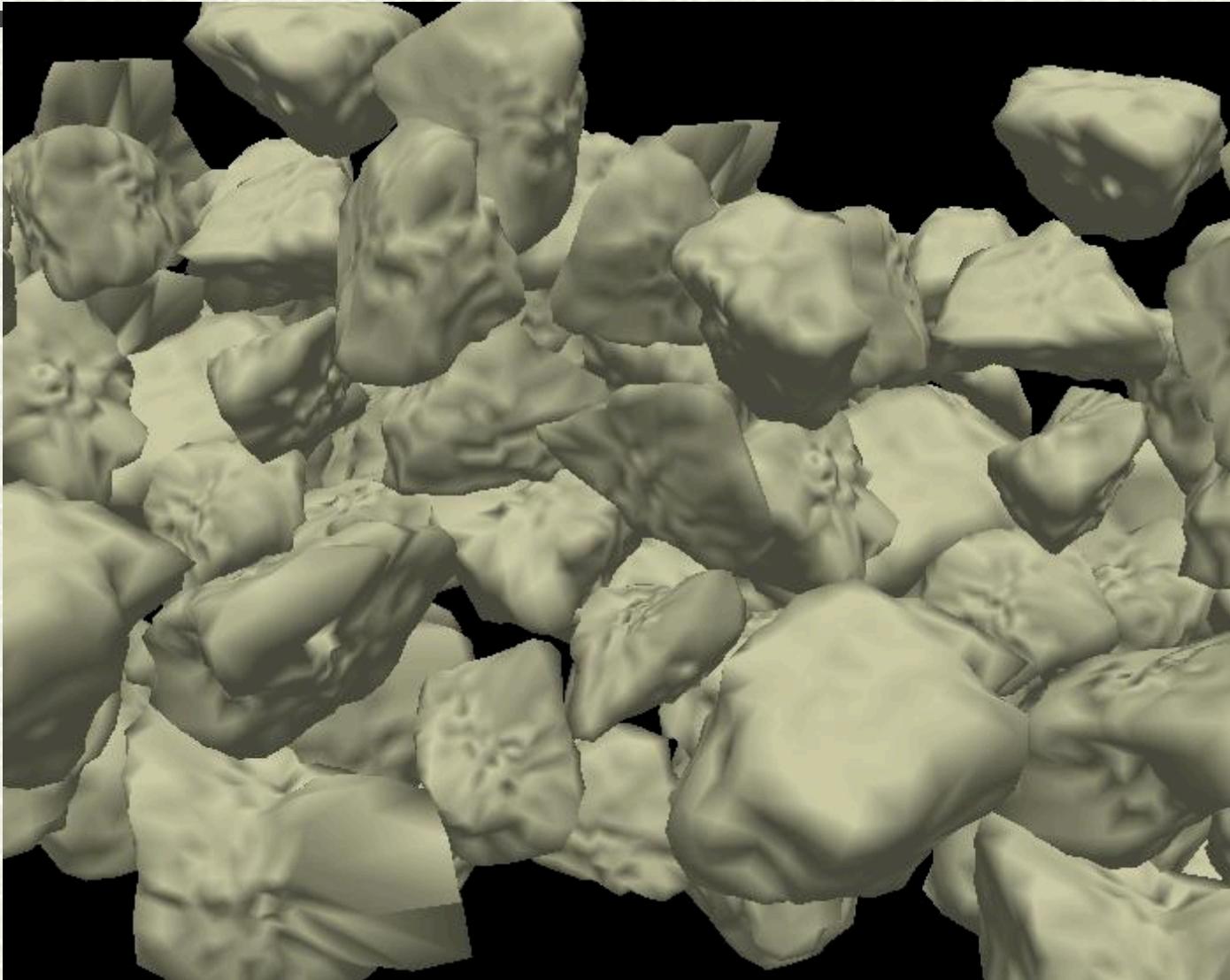
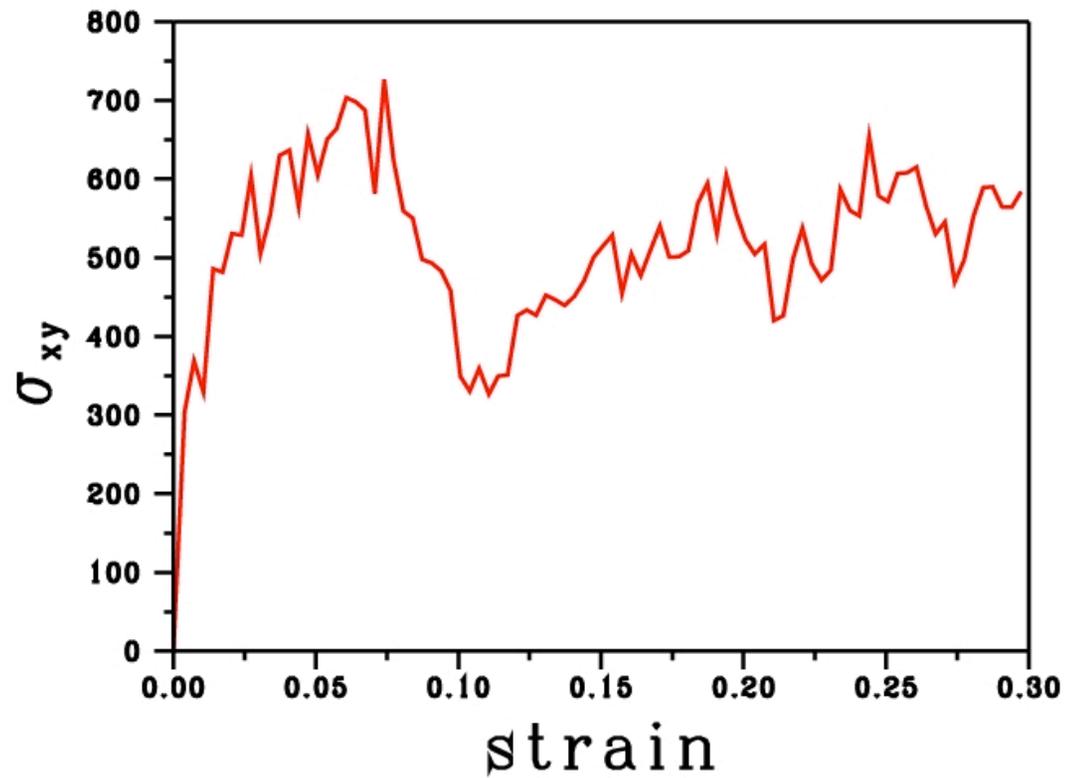


Figure 5. Interaction forces measured between a micrometric flat C–S–H surface and a C–S–H nanocrystal at the top of an AFM tip immersed in Ca(OH)₂ solutions of different concentrations (series 1 in Table 1). Lines are only guides for eyes.

Cement Particles



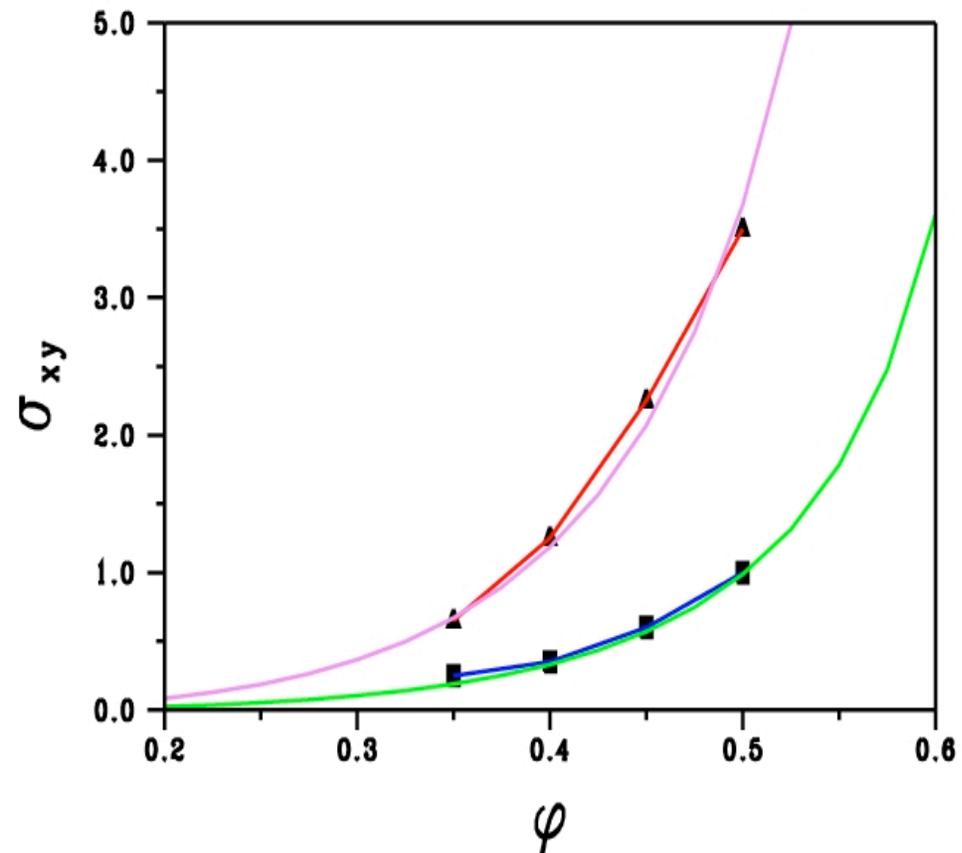
Cement Particles



Yield Stress vs. Volume Fraction

$$\sigma_y = m \frac{\sigma_{y1}^m + \sigma_{y2}^m - \sigma_{y1}^m \sigma_{y2}^m}{\sigma_{y1}^m + \sigma_{y2}^m - \sigma_{y1}^m \sigma_{y2}^m}$$

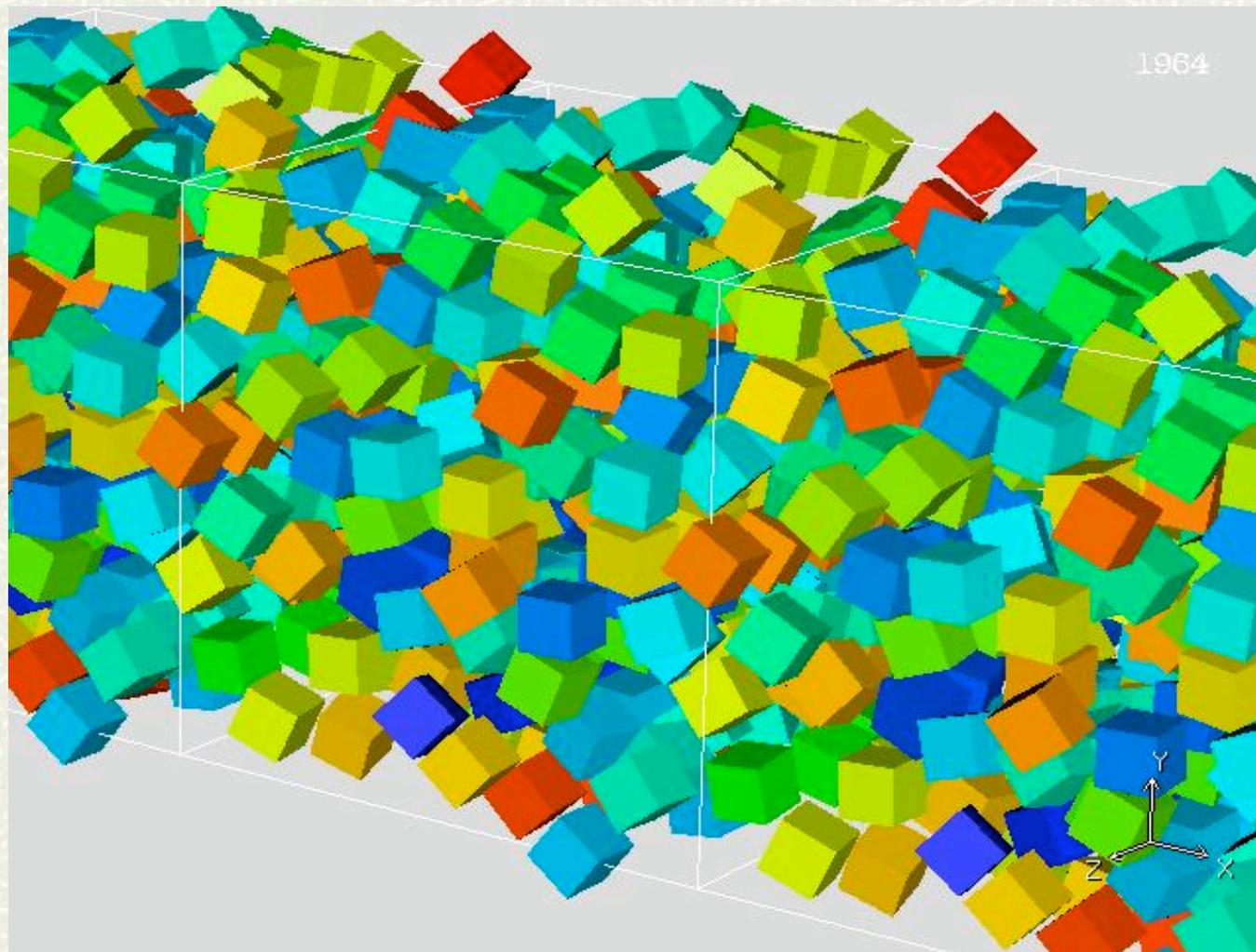
Flatt and Bowen



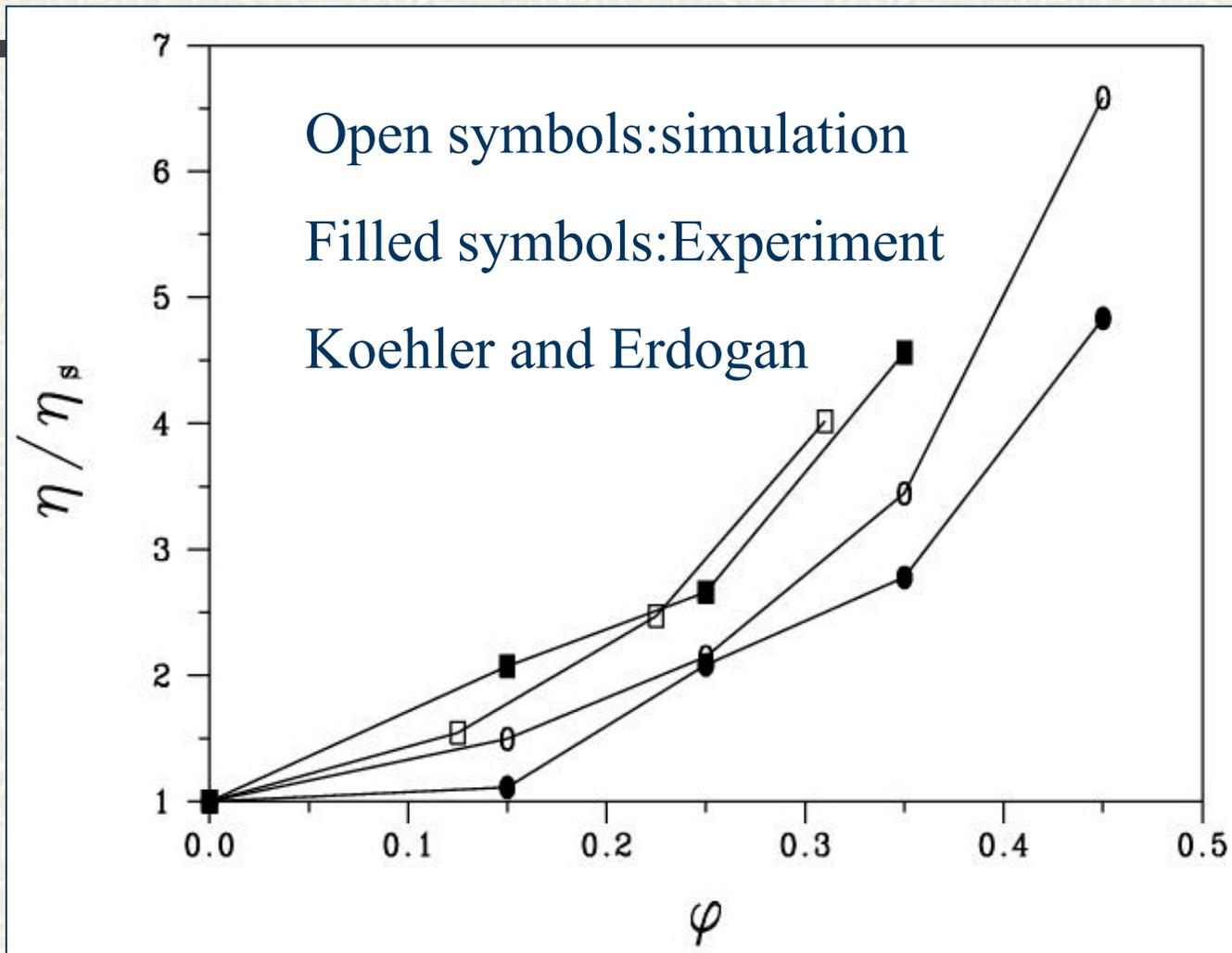
Acknowledgements

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 - # VCCTL, ACBM
 - # NASA
-

Sheared Cubes



Spheres and Cubes



Revisit Bingham Model

