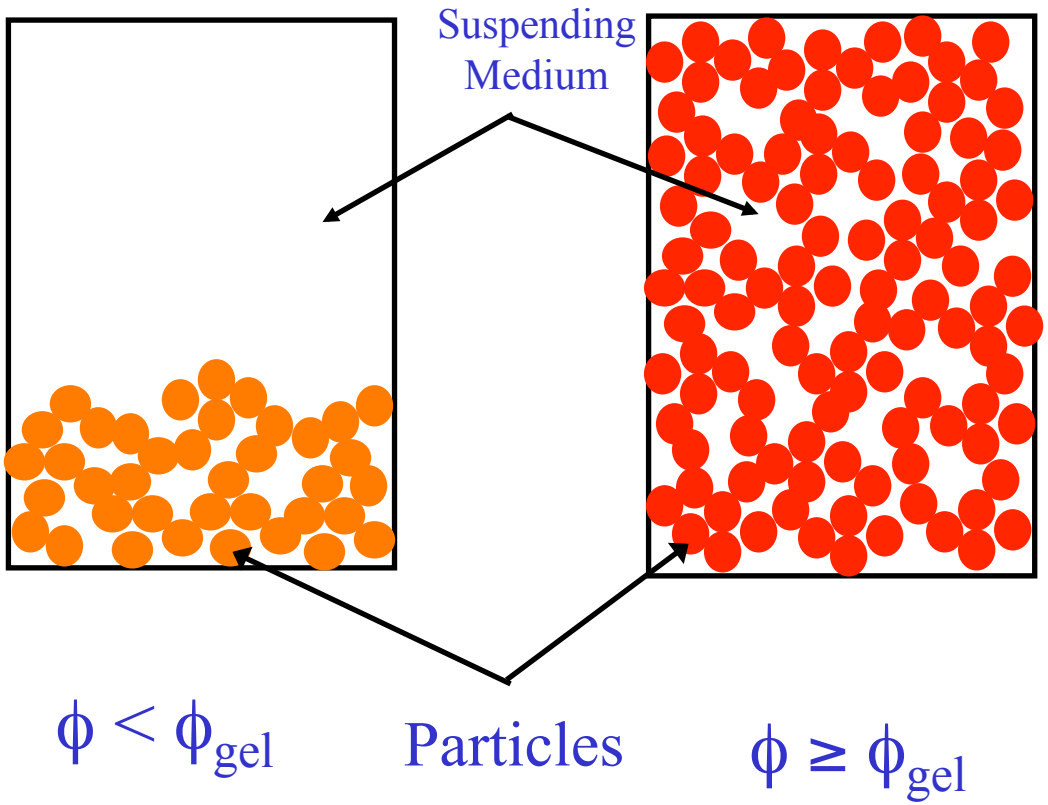
Network Strength and Failure in Coagulated Suspensions as a Probe of Inter-particle Forces

Peter Scales

Particulate Fluids Processing Centre
Dept. of Chemical and Biomolecular Engineering
University of Melbourne

Gelled Suspensions



Flow properties typified by:

- Yielding
- Shear thinning behaviour at concentrations above ϕ_{gel}

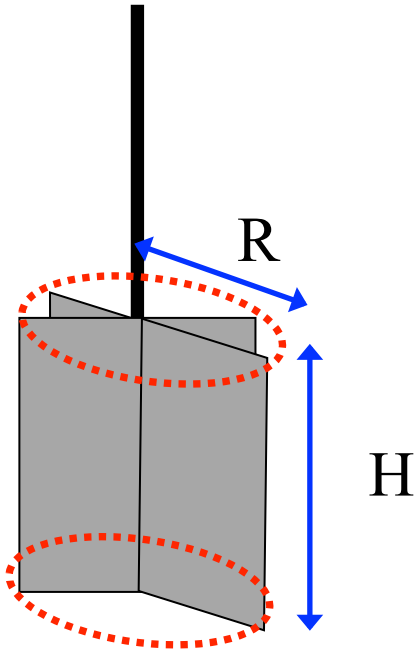
Implication is that the yield stress will show a strong dependence on the two body force between particles

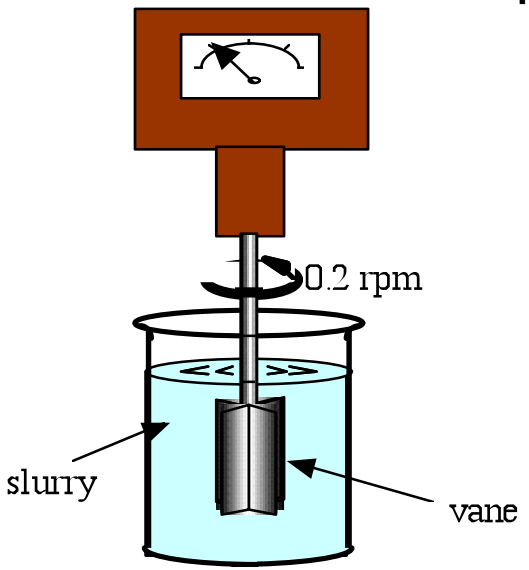
Gelled Suspensions

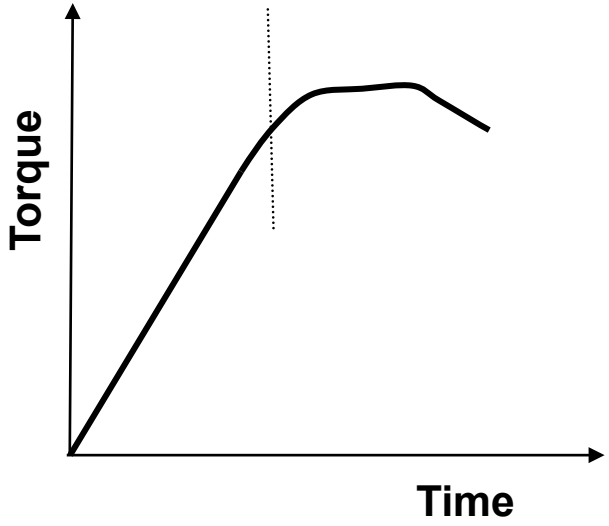
AGGREGATION	FORCES
Coagulation	electrostatics and/or VDW
Bridging flocculation	molecular bridging
Depletion flocculation	osmotic
Hydrophobic	capillarity between surfaces
Precipitation	chemical bonds
*	
*	
*	

Yield Stress Measurements - Shear

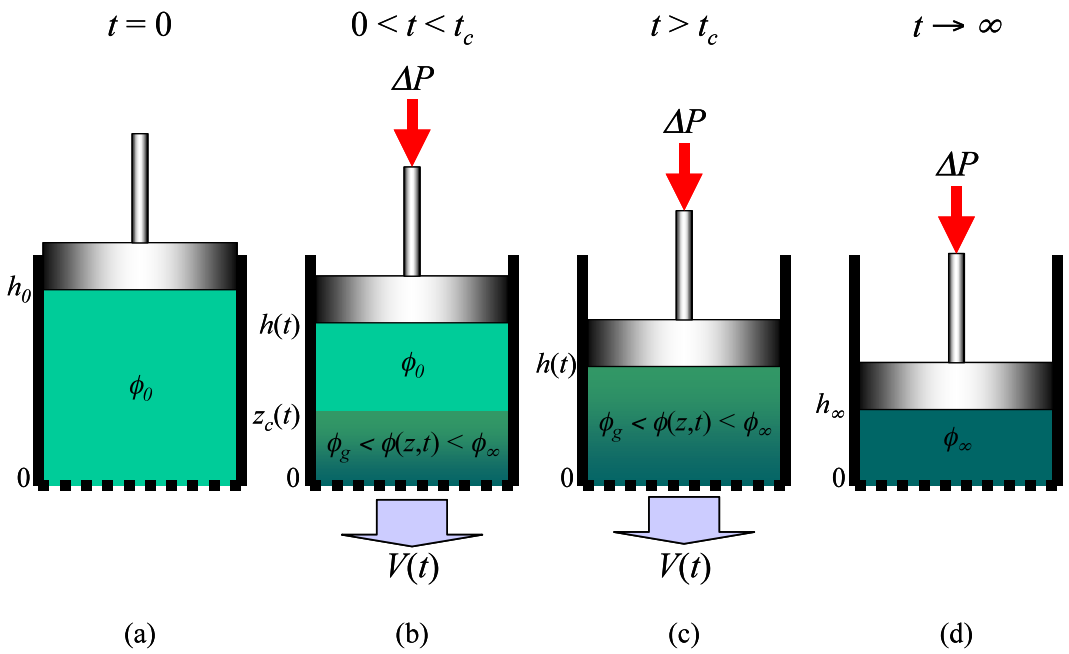
Vane Technique





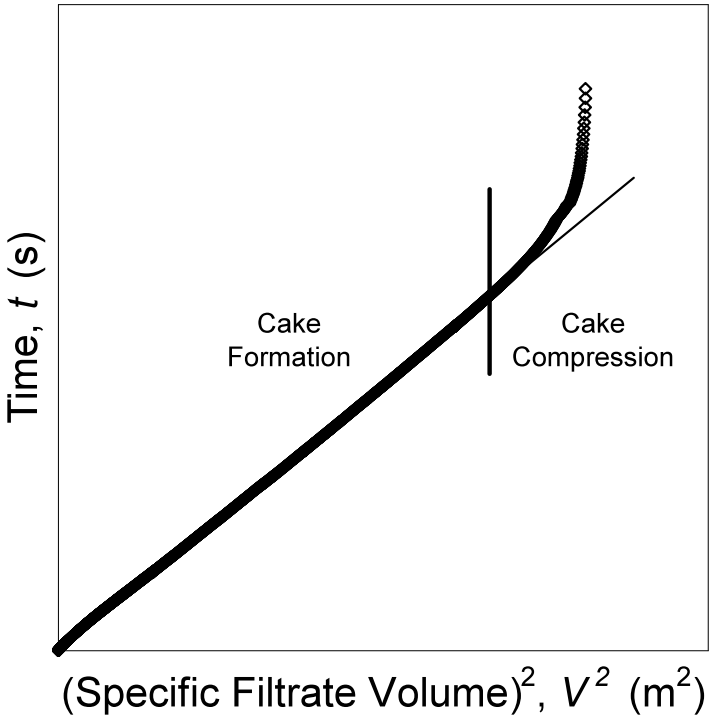


Yield Stress Measurements - Compression



(a) Initial condition; (b) Cake formation;
(c) Cake compression; (d) Equilibrium condition

Typical constant pressure filtration test results



Coagulated Particulate Suspensions

AKP ceramic grade alumina

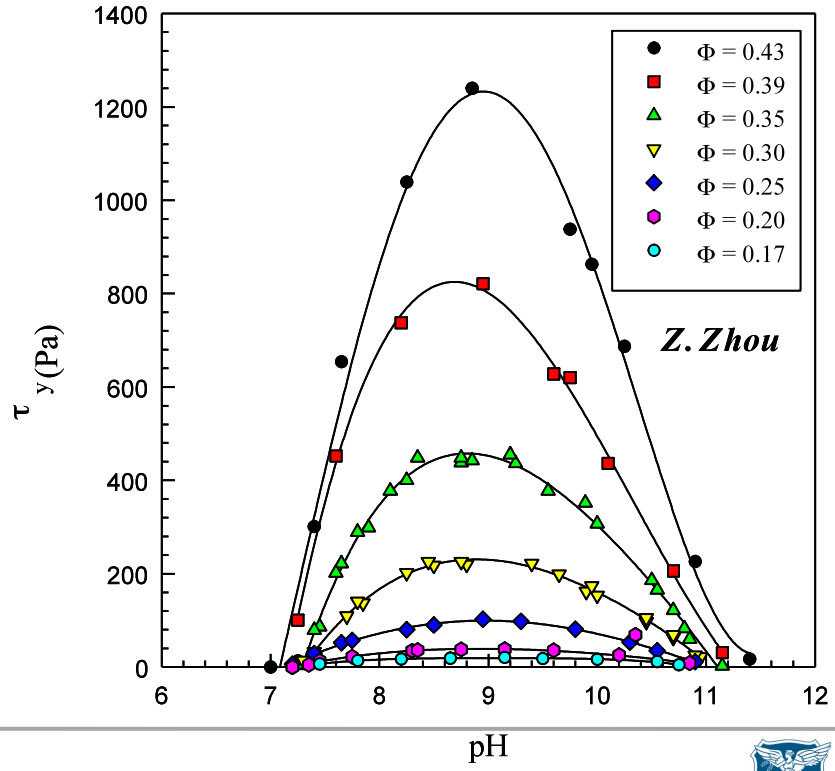
IEP = pH 9.2

Gel point approx 8-12 v/v %

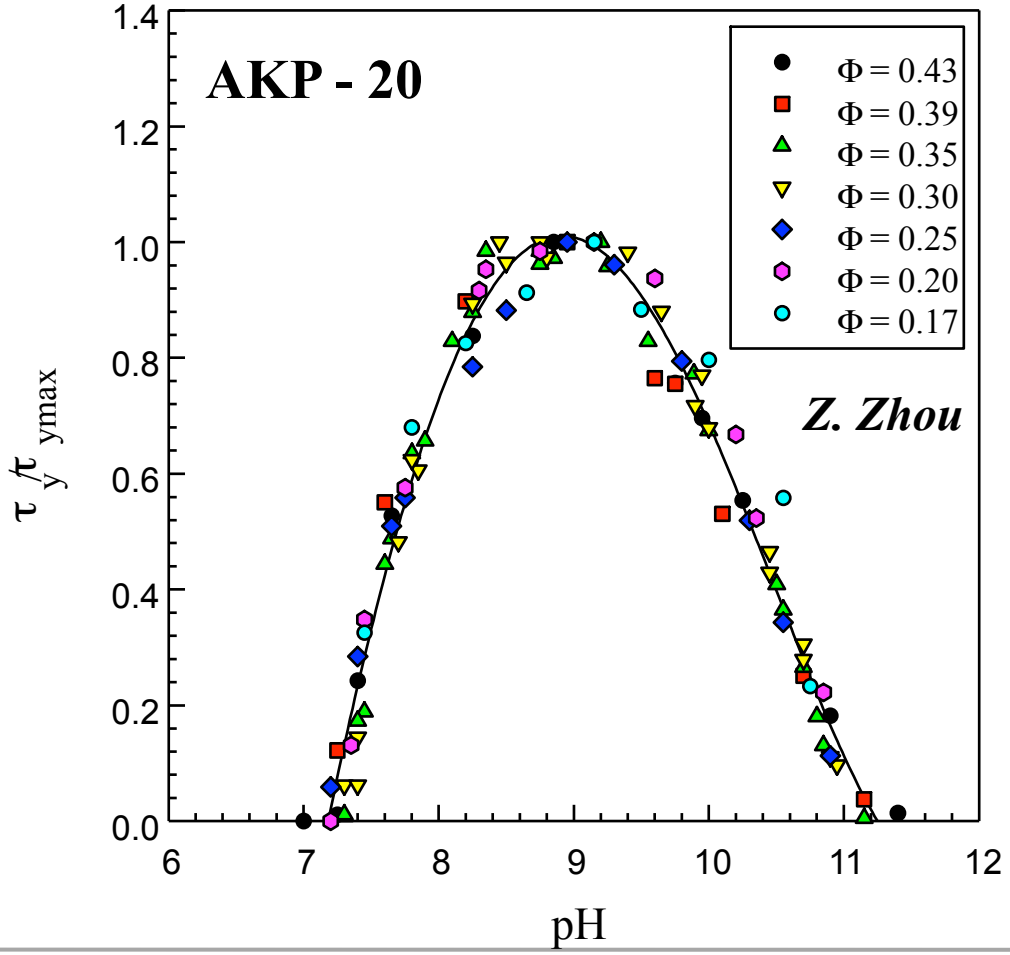
τ_y shows a dependence on:

- Particle interaction
- Particle size (d^{-2})
- Particle type
- Particle shape
- Particle concentration

$$\tau_y = \frac{0.011\phi K(\phi,d)}{\pi}\left(\frac{A}{h_o^2} - \frac{24\pi\varepsilon\kappa\zeta^2}{\left(1+e^{\kappa h_o}\right)}\right)\frac{1}{d}$$



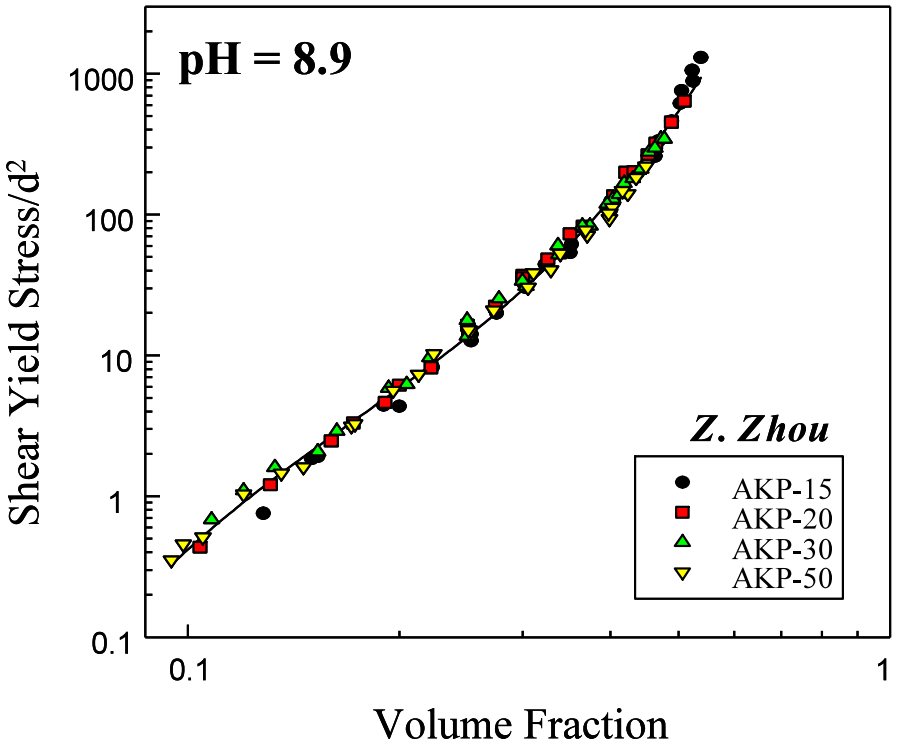
Shear Rheology

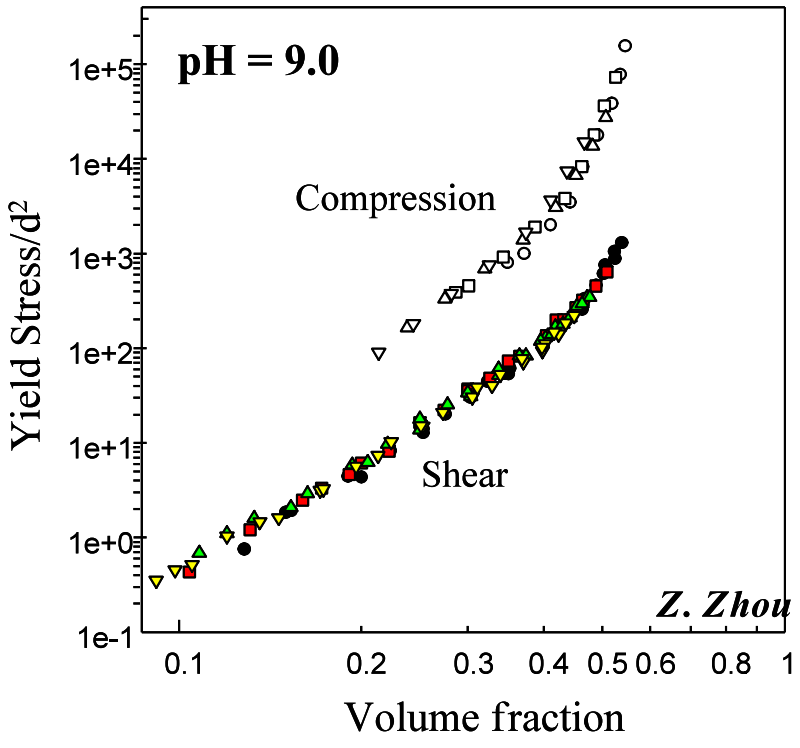


$$\frac{\tau_y}{\tau_{y\max}} = 1 - \frac{24\pi\varepsilon\kappa\zeta^2 h_o^2}{A\left(1+e^{\kappa h_o}\right)}$$

Scales et al., AIChEJ, 44: 538-544 (1998)

Yield Stress



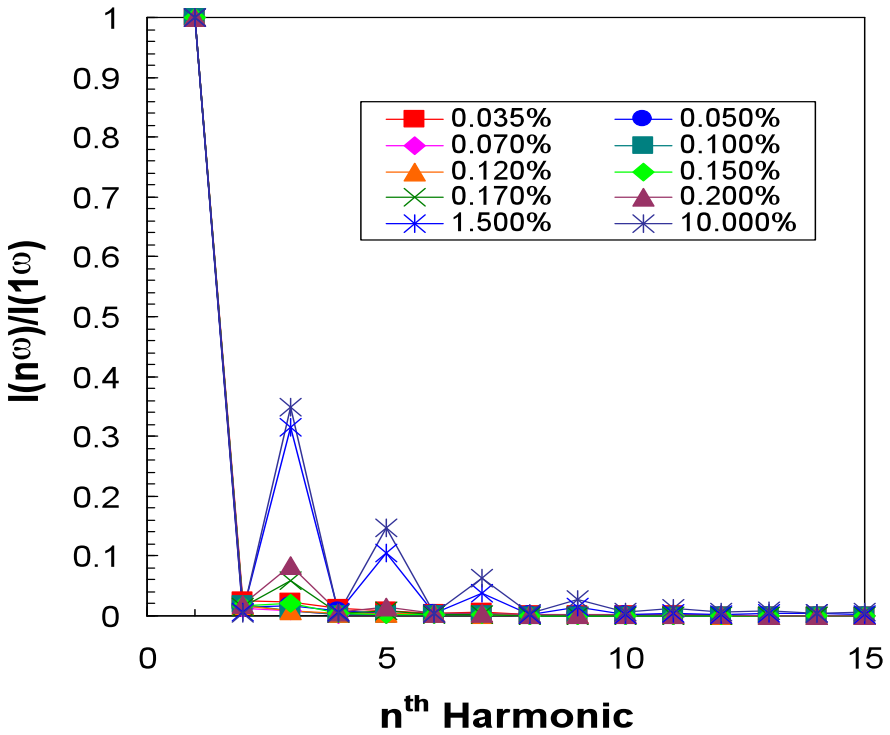


Zhou et al., *CES*, 56: 2901-2920 (2001)

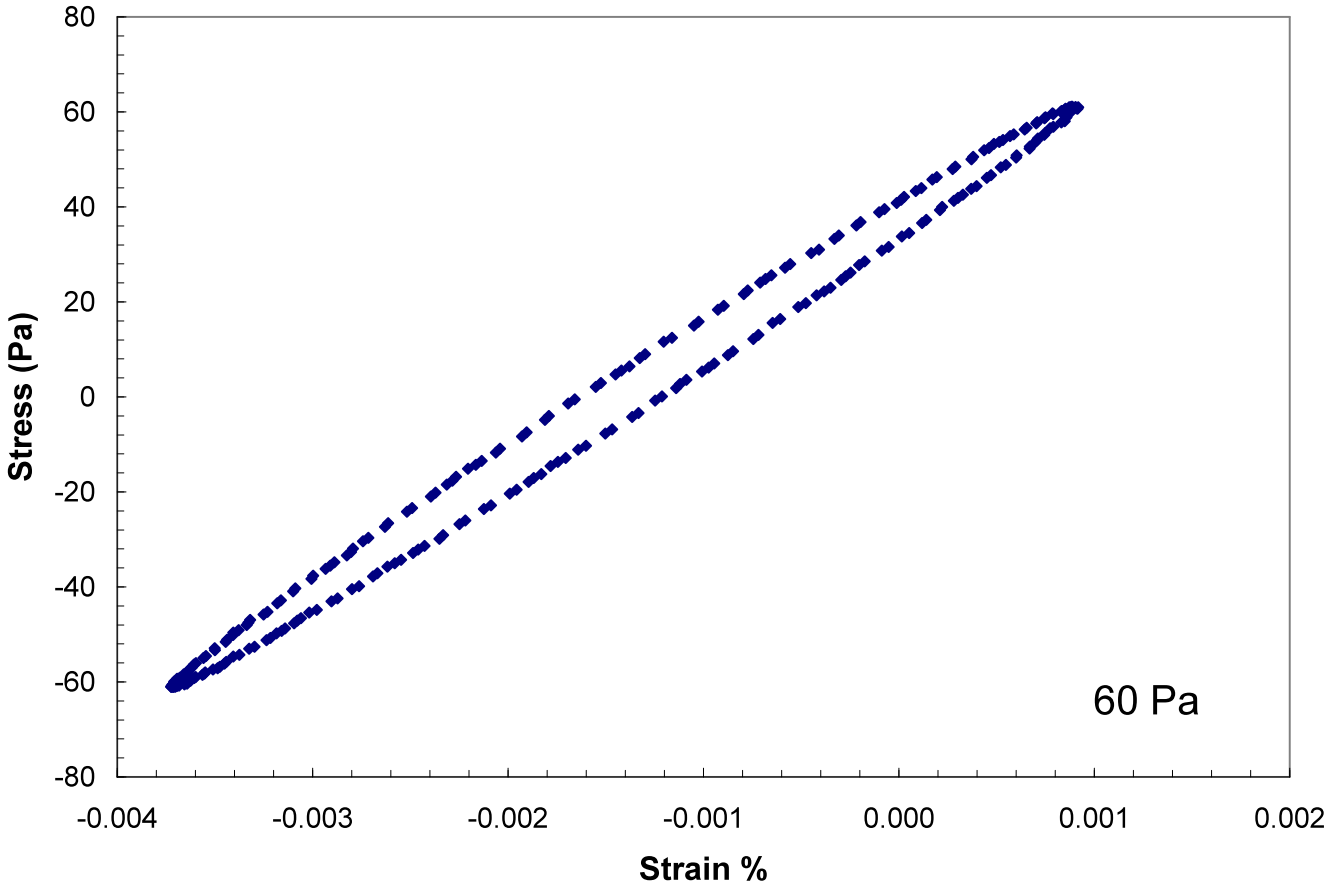
Critical Strain Measurements

Measured using small amplitude oscillatory stress (SAOS) in a vane and cup configuration with Fourier Transform to detect the onset of flow

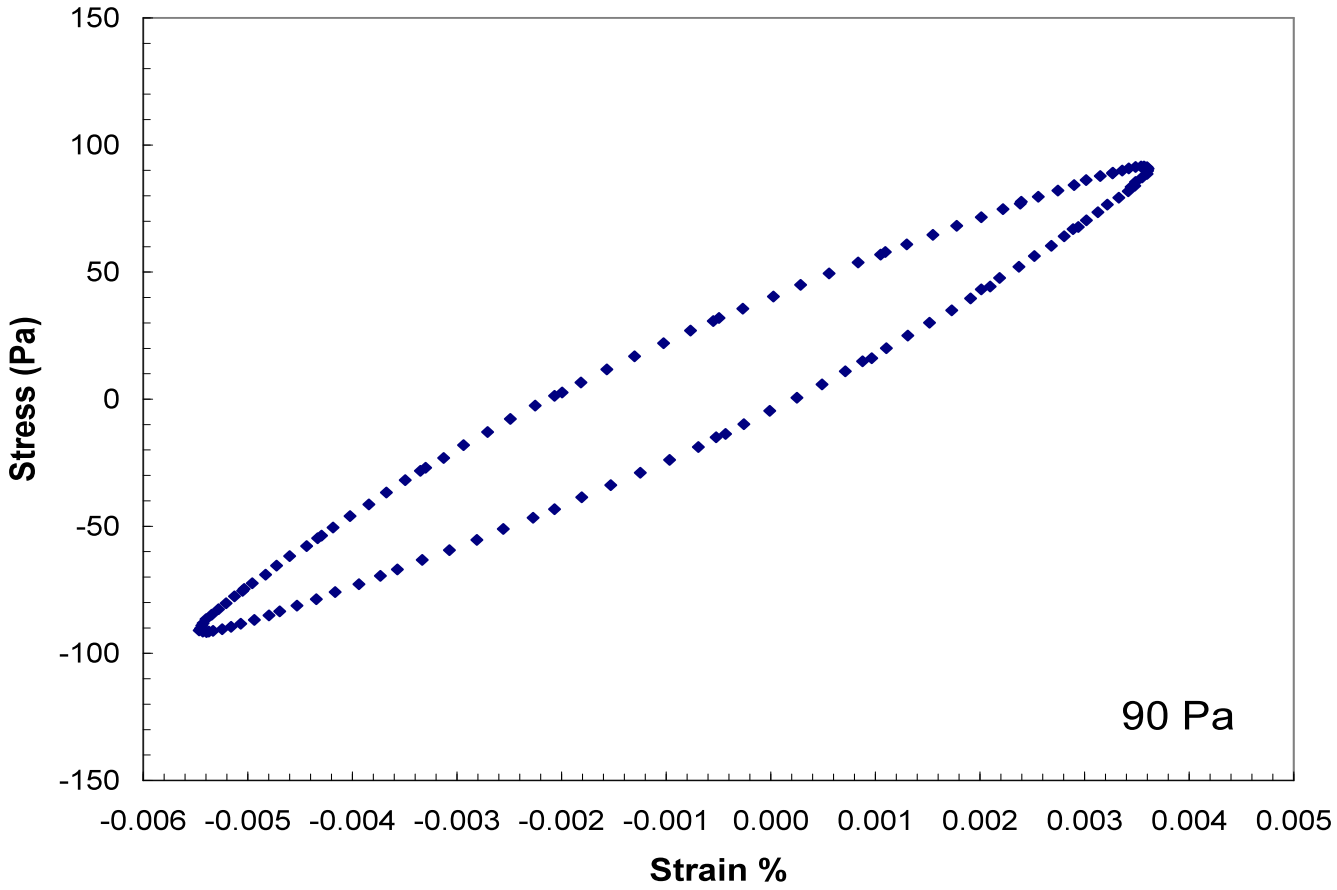
- critical strain is detected as the growth of the ratio of first to third harmonics



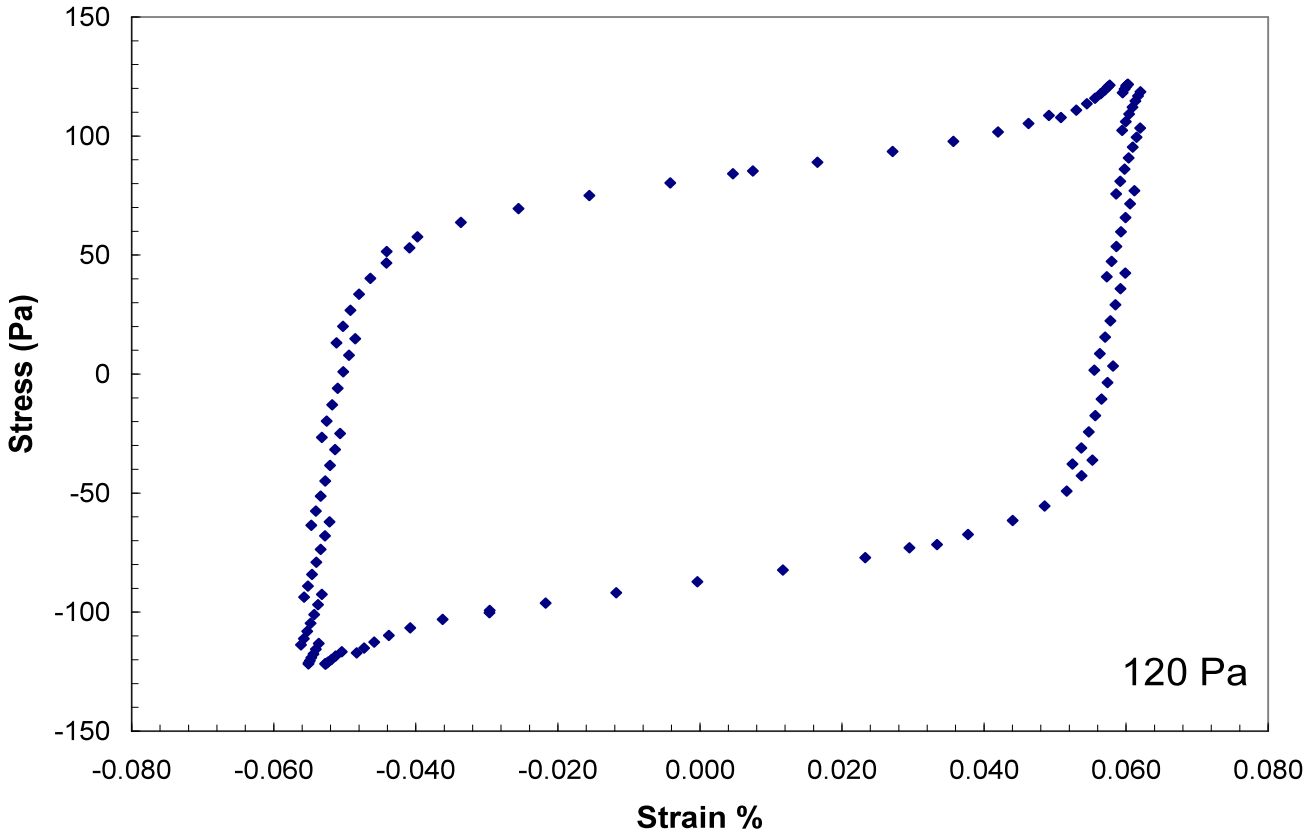
Stress-Strain Plots



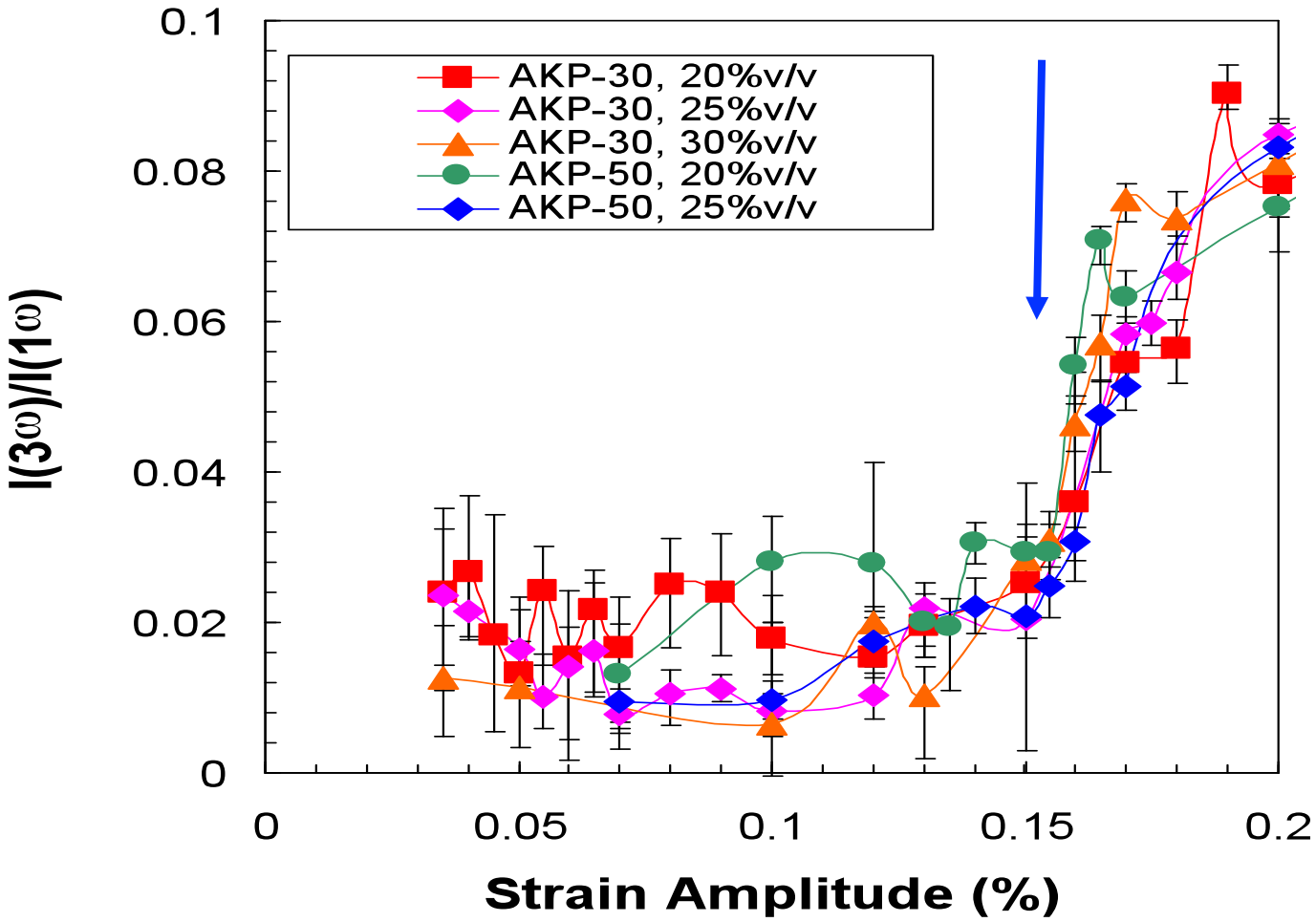
Stress-Strain Plots



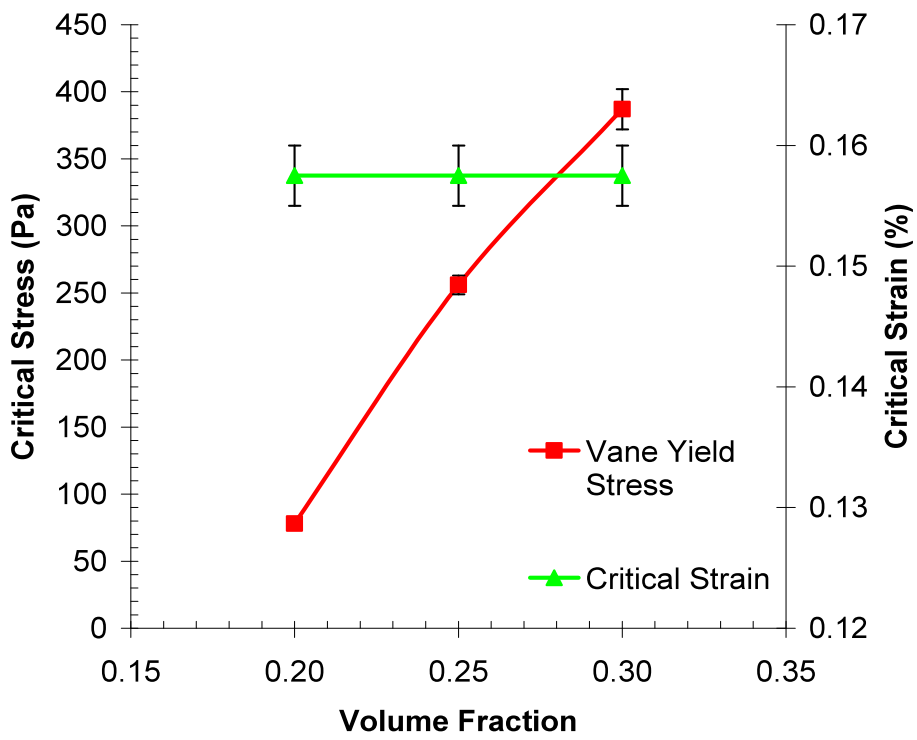
Stress-Strain Plots

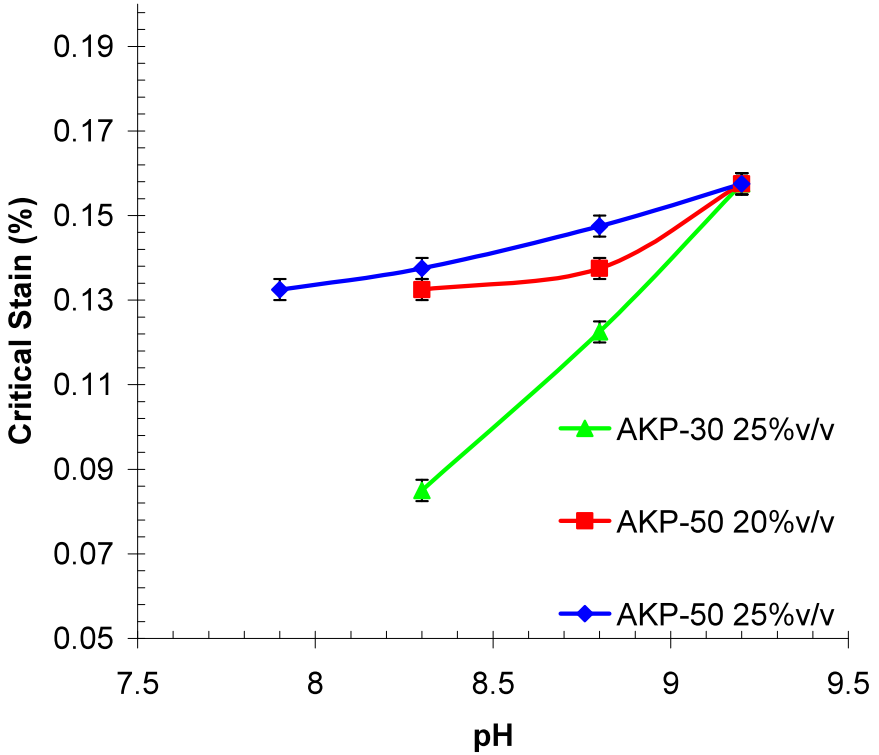


Critical Strain Results (IEP)



Strain Comparison





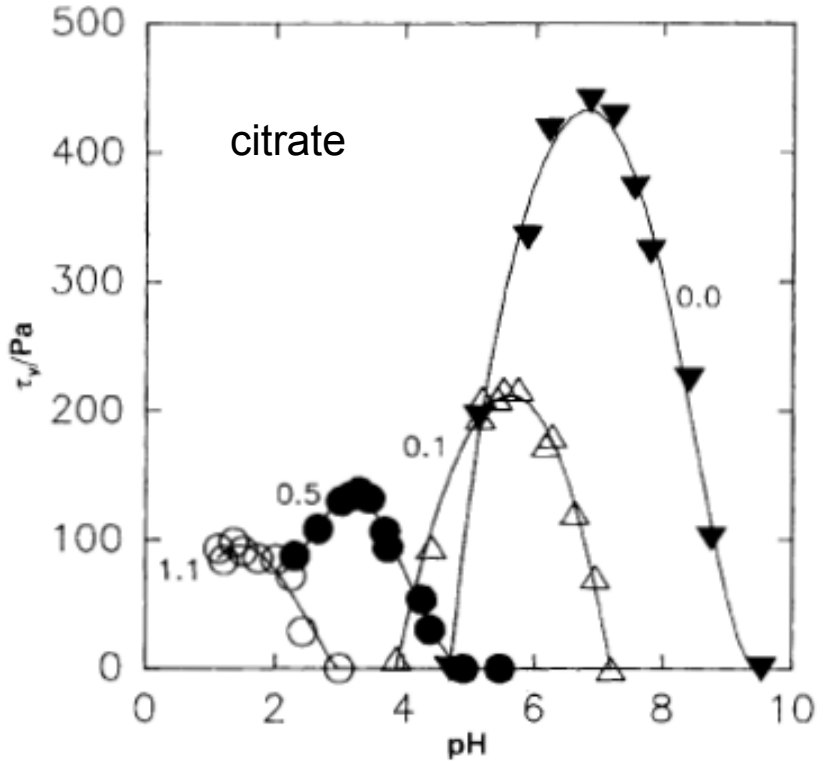
Coagulated Systems Overview

- Suspension yield stress scales with the inter-particle force in a predictable way but shows strong dependence on particle size and volume fraction

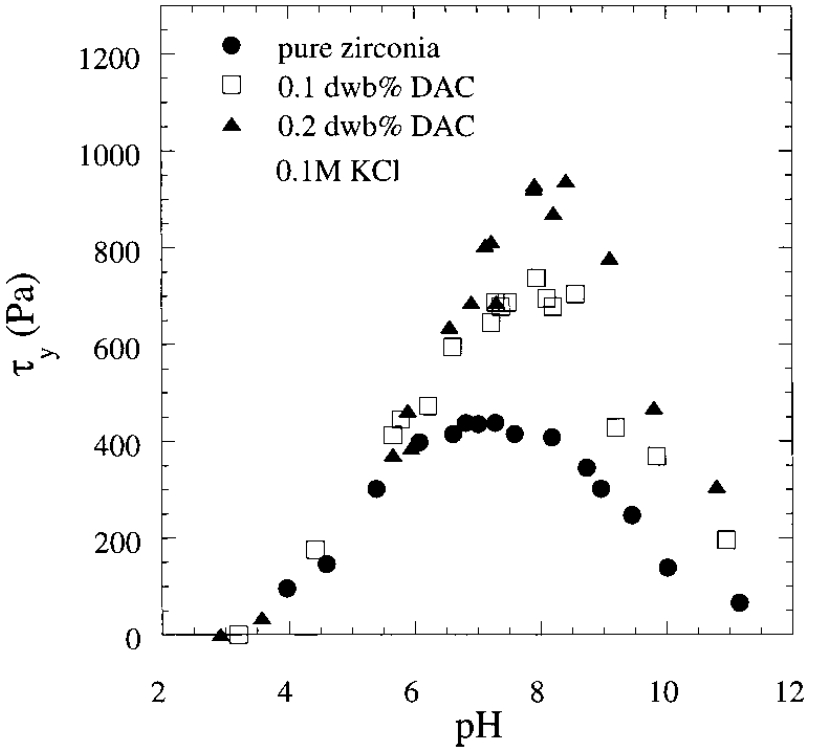
- Critical strain (yield strain) in coagulated particulate suspensions appears to mimic the magnitude of the inter-particle (pull off) force in these systems (this makes it a solids independent parameter?)

- Measurement of the critical strain still needs work. Analysis shows that stress at failure for dynamic systems is less than the vane yield stress

Hydrophilic versus Hydrophobic Surfaces

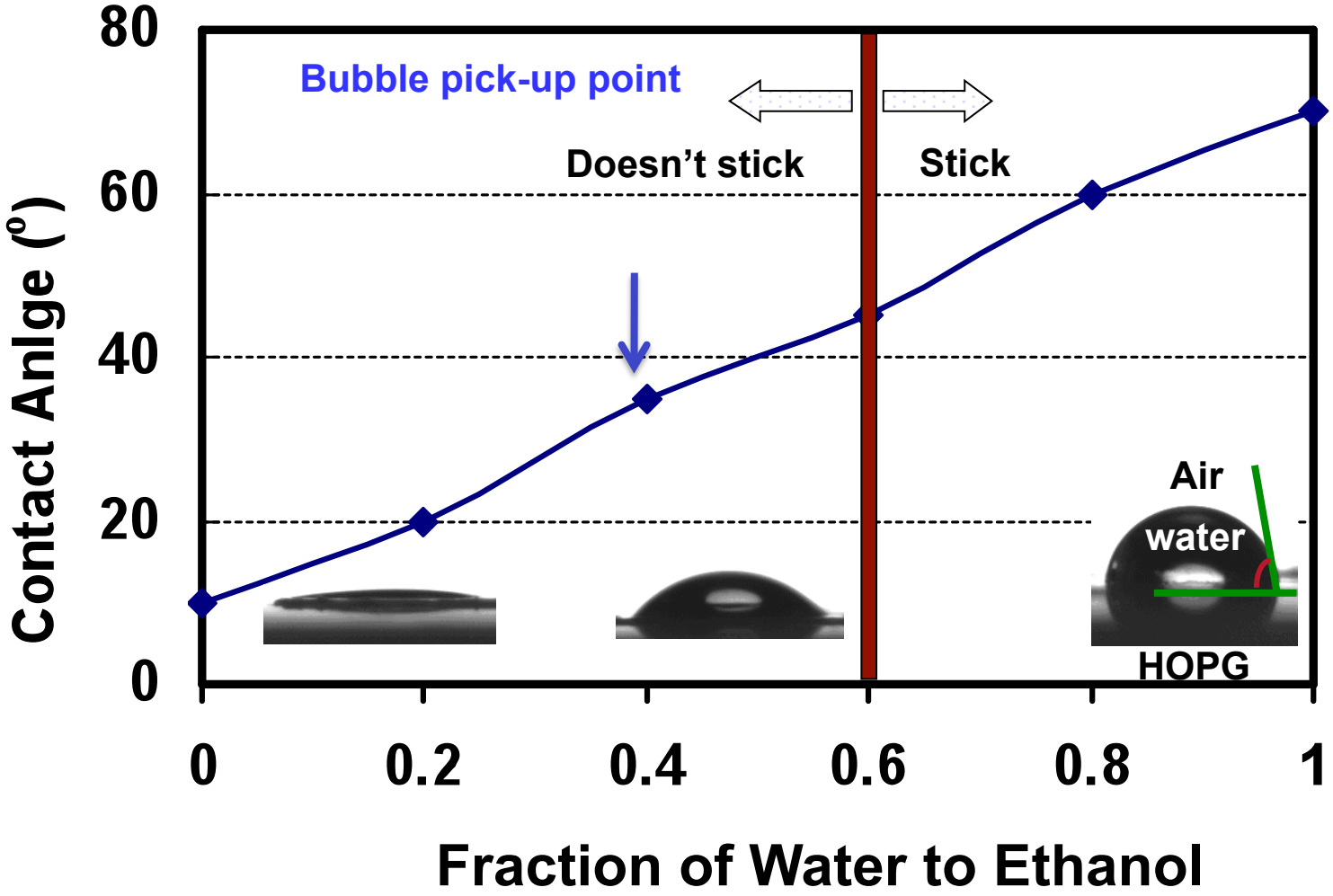


Leong et al., J.Chem.Soc.Farad, 89: 2473-78(1993)

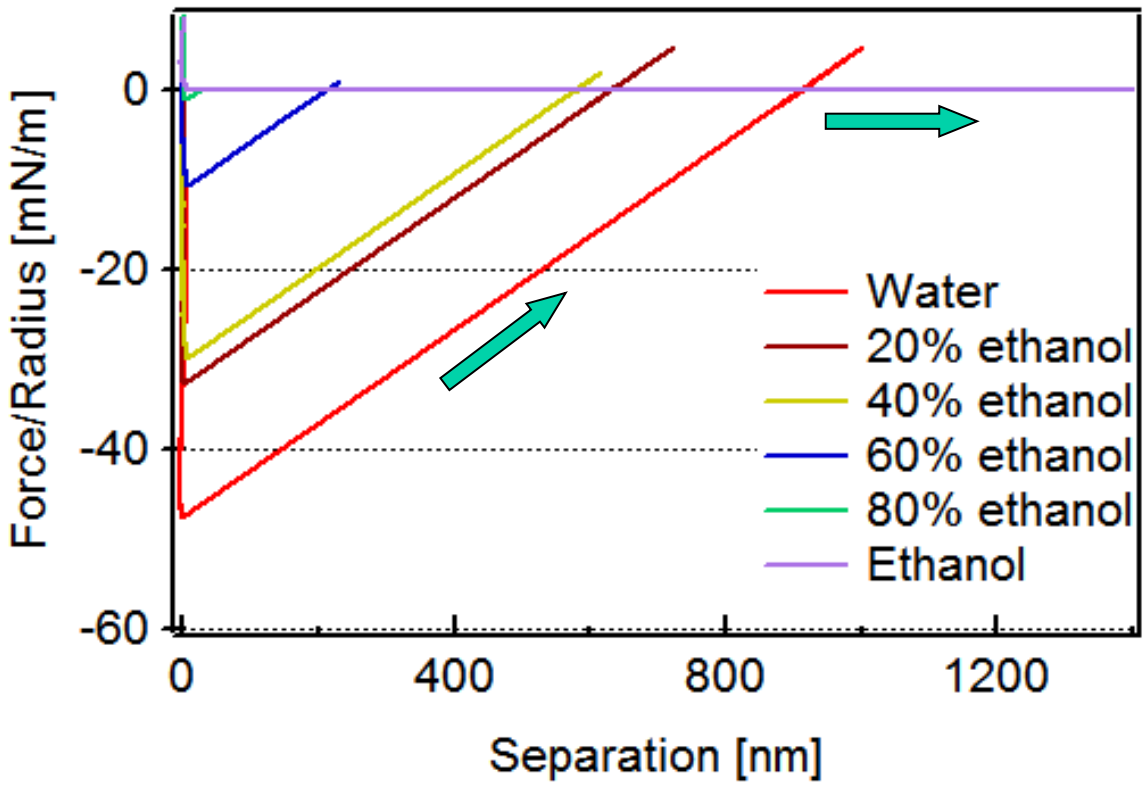


Solomon et al., Langmuir, 15: 20-26 (1999)

HOPG wettability

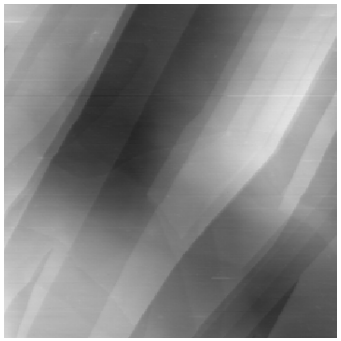


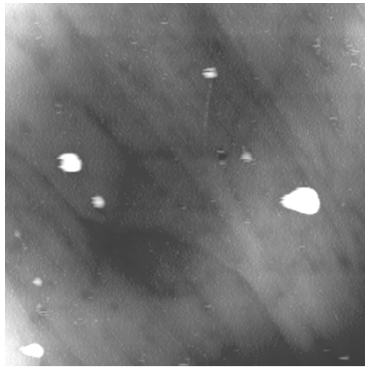
Forces between carbon surfaces (HOPG) (Ethanol-Water)

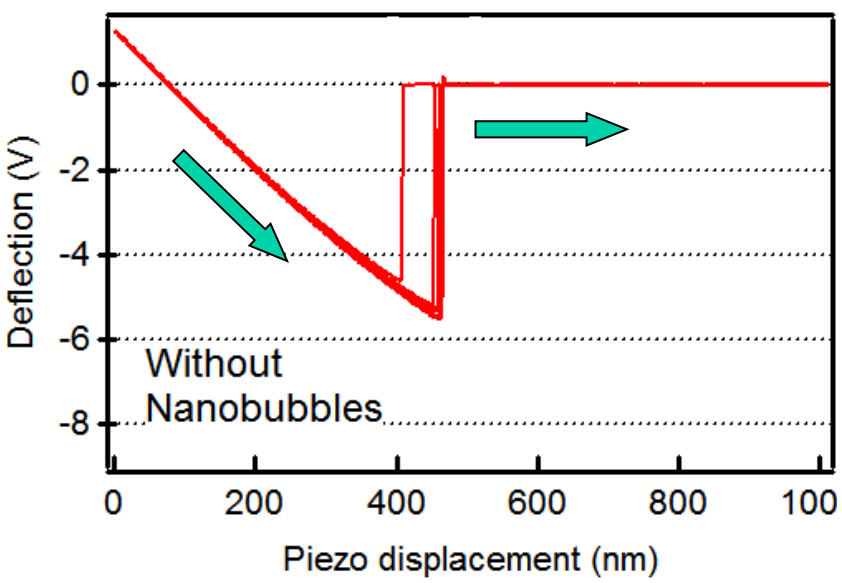


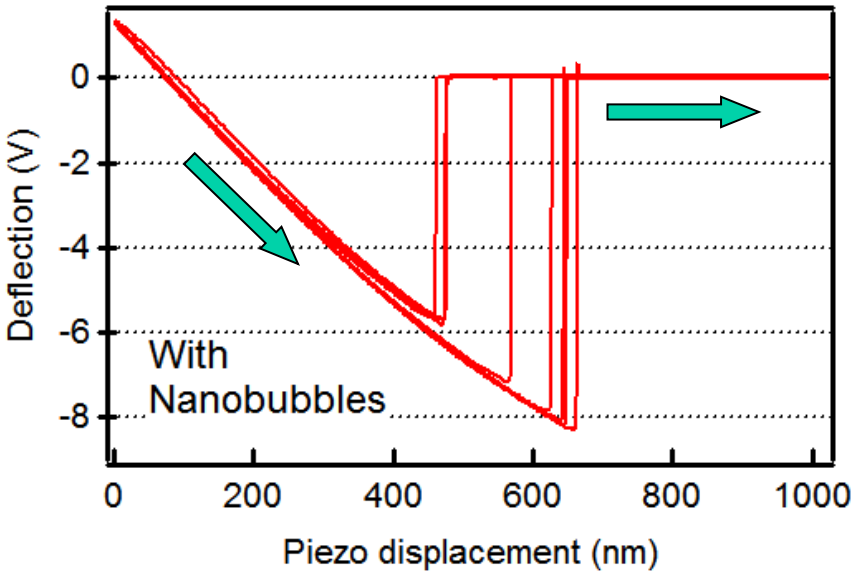
Hupka et al., Langmuir, 26: 2200-10 (2010)

HOPG with and without nano-bubbles

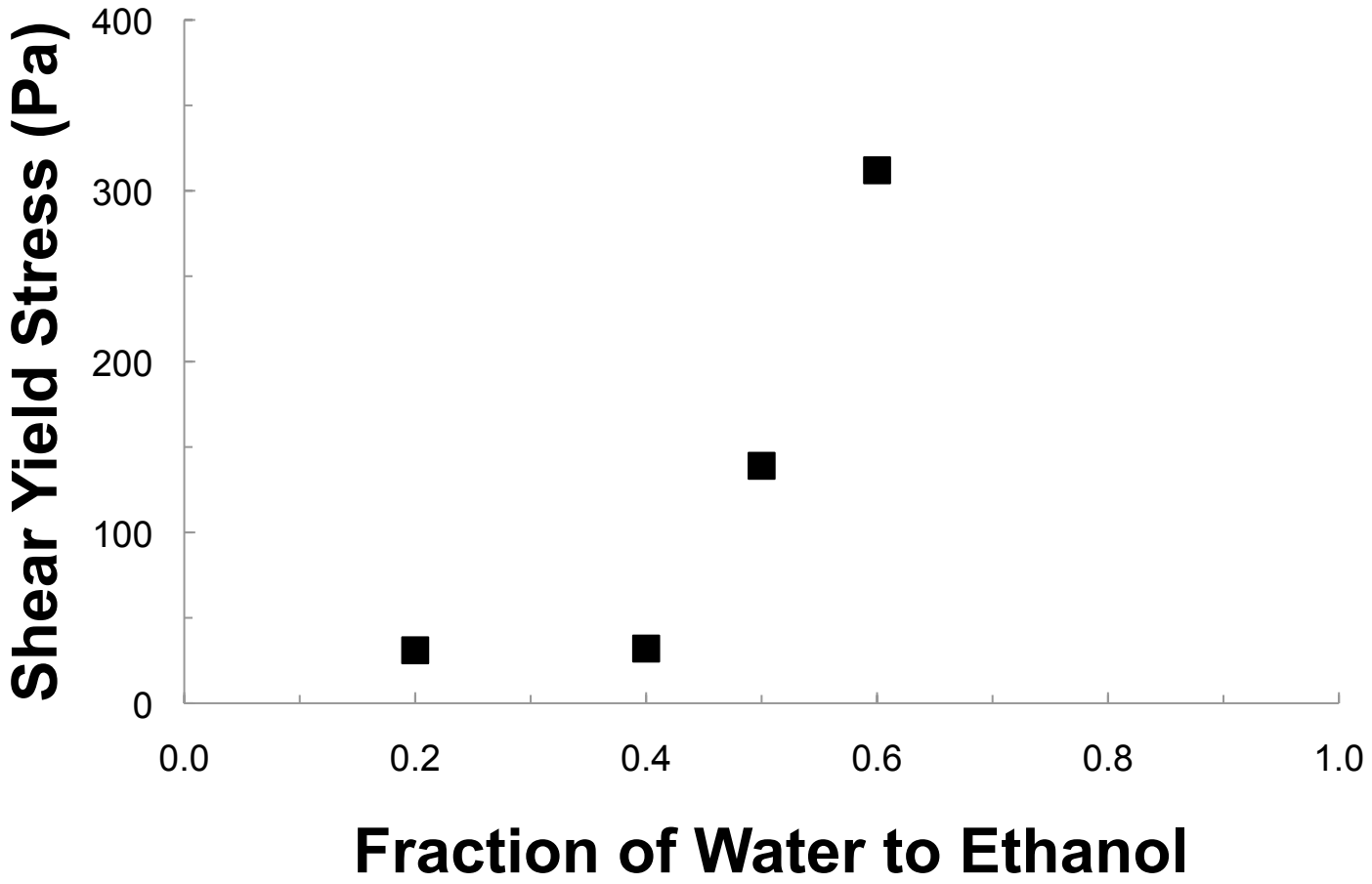








Carbon Yield Stress



Hydrophobic Systems Overview

- The suspension yield stress once again trends as the inter-particle force although the dependencies have not been quantified (data is still sparse)
- A scaling of the yield stress to the wettability and the length scale of the capillary force seems obvious.
- Critical strain measurements in this system should be interesting

Acknowledgements

Tom Healy
YK Leong
David Boger
Richard Buscall
PC Kapur
Z Zhou
Stephen Johnson
Mike Solomon
Jonathon Foong
H Kodama
Xuehua Zhang
Ashish Kumar