Microscale yielding of fiber gels

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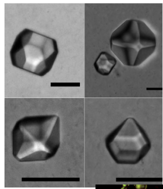
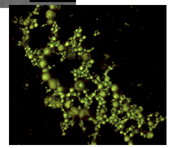
Research Program - Soft Materials

Shape



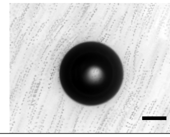
Complex morphology that enables targeting, responsiveness, and specificity

Structure



Microstructured complex fluids with minor amounts of colloids, polymers, and surfactants to enhance function

Flow



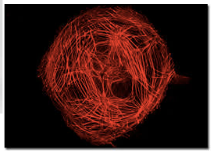
Structure-driven rheology control for multiple-function performance

Suspension applications

Foods

Pretties

Viruses

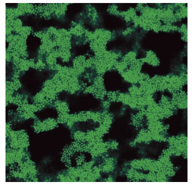


Organelles

Yield stress fluids

$$\dot{\gamma} = 0,\ \sigma < \sigma_y$$

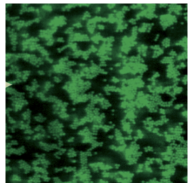
When exerted stress does not exceed the yield stress, no flow or motion occurs



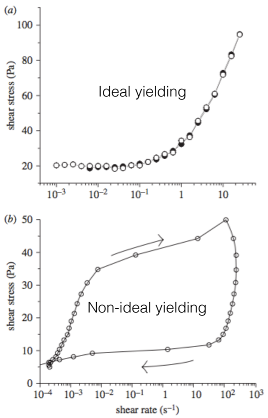
$$\sigma = \sigma_y + K\dot{\gamma}^n\ ,\ \sigma > \sigma_y$$

Herschel-Bulkley eqn.

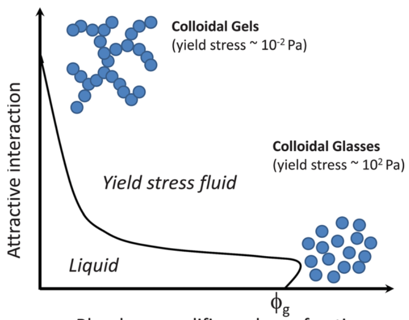
Above the yield stress, flow resembles a power-law or even Newtonian fluid



Structure and yielding

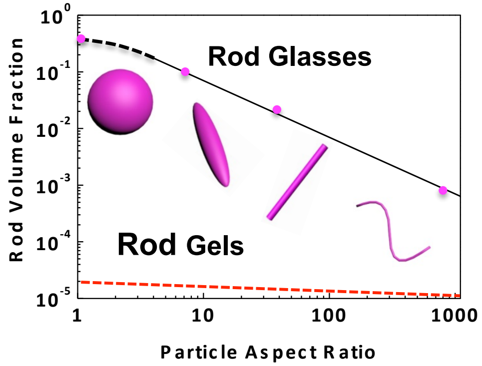


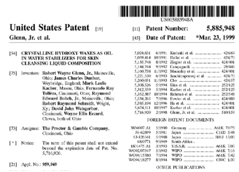
Moller et al., 2009



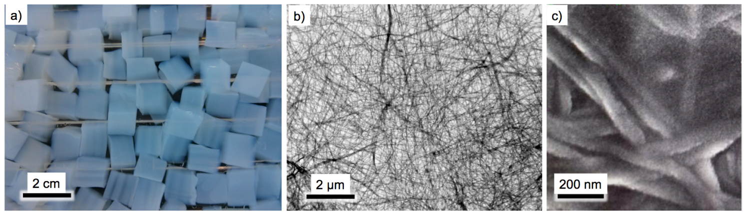
Emady et al., J. Rheology 57, 1761, 2013
(after Trappe and Sandkuhler, 2004)

Rods and Fibers





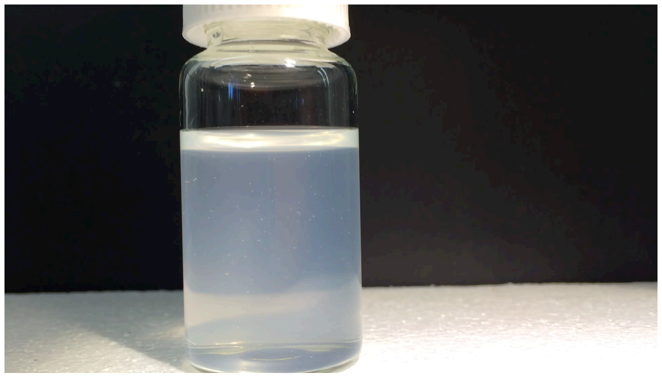
Bacterial cellulose



Sustainable material with attractive efficiency for rheology modification of formulated products.

Especially attractive is the ability to impart a useful yield stress **without a significant viscosity increase.**

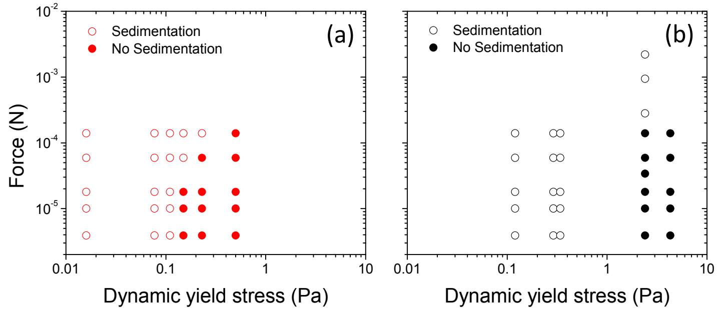
Low viscosity but solid-like suspension from yield stress



Sparse networks/yielding

Non-ideal yielding
Microfibrous cellulose

Ideal yielding
Carbopol



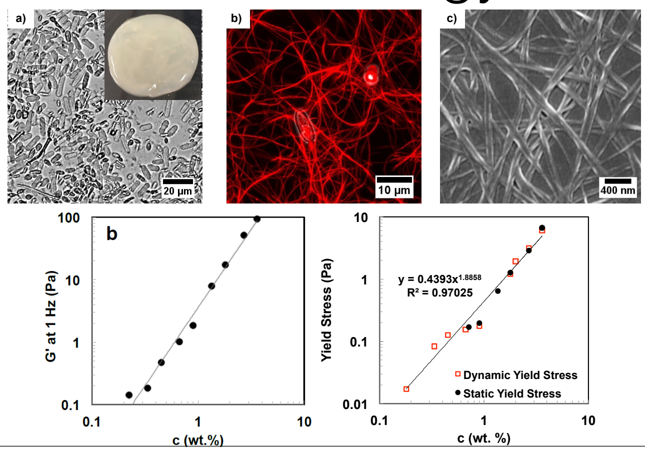
Sparser network shows significant advantages in suspension over denser, glassy system, why?

Emady et al., J. Rheology 57, 1761, 2013

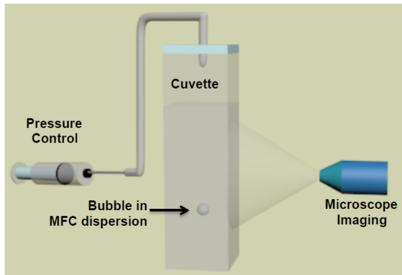
Key questions

- Why are fibers more efficient at imparting a yield stress than we expect from aspect ratio?
- How should we assess flow of suspended particles with dimensions close to structural elements?

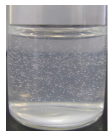
Bulk rheology



Bubble microrheometer



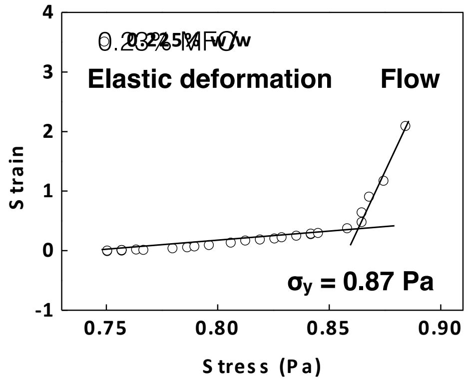
A single suspended bubble is used as a sensitive probe whose stress can be varied through a computer-controlled pressure, providing quantitative rheology as well as assessment of suspension flow and stability.



Strain, yielding, flow

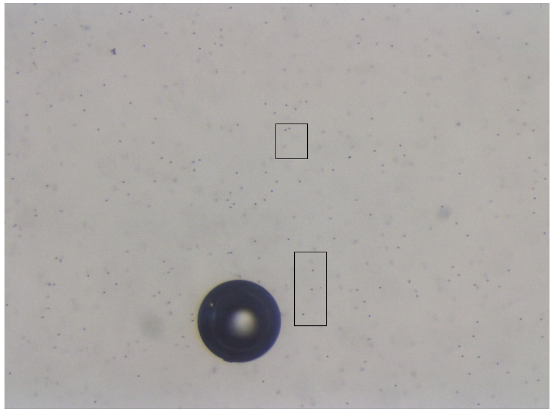
Kymograph

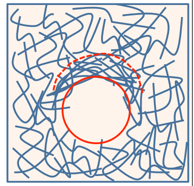
Yield stress determination



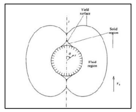
Technique shows transitions in viscoelastic system at subtle stress levels and on micron length scales.

Evidence of restructuring

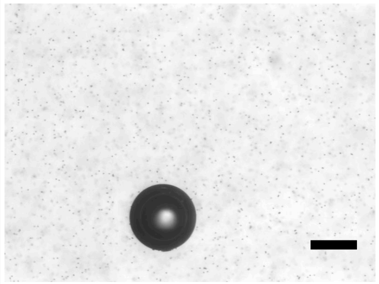




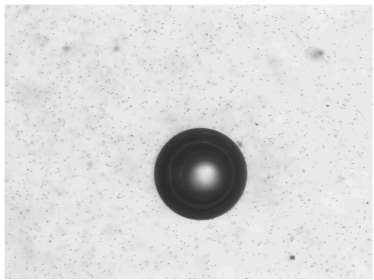
Flow field



0.23% MFC

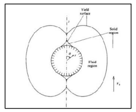


0.67% MFC

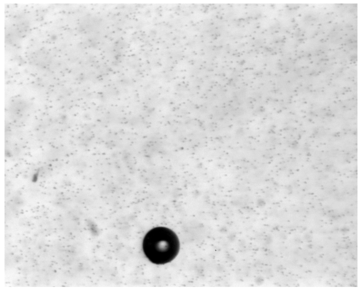


6 μm polystyrene tracer particles

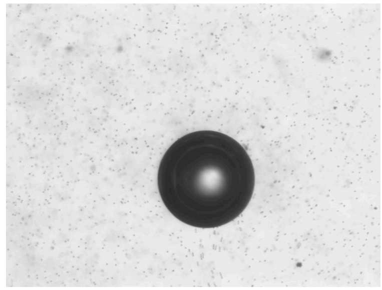
Results: Flow field



0.23% MFC

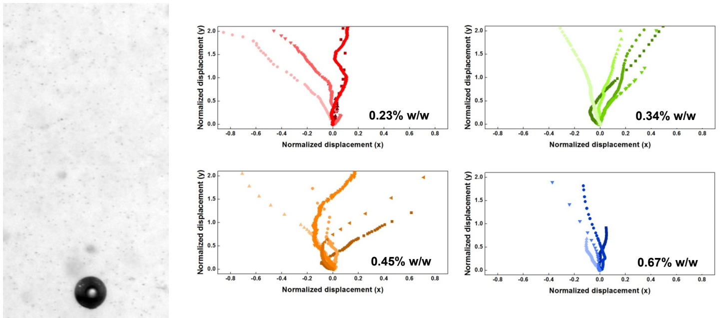


0.67% MFC



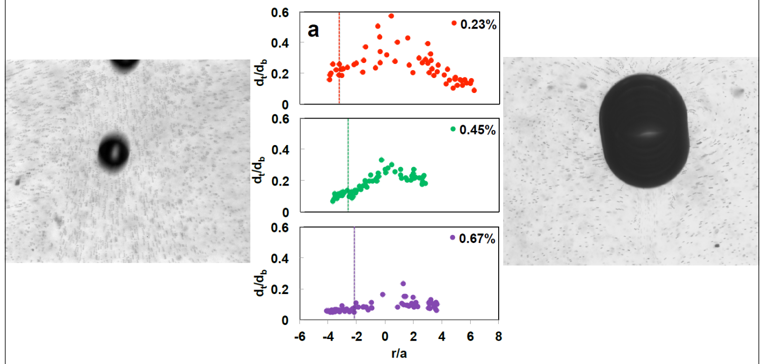
Every six images combined into single frames

Results: Flow field



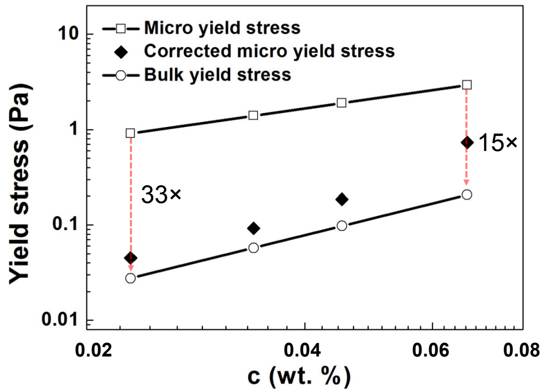
Trajectories of yielded bubbles highlight heterogeneity

Results: Flow field

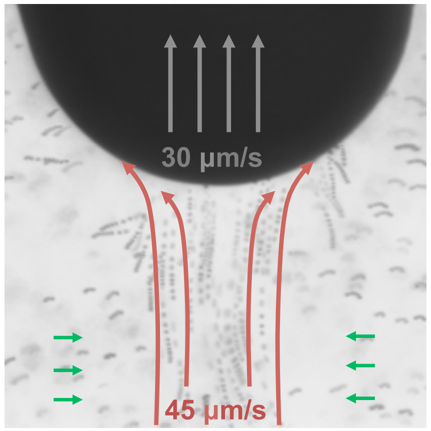


Using these results we are able to predict the difference we see between microscale and bulk yield stress measurements.

"Correction"



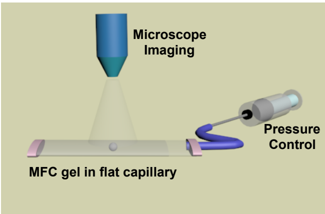
Two-fluid behavior?



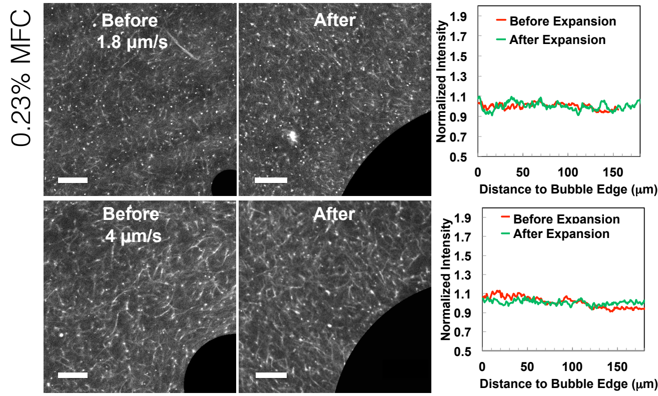
Velocity of following tracers faster than bubble yielding the fluid

Consistent with consolidation observed earlier

Static network deformation

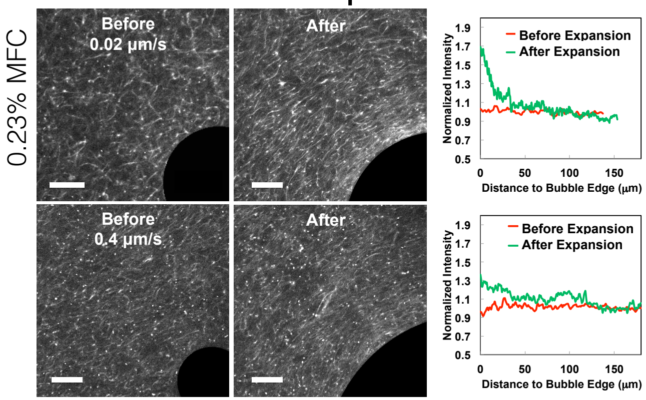


Fast expansion



Structure expands without significant compression at high rates.

Slow expansion



Network compresses by squeezing water out at low rates

Conclusion

- Fibers form gels at low volume fractions in water with a unique combination of useful yield stress and low viscosity.
- Microrheology accesses performance and structural properties that are missed by bulk techniques
- Fiber structures can disperse stress more efficiently than glassy jammed structures by restructuring.
- Responsiveness of network via local restructuring aids in enhancing suspension ability and robustness during deformation but results in widespread heterogeneity.