Rheology and Shear-Induced Structural Evolution in Model Conductive Carbon Black Suspensions

Julie B. Hipp[1], Jeffrey J. Richards[2], Norman J. Wagner[1]
1. University of Delaware, Department of Chemical and Biomolecular Engineering
2. Northwestern University, Department of Chemical & Biological Engineering

1. Motivation

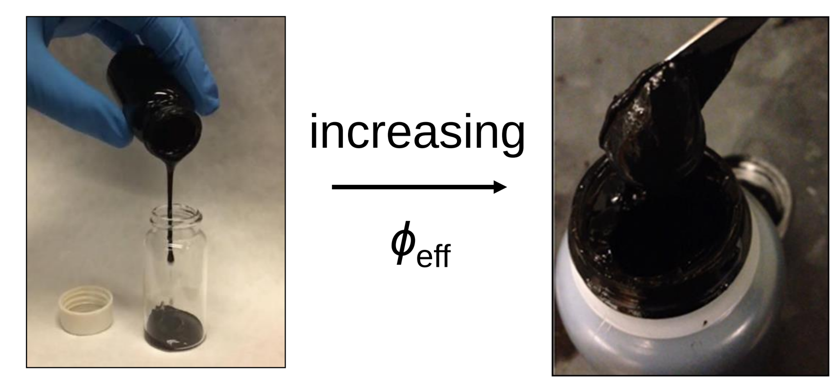
The flow-induced structural behavior of carbon black suspensions has been widely investigated due to its relevance in many applications including inks, coatings, paints, and electrochemical energy storage methods.

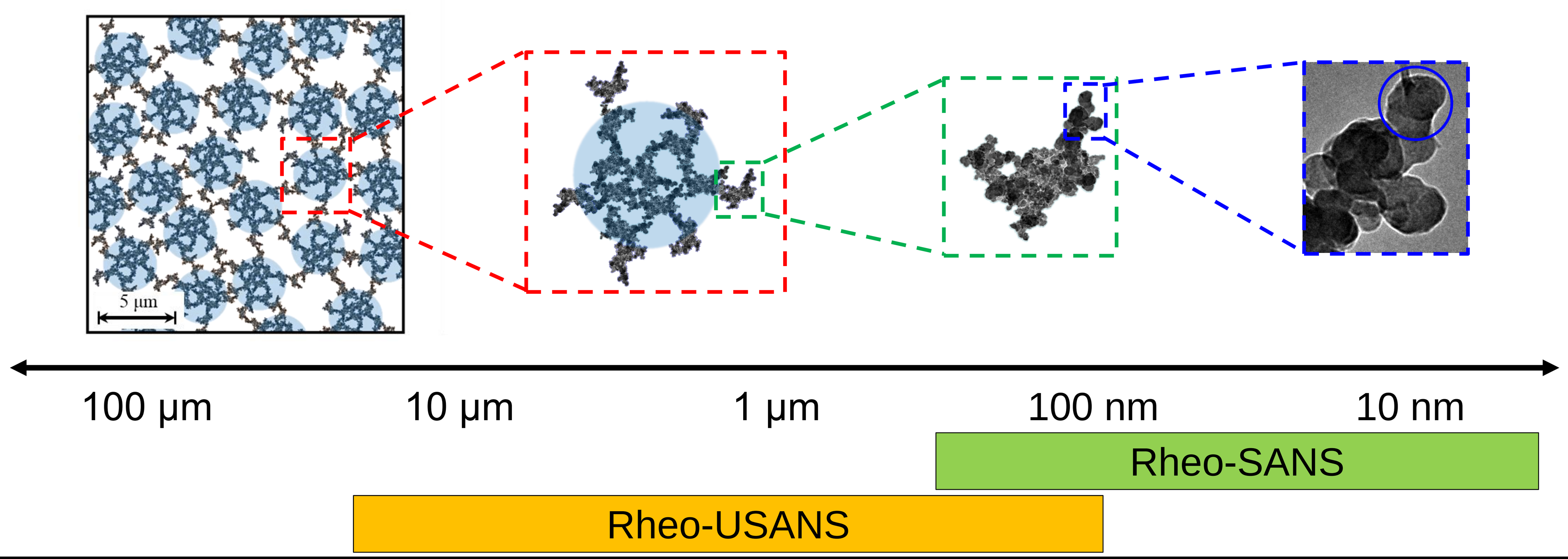
Carbon black has been studied in a variety of media, but a direct measurement of the structure of these suspensions while under shear has proven to be challenging, especially at higher volume fractions.

Goal: Measure and understand the flow-induced microstructural behavior of carbon black suspensions in general using simultaneous rheological and structural measurements.

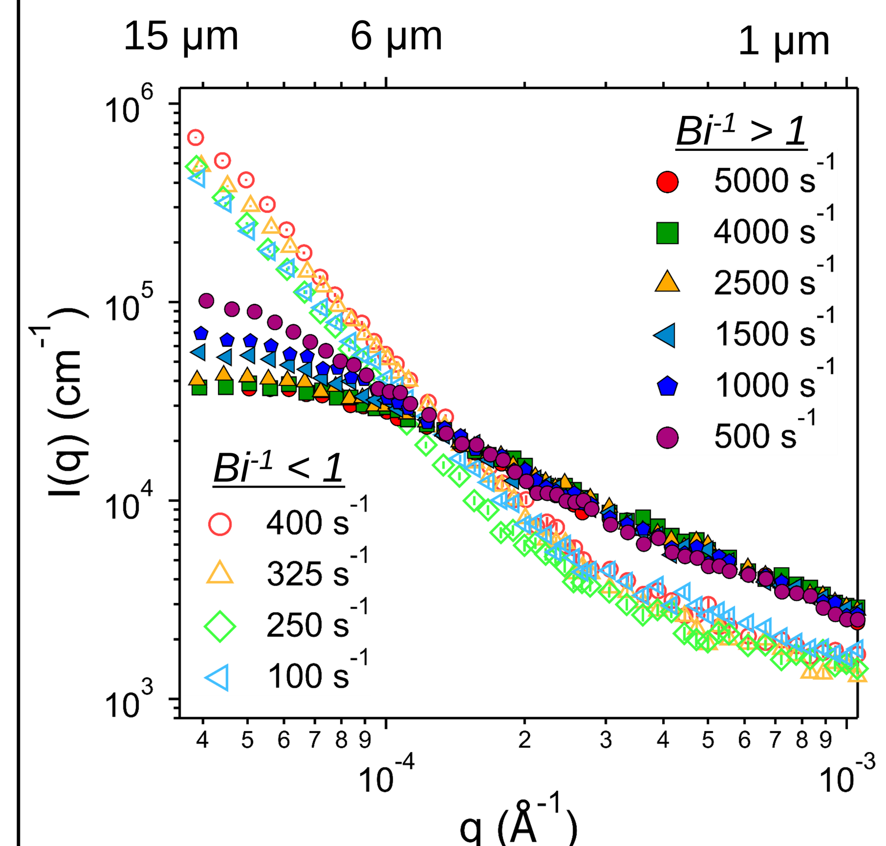
2. Hierarchical structure of high-structured carbon blacks

Carbon black type	Suspending fluid	ϕ_{eff}
Vulcan XC-72	Propylene carbonate	0.12, 0.20, 0.27
Vulcan XC-72	Light mineral oil	0.12, 0.20, 0.27
KetjenBlack EC-600JD	Light mineral oil	0.20, 0.27

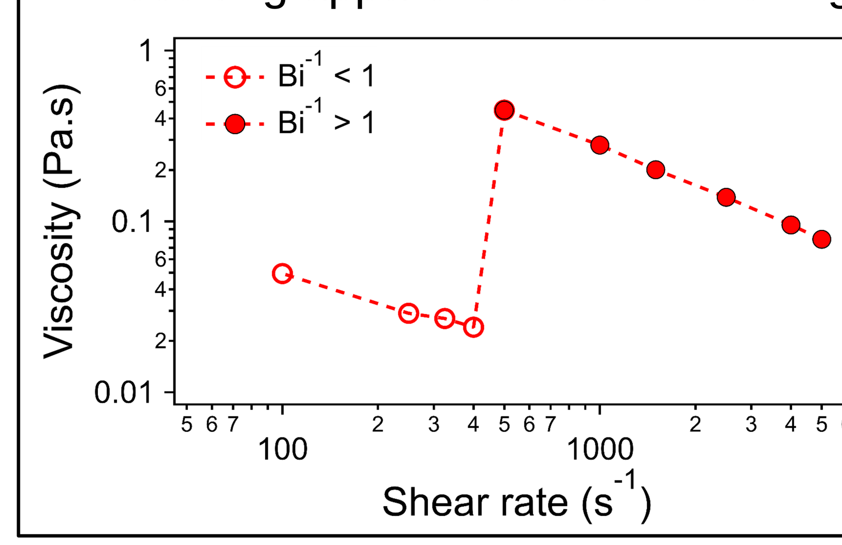




3. Structural transition across Bi^{-1} = 1 for all suspensions

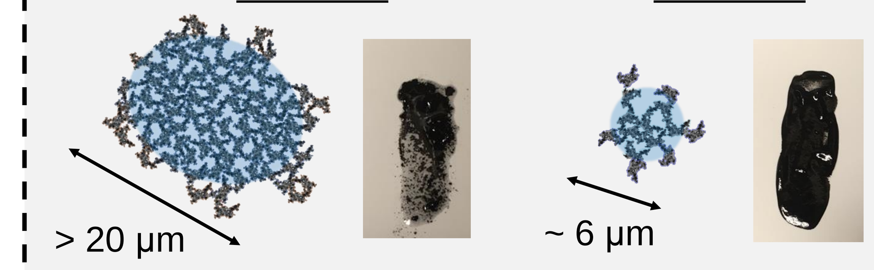


Resulting apparent shear-thickening

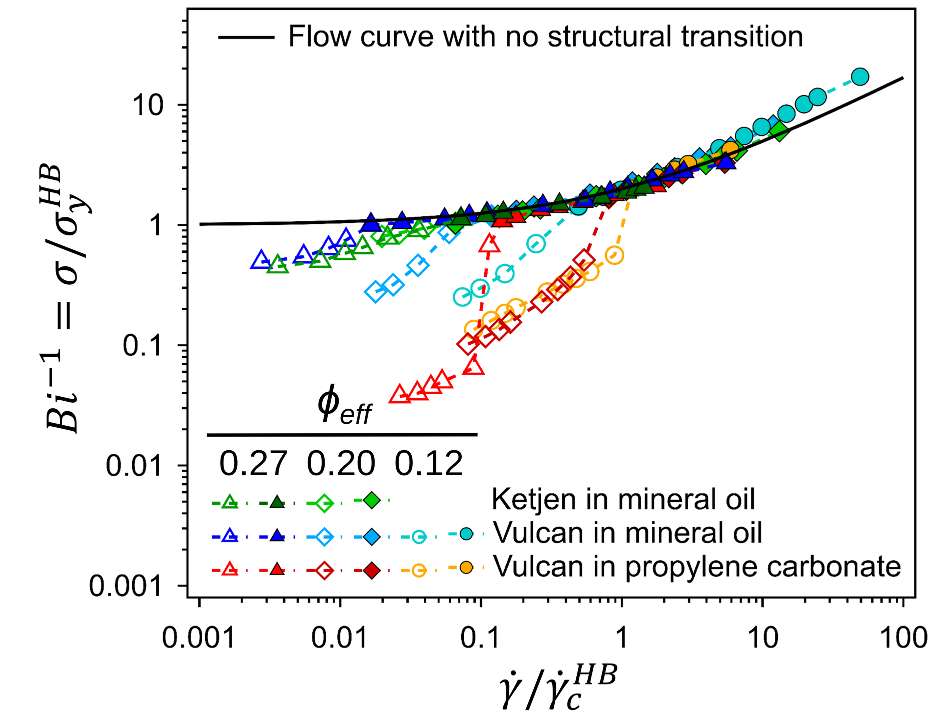


A bifurcation in agglomerate structure is measured around Bi^{-1} = 1. This structure change is evident in the rheology.

$$Bi^{-1} = \sigma/\sigma_{y,app}$$

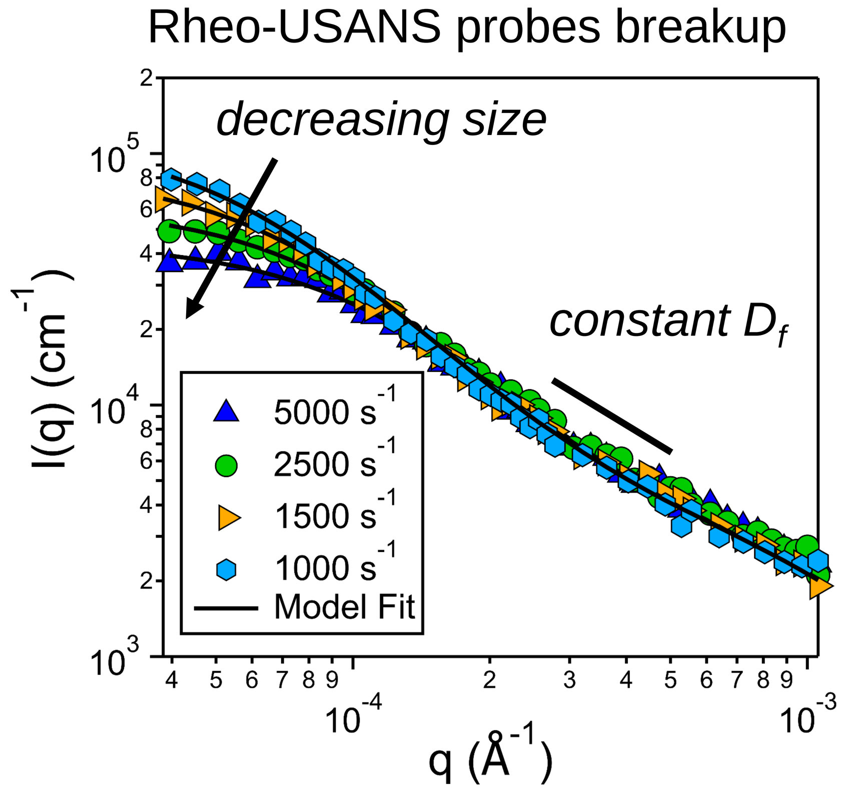


Evidence of structure transition after 300 s

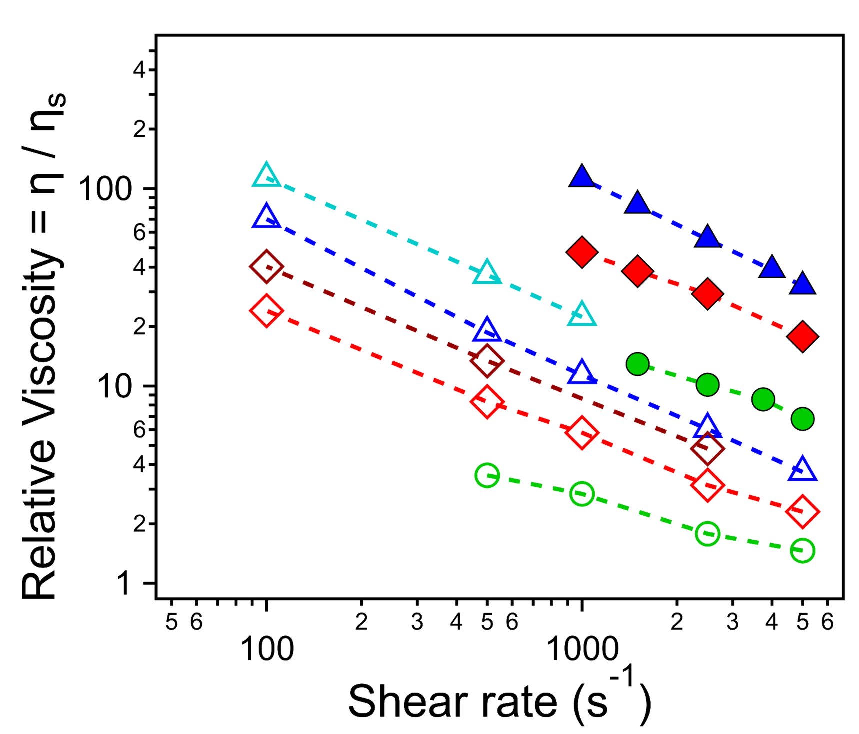


4. Rheological and structural behavior at Bi^{-1} > 1

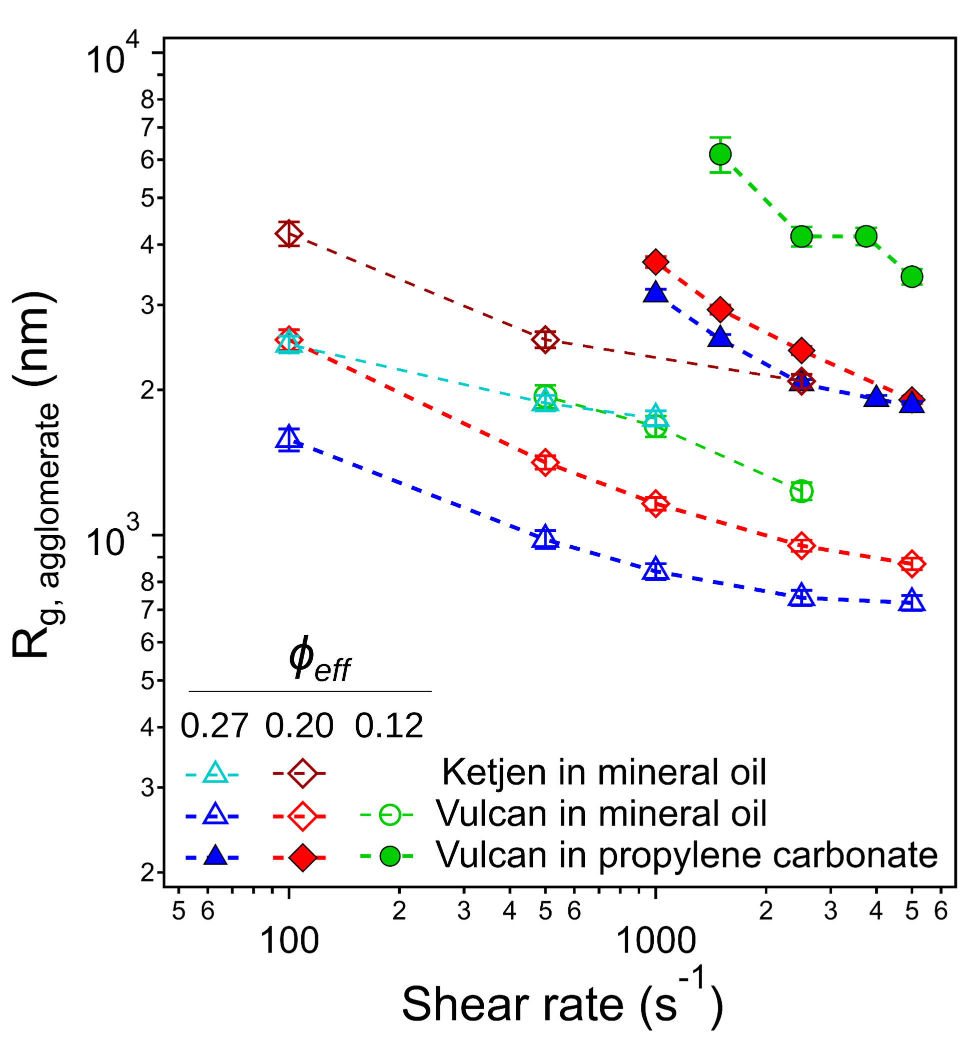
Rheo-USANS probes breakup



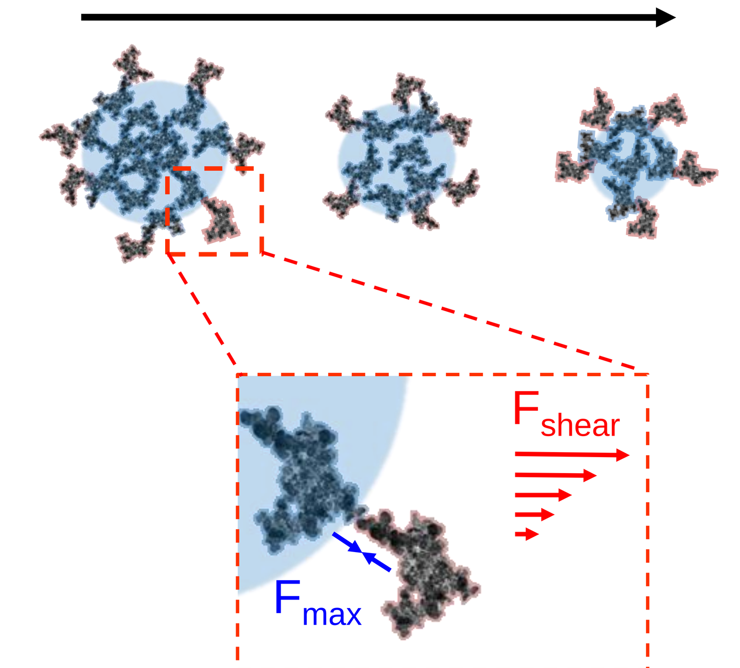
Shear-thinning coincides with breakup



At Bi^{-1} > 1, Rheo-USANS measurements are used to quantify the effect of shear on agglomerate size, $R_{g,\ aggl}$, and fractal dimension, D_f. These results show that agglomerates break up self-similarly with increasing shear rate. The extent of this breakup is a complex function of ϕ_{eff}, suspending fluid, carbon black type, and interaction potential.



5. Agglomerate breakup depends on the Mason number



Mason number (*Mn*):

From Stokes' law:

$$F_{shear,\,dilute} = 6\pi\eta_s\dot{\gamma}a^2$$

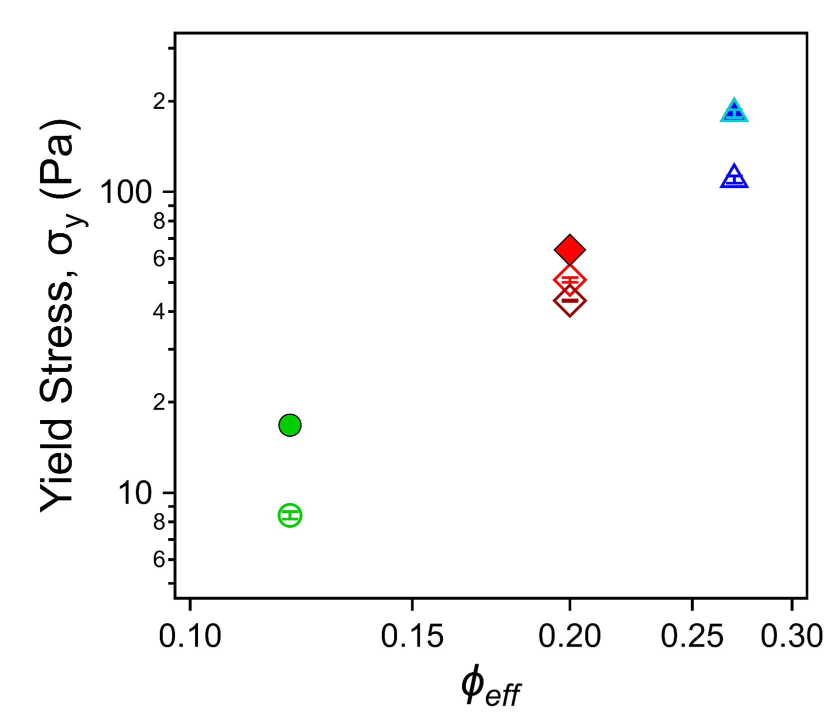
Suspension as an "effective medium":

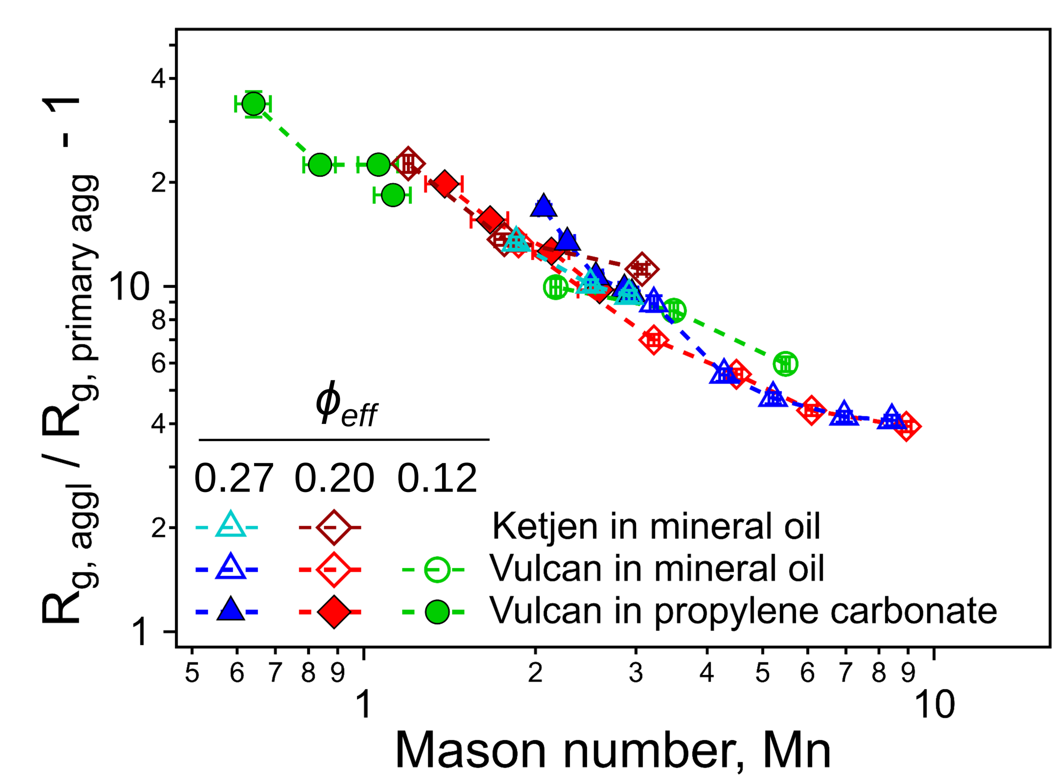
$$F_{shear,dense} = 6\pi\eta_{bulk}\dot{\gamma}a^2 = 6\pi\sigma a^2$$

F_{max} is related to the yield stress [5]:

$$\sigma_y = C\frac{\phi^2}{a^2}F_{max}$$

$$Mn = \frac{F_{shear,dense}}{F_{max}} = C6\pi\phi_{eff}{}^2\frac{\sigma}{\sigma_y}$$

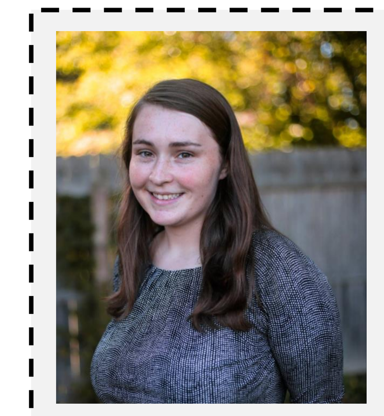




6. Conclusions

General behaviors observed:

- The inverse Bingham number, Bi^{-1}, predicts a transformation in agglomerate structure.
- Agglomerates breakup self-similarly at Bi^{-1} > 1.
- At Bi^{-1} > 1, the breakup of agglomerates depends on the Mason number, *Mn*.



Questions? Contact me at jhipp@udel.edu

7. Acknowledgements

- Paul Butler
- Yun Liu
- Paul Kienzle
- AkzoNobel
- Cabot Corp.

8. References

[1] J.J. Richards, J.B. Hipp, *et al*. *Langmuir*, **33**(43), 12260-12266, 2017. [2] Hipp *et al. J. Rheol.*, **63**(3), pp. 423-436, 2019. [3] B. Hammouda, *J. Appl Cryst*, **43**, 716-719, 2010. [4] J. Teixeira, *J. Appl Cryst*, **21**, 781-785, 1988. [5] Russel, *et al.*, *Colloidal Dispersions*, (1989). [6] Martys *et al.*, *Eur. Phys. J. E*, 35(20), pp. 1-7, (2012). [7] Eberle, *et al.*, *Phys. Rev. E.*, **89**(050302), pp. 1-5, (2014).