Rheology measurements of viscous fluid with solid suspensions under oscillatory shear

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Viscous fluids containing solid particles are ubiquitous in nature. Some examples are crystal bearing magma, mud and water saturated sand. When particles contain solid particles, peculiar rheology such as larger effective viscosity, presence of yield stress, non-Newtonian viscosity and viscoelasticity are known to appear. There have been two directions of research on rheology of suspensions. One is from chemical engineering where mainly small particle Peclet number regimes have been investigated. The other is from study of soil mechanics, where studies have been motivated from finding the liquefaction threshold. Although the latter experiments have been done in large Peclet number regimes, systematic studies of packing fraction, particle size and fluid viscosity dependence are lacking. In this paper, we show the results of rheological measurements made by varying these parameters.

Measurements were made using HAAKE rheocope in a cone and plate geometry. For the suspensions we used 8 and 40 micron polystyrene particles and silicone oil. We impose an oscillatory shear with a controlled peak stress value and measured the strain and phase. Parameters of measurements are peak stress value and its frequency. We changed the frequency in the range of 0.01 to 10 Hz.

Under a fixed frequency, we increased the peak amplitude and measured the storage (Gprime) and loss (Gdoubleprime) modulii and confirmed that there are following 3 regimes (Hymann et al. 2002); (I) a linear viscoelastic regime where the modulii are independent of amplitude, (II) a shear thinning regime and (III) a shear thickening regime. When we made a stress sweep measurement by incrementally increasing the peak stress, followed by decreasing the peak stress, we find that the measured modulii is reversible in regime (I), whereas it is irreversible in regimes (II) and (III). The threshold which separates the regimes is better defined by strain (rather than stress) and we define them as g1, g2 for regime boundaries of (I)-(II) and (II)-(III), respectively. From changing the parameters, we find that g1, g2 is independent of frequency and viscosity. When we increased the particle packing fraction from 0.2 to 0.6, g1 decreased from the order of 1 to 0.1, whereas g2 decreased from the order of 10ˆ-3 to 10ˆ-4. These results suggest that g1 and g2 are related to the distance between the particles. We can qualitatively associate g1 as the critical strain needed to overcome the interparticle friction, and g2 as that needed for the collision between the particles. Indeed, we find that g2 is of the same order of magnitude as the strain calculated by scaling interparticle distance by the particle radius.

The frequency used for measurement in the present experiments is similar to that of the seisimic waves, and may be used to understand the physics underlying liquefaction. We can associate g1 to the critical strain of liquefaction threshold, and g2 to the critical strain to cause dilatancy. Our measurement also suggest that liquefaction in a more viscous magma chambers is possible if these strain conditions are met.

Hymann et al., Investigation of the solid-liquid transition of highly concentrated suspensions in oscillatory amplitude sweeps, J.Rheol., 46, 93-112, 2002.