A Frictional Transition is not Fictional

Revealing the frictional transition in shear thickening suspensions
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Recommended with a Commentary by Bulbul Chakraborty, Brandeis University

Dense suspensions can respond to shear in ways that are counterintuitive. They are liquid-like at rest, however, when they are agitated, they can become highly viscous or even solid-like. Impact-driven solidification and discontinuous shear thickening are examples of such behavior that are currently being investigated with vigor.

Much of the recent studies have been motivated by the idea that a frictional transition drives these phenomena, and a theoretical framework has been proposed [1]. The rheological behavior predicted by the theory has been verified in numerical simulations [2] and experiments [3]. The experimental study reported in the recent PNAS paper by Cécile Cavaud and collaborators, “reveals” the underlying frictional transition by directly measuring the effective friction coefficient of the suspension through experiments inspired by granular physics. The results demonstrate that the macroscopic, shear thickening rheology emerges only if shear creates frictional contacts in an initially frictionless suspension.

The physical picture that the series of experiments reported in this paper put to the test is the following. The particles in a shear-thickening suspension experience a short-range repulsive force that keeps them from making contact, or, coming within the roughness length scale characterizing the particles. If these suspensions are subjected to increasing shear-rate, at some point the increased stress can overcome the repulsive potential creating frictional contacts. The Wyart-Cates theory combines this physical picture with the established fact that the density at which the viscosity of a suspension diverges decreases as the friction coefficient of a suspension increases.

The authors set out to directly measure the friction coefficient of a suspension by borrowing a tool from the granular world: measure the avalanche angle in a rotating drum under quasistatic conditions. The effective friction coefficient is given by the tangent of this angle. They also use another, traditionally, granular tool, which is to look at compaction and dilatancy. Broadly speaking, and the reader is urged to read the article to appreciate the elaborate experimentation, a sediment from a frictional suspension can be compacted and the avalanche behavior of the compacted sediment depends on how much it has been compacted because of the phenomenon of Reynolds dilatancy. On the other hand, frictionless sediments exist in only one state of compaction. These experiments are all performed at low confining pressure thus probing the intrinsic nature of the suspensions.

The first set of experiments using these tools establishes that a suspension of glass beads in water, whose rheology is Newtonian, has a large avalanche angle and exhibits dilatancy indicating the frictional character of the suspension. In contrast, potato starch particles suspended in water, which is known to shear thicken, exhibits a small avalanche angle and no dilatancy effects or change in packing fraction under compaction. These results suggest that there is a short-range repulsive force that keeps the starch particles apart and that this suspension shear thickens because shear can overcome this repulsive force.

The next set of avalanche and dilatancy experiments were performed on a model suspension where the short-range repulsion can be varied to directly test the frictional transition as the range of the interaction is tuned. The model suspension is that of silica beads in water to which the authors add varying amounts of salt to screen the electrostatic repulsive force between the particles. They demonstrate that there is a pretty sharp transition to frictional behavior when the ratio of the roughness length scale of the particles to the Debye screening length gets close to unity. These avalanche and dilatancy experiments thus clearly establish that under a given, small, confining pressure, a frictional transition can be induced by tuning the short-range interaction.

The crowning set of experiments is one that is rheological and explores the shear thickening behavior of the model suspension. What these experiments establish is that if the suspension at low pressure is already frictional (Debye screening length small compared to roughness scale), the suspension does not shear thicken whereas if it is frictionless *to begin with,* it does. The experiments, therefore, provide a compelling verification of the theory and reveal the frictional nature of the discontinuous shear thickening transition.

What these experiments do beautifully is establish a connection between microscopic contact physics and macroscopic rheology. The framework of Wyart and Cates [1] is a theory of rheology. A challenge for theorists is to construct a theory that bridges the microscopic and the macroscopic. The appearance of friction as the crucial ingredient poses particular difficulties in constructing such a theory. Some progress has been recently made in this direction [4] by generalizing tools that were used to understand shear-jamming in granular systems [5].

References

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