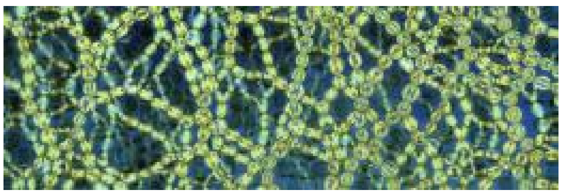
How granular material becomes solid: Stress causes clogs in coffee and coal

December 14 2011



Photoelastic grains under shear. Photo: Behringer Group, Duke University

It's easy to get in a jam. But it's much harder to explain exactly how or when it started.

Scientists still aren't sure what causes clogs in flowing macroscopic particles, like corn, coffee beans and coal chunks. But new experiments by Duke physicist Robert Behringer and his colleagues suggest that when particles undergo a force called shear strain, they jam sooner than expected. The results appear in the Dec. 15 issue of *Nature*.

Shear strain is sort of like cupping sand between your hands, and then, without changing the width between them, moving one hand forward and the other hand backward, Behringer said. Not much sand flows between your hands with a force like this.

Many flows, including those of nuts, coffee and coal, inherently produce this type of movement among grains, but the design and engineering for hoppers and other dispensers that don't account for it won't work well, Behringer said.

The new work "points out the deficiencies in our current theoretical framework for when granular materials jam," said Corey O'Hern, an expert in granular media at Yale University who was not involved in the new study.

A deeper understanding of this point will lead to the design of new composite granular matter and also to the development of advanced materials that could counter weapons of mass destruction, including amplifiers and other countermeasures for deflecting blast waves, he said.

In past studies, physicists calculating how grains flow estimated their jamming point without accounting for friction forces among individual particles. Eliminating friction makes jamming easier to explain mathematically. It also suggested that just an increase in density would cause granular materials to jam.

"It's been an uphill battle to convince the scientific community that friction is important, and that shear causes jamming where it was not expected. No other experimentalists have really looked at what's happening with both friction and shear," Behringer said.

In his new experiments, Behringer and his team controlled the number of discs placed in a box designed to produce a shear strain. The researchers applied the shearing strain while allowing the discs to flow where they wanted.

The discs had distinct properties that allowed the team to measure the force each one experienced due to friction and shearing. The team also took pictures showing how those forces developed into branched chains, which spread through many discs and ultimately block their flow. The images and experiments show that because of friction forces and shear strain, the discs jammed when they were much farther apart, or at a lower density, than what had been previously predicted.

It's not just the number of particles that put them in a jam, it's also the strain and the real-world forces, like friction, that cause the back-up, Behringer said. The discovery could change the design of coal and grain silos and even the bulk dispensers at Whole Foods.

Friction and shear reveal the richness of possible states of granular matter, pointing scientists down a road paved with new discoveries, said Daryl Hess, program director for condensed matter and materials theory at NSF. Studying these new states of granular matter may also expose deeper connections between jamming and seemingly unrelated phenomena, from earthquakes to transformations occurring in other kinds of matter, like water to ice, he said.

More information: "Jamming by Shear," Bi, D. Zhang, J., Chakraborty, B., and Behringer, R. Nature. 480:7377, 355-358. DOI: 10.1038/nature10667

Provided by Duke University