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The co-authors on these from Smith College are undergraduate physics majors.

Spatial Force Correlations in 3D Granular Flow
(2009 March APS meeting)

Kelsey Hattam, Alisa Stratulat, Efrosyni Seitaridou, Nalini Easwar, Smith College, Northampton, MA, Narayanan Menon, University of Massachusetts, Amherst, MA.

We measure the force delivered at four locations on the boundary of a 3D flow of mono-disperse glass spheres in a vertical, cylindrical chute. A variable opening at the bottom is used to change the flow velocity v_f from 3 to 30cm/s. The force is measured at 80KHz, allowing us to resolve individual collisions. We measure two-point spatial correlations in the flow direction and normal to it. The equal-time correlation between forces that are higher than a threshold shows a weak but measurable spatial correlation. This correlation shows no spatial directionality or dependence on flow rate. The time correlations are synchronous between diametrically opposed locations, and shifted in time between locations along the flow. From the time-lag we determine that the correlations are carried up the flow at speeds ~ 1000 v_f . This speed increases as the flow approaches jamming.

Supported by NSF DMR 0606216 and NSF MRSEC DMR 0213695

Shear zones at the walls of a 2D gravity-driven flow of grains
(2009 March APS meeting)

Kelsey Hattam, Nalini Easwar, Smith College, Northampton, MA; Narayanan Menon, University of Massachusetts, Amherst, MA.

We study the flow of spherical grains under gravity in a vertical, straight-walled 2-dimensional hopper, where the flow velocity is controlled by a taper at the outlet. We perform these studies both for monodisperse steel spheres as well as for a bidisperse system of equal numbers of spheres with a ratio of diameters of 1.25. The monodisperse system shows crystalline order even in flow, whereas there is no obvious structural order in the bidisperse system. The velocity profile across the flow is profoundly different in the two systems: the wall shear zone in the monodisperse system extends only a few particle diameters, and there are only small velocity gradients in the bulk of the flow. In contrast to this nearly-plug-like flow, there are significantly broader shear zones in the disordered flow. We report these profiles as a function of the width of the hopper in order to study the scaling of the shear zone with the system size, and with the flow rate.

Supported by NSF DMR 0606216 and NSF MRSEC DMR 0213695

Evidence for re-entrant behavior in laponite–PEO systems

Hossein A. Baghdadi, Elizabeth C. Jensen, Nalini Easwar, Surita R. Bhatia, Journal: Rheologica Acta, ISSN: 0035-4511, Vol: 47, Issue: 2,(2008)

Abstract:
We observe evidence of re-entrant behavior in dispersions of a discotic clay, laponite, with added polymer. Under basic conditions, neat laponite forms a disordered colloidal glass. Rheologically, this phase behaves as a viscoelastic solid, and dynamic light scattering shows evidence of non-ergodic behavior. Addition of low molecular weight poly(ethylene oxide) (PEO) melts the glass, resulting in a low-viscosity liquid with fast dynamics. We believe this is due to a depletion force caused by excess PEO chains in solution. A viscoelastic solid is re-formed with the addition of high molecular weight PEO, which we believe to be caused by polymer chains bridging between laponite particles. The physics in our system is quite different from the hard sphere/nonadsorbing polymer systems for which re-entrant glass transitions have been reported in the literature; however, we believe there may be similarities between these phenomena. To our knowledge, this is the first evidence of a type of re-entrant behavior in anisotropic colloids

Force fluctuations in collisional and frictional granular flows

Emily Gardel, Efrosyni Seitaridou, Ellen Keene, Nalini Easwar, Smith College, Northampton, MA., Narayanan Menon, University of Massachusetts, Amherst, MA.

We make measurements of the force delivered to the wall in 2D and 3D flow geometries to explore the difference between collisional and frictional flows, and between flow geometries with and without velocity gradients in the flow direction. The distribution of force fluctuations has an exponential tail at large force in collisional flows, but falls off slower than an exponential in frictional flows. We do not see a clear signature in the force distribution of the approach to jamming and therefore the connection to force distributions in quasistatic flows remains to be understood. However, the temporal characteristics of the force fluctuations do show the approach to jamming. As reported earlier, the distribution of collision times tends to a power law in collisional flows. Similarly, the power spectrum of forces in frictional flows develops power-law behaviour at low frequencies as jamming is approached.

Supported by NSF DMR 0305396 and NSF MRSEC DMR 0213695

Crossover from collisional to frictional regime in a 3-dimensional granular flow

Efrosyni Seitaridou, Ellen Keene, Nalini Easwar, Narayanan Menon

We have made measurements of the fluctuations in the pressure at several points on the boundary of a 3-dimensional, gravity-driven flow of slightly-polydisperse, smooth glass spheres. The flow is contained in a cylinder, with the flow rate being controlled over a factor of 30 by an aperture far downstream of the pressure measurement. As the flow velocity is decreased, we observe a crossover from a situation where momentum is transferred to the walls almost entirely by collisions to a situation where balls are almost always sliding against the walls. We parametrize this transition by measuring the fraction of time that a ball is in contact with the wall, a number that tends to unity in very slow flows prior to jamming. We present measures of the statistics and temporal fluctuations of the force delivered to the wall in both regimes. We find that in the collisional regime distributions of force are similar to those previously found in 2-dimensional flows [(1)], however, the distributions in the frictional regime are fundamentally new.

Supported by NSF DMR 0305396 and NSF MRSEC DMR 0213695

(1) E. Longhi, N. Easwar and N. Menon, Phys.Rev.Lett, **89** (2002)

Spatial and temporal correlations of Velocity and Force in a 2D Granular Flow

Emily Gardel, Sonia M. Dragulin, Nalini Easwar (Smith College, Northampton, MA.), Narayanan Menon (University of Massachusetts, Amherst, MA.)

We have measured the impulsive forces delivered at the wall of a 2D hopper by a flowing granular medium consisting of 3mm steel spheres. We also report high-speed video measurements of the particle velocity at several points in the flow, synchronized with the force measurements. Equal-time correlations between the force at the wall and the flow velocity fall off only slowly when the wall force is correlated with the velocity at various points across the channel, but die away on the scale of 1 or 2 bead diameters upstream or downstream. These data support a picture of short-lived chains of frequently colliding particles[1] that are a particle diameter in width, but extend far enough transverse to the flow direction to make transient load-bearing bridges that cause bulk fluctuations in the flow velocity. However, the time-dependence of these spatial correlation functions also indicate that while the force-bearing structures are local in space, their influence on the flow velocity extends far upstream in the flow, albeit with a time-lag.

Supported by NSF CAREER DMR-9874833 and NSF MRSEC DMR-0213695.

[1] A. Ferguson, B. Fisher and B. Chakraborty, arXiv.org/abs/cond-mat/0301201

Local Correlations of Velocity and Force in a 2D Granular Flow

Emily Gardel, Sonia M. Dragulin, Nalini Easwar (Smith College, Northampton, MA.), Narayanan Menon (University of Massachusetts, Amherst, MA.)

We have reported measurements of the local force delivered to the wall of a 2D hopper by a flowing granular medium of 3mm steel spheres[1]. We now report improved measurements of the fluctuations in force at the wall in order to study the low-force end of the force distribution, which is thought to be an indicator of the approach to jamming. We also report high-speed video measurements of the particle velocity near the wall, synchronized with the force measurements. Autocorrelations of the velocity in the flow direction show a characteristic decay time that is much longer than the mean collision time. We present evidence that the velocity fluctuations are controlled by fluctuations in the wall force: the equal-time cross-correlations between the velocity fluctuations at the wall, and the average magnitude and frequency of impulsive forces show that wall forces and flow speeds are anti-correlated; an increase in the momentum transferred to the walls either due to an increased frequency of collisions or a larger impulse transmitted per collision leads to a decrease in the flow velocity.

Supported by NSF CAREER DMR-9874833 and NSF MRSEC DMR-0213695.

[1] E. Longhi, N. Easwar and N. Menon, Phys.Rev.Lett, **89** (2002)