Invited speaker of GFR 2024

How a pinch of polymer in a granular medium dramatically modifies the rheology

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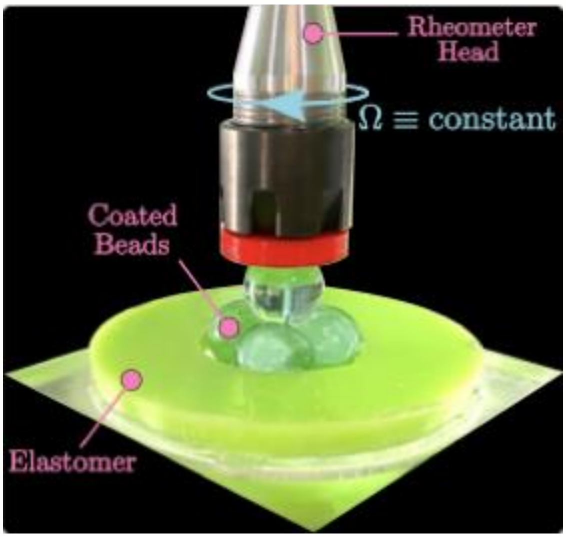
Coating processes are widely used in the powder industry. Their role is complex, as the coating can promote the flowability of the material, but also introduce cohesion between the particles. In this talk, I will present a study of the rheology of a model material composed of silica particles coated with a thin layer of PBS (polyborosiloxane). We show that the presence of the polymer coating considerably modifies the rheology by introducing complex lubrication effects. By combining pressure-imposed rheology on the bulk material, particle-scale tribological measurements and discrete numerical simulations, we are able to understand the complex role of the coating and propose a mean-field theory for predicting the rheology from the particle properties.



Flow and entanglement of dense suspensions of soft fibers

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Preference: TALK in Session 2.

Keywords (5 max): Fibers, Suspensions, Entanglements.

Suspensions of soft fibers are involved in a large range of processes, such as the manufacturing of paper or biomedical scaffolds. In particular, dense suspensions of microfibers can entangle to form viscoelastic gels, for example when extruded [1,2]. The structure of these suspensions, especially the entanglements and deformation of the fibers, directly impacts the resulting elasticity of the fibrous network. Understanding the parameters that play a role in the creation of these fiber entanglements and the resulting rheological properties of the gel is essential.
Here, we produce uniform suspensions of soft hydrogel fibers with a control over the characteristics of the fibers and the density of the suspension. In order to probe the presence of entanglements, we develop a model drainage experiment. A dilute suspension is placed in a container with an opening of controlled size. As we open the hole, the suspension drains under the action of gravity and may flow out of the container. Depending on the pressure gradient and the fiber characteristics, the suspension either flows as a dilute suspension or concentrates to form a gel-like elastic network (Figure 1). Entanglements can either accelerate the extrusion as the fibers are pulled together as an elastic network, or hinder the flow through the constriction (jamming). We determine the conditions for jamming or flow. We further perform a rheological study of these suspensions to investigate the link between the suspension flow regime and its rheological signature, in particular characterize their yield stress.

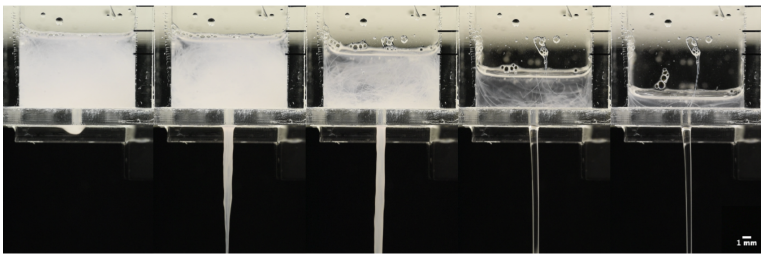

Figure 1: Snapshots of an experiment where a suspension of long and flexible hydrogel fibers (Diameter = 100 μm, Length = 3 cm) is flown through a constriction (time interval : 4 s).

[1]Perazzo, A. et al. *Journal of Applied Physics*,**114**, 123-135, (2017).
[2]Pan, Z., et al. *Nat Commun* **14**, 1242, (2023)

Role of inter-particles forces in the rheology of non-Brownian suspensions

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Preference : TALK session 2

Keywords : non-Brownian suspensions, shear-thinning, Jamming volume fraction, friction, adhesion

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Abstract : The study of the rheology of non-Brownian suspensions has made considerable progress over the last ten years, through experimental work and numerical simulations. These studies showed that the rheological properties of concentrated non-Brownian suspensions are essentially controlled by direct contact forces between particles: normal (adhesion) and tangential (friction) forces [1, 2, 3].
In this study, we aim to establish quantitative links between the rheological properties of these suspensions and microscopic interactions between particles. For this purpose, we have particule suspensions of 80 µm in diameter whose surface properties (adhesion, roughness, PEG brushes grafting…) are carefully controlled by click-chemistry [4].
Rheological measurements are performed using a rheometer with parallel-plate geometry.
To quantify pair-wise contact forces (adhesive and frictional), we use Atomic Force Microscopy (AFM).
Our results showed an overall shear-thinning behaviour for all types of suspensions represented by a jamming volume fraction that increases with shear-stress. AFM quantified contact forces are introduced in existing models to predict the rheological properties of suspensions.
We find a rather good agreement between experiments and model predictions [5, 6], especially regarding the effect of adhesive forces that lead to low jamming volume fractions. For non-adhesive (purely frictional) suspensions, shear-thinning can be captured by the decrease of the interparticle friction coefficient with normal load that has been measured with AFM.

[1] Chatté, G., J. Comtet, A. Niguès, L. Bocquet, A. Siria, G. Ducouret, F. Lequeux, N. Lenoir, G. Ovarlez, and A. Colin, 2018, Soft matter 14(6), 879.

[2] Lobry, L., E. Lemaire, F. Blanc, S. Gallier, and F. Peters, 2019, Journal of Fluid Mechanics 860, 682.

[3] Arshad, M. et al. *Soft Matter* 17.25 (2021): 6088-6097.

[4] Moratille, Y. et al. *J. Coll. Interf. Sc.* 607 (2022): 1687-1698.

[5] Zhou, J. Z., P. H. Uhlherr, and F. T. Luo, 1995, Rheologica acta 34(6), 544.

[6] Richards, J. A., B. M. Guy, E. Blanco, M. Hermes, G. Poy, and W. C. Poon, 2020, Journal of Rheology

Rheology of Dense Suspensions under Shear Rotation

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Preference : TALK, preferred session « Granular media and dense suspensions »

Keywords (5 max): dense suspensions, transients, rheometry

Abstract : Dense non-Brownian suspensions exhibit a spectacular and abrupt drop in viscosity under change of shear direction, as revealed by shear inversions (reversals) or orthogonal superposition. Here, we introduce an experimental setup to systematically explore their response to shear rotations, where one suddenly rotates the principal axes of shear by an angle θ, and measure the shear stresses with a biaxial force sensor. Our measurements confirm the genericness of the transient decrease of the resistance to shear under unsteady conditions. Moreover, the orthogonal shear stress, which vanishes in steady state, takes non-negligible values with a rich θ dependence, changing qualitatively with solid volume fraction Φ and resulting in a force that tends to reduce or enhance the direction of flow for small or large Φ. These experimental findings are confirmed and rationalized by particle-based numerical simulations and a recently proposed constitutive model. We show that the rotation angle dependence of the orthogonal stress results from a Φ-dependent interplay between hydrodynamic and contact stresses.

Cohesive granular flow down an inclined plane : discrete and continuum numerical simulations

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Preference : TALK - S2

Keywords : Granular flow, Cohesion, Rheology

Abstract : Cohesive granular flows are omnipresent in geophysical situations as well as in engineering applications. But the way in which cohesive strength at grains scale affects global flow behaviour is still lacking understanding. In this work, we use Contact Dynamics algorithm [4] to simulate a $2D$ cohesive granular flow of constant thickness over a rough inclined plan. Bagnold-like profile is firstly recovered from dry flow, from which we can calibrate the parameters in the classical $\mu(I)$ rheology [3]. Then contact adhesion characterised by a dimensionless granular Bond number B_o is considered for each particle collision [5] and steady uniform flow states are obtained by adjusting the plan inclination for different cohesive levels. Assuming the cohesive system obeys ideal Coulomb behaviour, the sheer state can be treated as the sum of a constant cohesive stress τ_c and a Coulomb stress $\mu(I)\sigma_n$ [2]. With regard to this, an analytical velocity solution can be established at equilibrium state. By comparing the analytical velocity profile with that of our simulations, we figure out the dependency of τ_c on the granular Bond number B_o. Besides, flow surface morphology is studied at different plan inclinations and cohesive strengths for a steady flow. The correlation between the characteristic length on the flow surface roughness and cohesive strength is found [1]. Moreover, as the no-slip velocity boundary condition at bottom is not verified in our discrete simulations, a study of the velocity at bottom v_0 is then conducted and a Navier-Robin boundary condition $v_0 = \lambda \partial v / \partial y|_0$ is discussed.

References

[1] A. Abramian, P.-Y Lagrée, and L. Staron. In: *Soft Matter* (2021).

[2] S. Deboeuf and A. Fall. In: *Journal of Rheology* (2023).

[3] P. Jop, Y. Forterre, and O. Pouliquen. In: *Nature* 441 (July 2006).

[4] F. Radjai and V. Richefeu. In: *Mechanics of Materials* (2009).

[5] P.-G. ROGNON et al. In: *Journal of Fluid Mechanics* (2008).

Rheology and structural organization of aqueous biphasic sytems

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Preference : TALK & S4 or S2

Keywords : nanosuspension, structural organization, aqueous biphasic systems

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Abstract : (Liquid Liquid Extraction (LLE) processes are often used for separating different elements in recycling industry. Generally, these processes use as solvents a mixture of water and a highly water-immiscible solvent to which a selective extractant molecule is added. The selective transfer of one element to the extracting phase, which is generally limited by diffusion, requires a large contact area between the two phases. The solvents used in LLE often had carcinogenic properties, limiting their use. However, new aqueous systems called Aqueous Biphasic Systems (ABS), consisting of a mixture of salt (e.g. Sodium Chloride - NaCl), ionic liquid (e.g. Tributyltetradecylphosphonium chloride - P4,4,4,14Cl) and water, and presenting a complex phase diagram with monodisperse and bidisperse aqueous zones, have recently shown their potential for LLE.

One question that arises is the structural organization of these complex systems ABS, both in the monophasic and biphasic zones of the phase diagram. By coupling neutron scattering structural[1] and rheological studies of these systems, we show that in the absence of added salt, the ionic liquid organizes itself as a nanosuspension, whose viscosity is in good agreement with Krieger-Dougherty model. We also discuss how the addition of salt modifies this microscopic arrangement and its impact on the rheology of the system. immediately.

[1] G. Meyer, R. Schweins, T. Youngs, J.-F. Dufrêche, I. Billard*, and M. Plazanet. The Journal of Physical Chemistry Letters, 13(12) :2731–2736, 2022

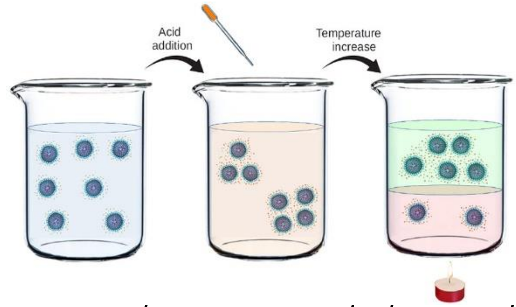

Figure: Phase separation in aqueous biphasic system. From 1

Memory and ageing effects in flows of dense colloidal suspensions

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Preference: TALK at S2/ Granular media and dense suspensions: from micro to rheology

Keywords: granular media, dense colloidal suspensions, ageing, memory, rheology.

Abstract: The packing of monodisperse particles continues to fascinate physicists. When particle size is reduced to the micrometre scale, these systems exhibit a peculiar behaviour. Thermal agitation causes creep flows that persist until the free surface of a pile becomes completely flat. One may ask whether the continuous vibration experienced by the particles can also cause the internal structure of a pile to evolve and exhibit time- and history-dependent effects. This question was addressed by studying the avalanche dynamics of several piles of monodispersed silica microparticles in water-filled microfluidic drums. Two types of pile preparation were carried out: one from the sedimentation of grains after homogenization, and other from successive avalanches generated by tilting a previous pile. Contrary to what is expected for memory effects in macroscopic systems, the results do not show changes in the avalanche behaviour of a pile generated by any of these procedures. On the other hand, we also explored the effects of longer waiting times before tilting the pile. Our observations indicate that as the waiting time increases, the onset of the avalanche is delayed and the flow slows down. It was confirmed that these ageing-like effects are not due to sample degradation, as old piles can be rejuvenated by agitation. Three hypotheses were tested to explain this phenomenon: changes in the compaction of the pile, evolutions in pile structure towards more organized packings, and kinetic effects linked to surface chemistry.

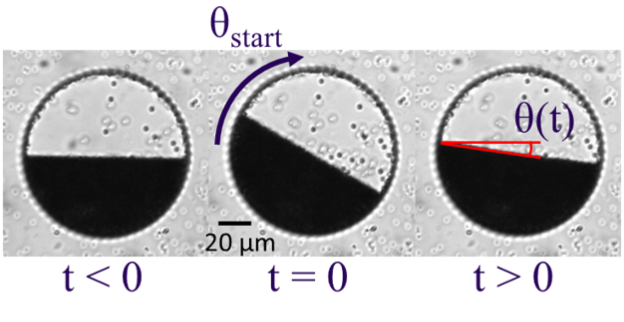

Figure 1: A pile of silica microparticles immersed in water (diameter = 1.93 μm) is tilted at an initial angle to generate an avalanche, then the angle is measured over time.

Adhesive strength of an artificial cemented granular soil with application to hydraulic failure

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Preference: TALK & session S2

Keywords (5 max): granular material, cementation, tensile yield, hydraulic failure, Archimedes number

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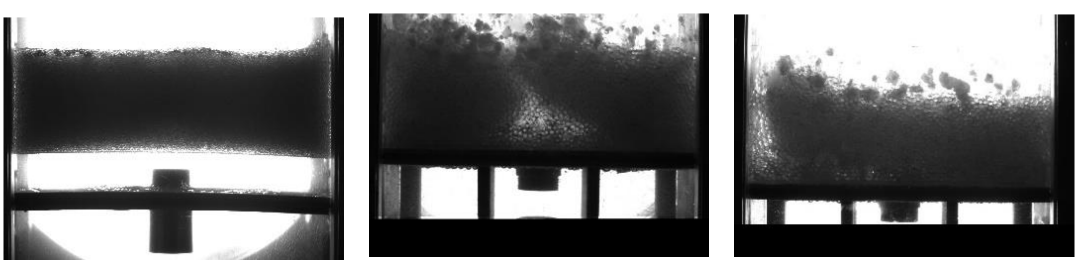
Abstract: This contribution presents work carried out on an artificial cemented material consisting of glass beads bonded together by solid paraffin bridges. A large number of microscopic experiments carried out under controlled mechanical stress at the contact between two bonded grains have enabled us to propose an empirical law relating the critical forces and moments of rupture to the diameter of the beads and the paraffin content in the medium. The use of this relationship then helped us to extend previous results of localized fluidization of a granular medium to the situation of hydraulic failure of our cemented soil, by extending Archimedes' number to this specific adhesive case.



(a) **(b)** **(c)**

Figure: Hydraulic failure modes in cemented soil layer by (a) uplift, (b) median crack, and (c) fluidized path

Penetration of a granular medium by a tip-growing tube

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Preference: TALK, in S4 Gels, polymers, foams and rheology at/with interfaces

Keywords (5 max): granular medium, eversion, soft tube, penetration

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Abstract: (250 Words Max) Anchoring a structure in the ground is a challenge that requires the application of significant external forces. However, anyone who spends a Sunday gardening knows that even young plants can develop impressive root networks without the need for external forces to anchor them. One peculiarity of roots is that they grow primarily at the tip. We mimic this growth using a soft cylindrical tube that everts on itself to understand whether this mode of penetration changes the interaction with a soil, modeled as a granular medium. The granular medium consists of a packing of beads and the penetration force of the everted tube is compared with the reference case of a rigid tube. For the rigid tube, we recover the classical quadratic dependence of the penetration force with depth, as friction is mobilized over the entire penetration depth. In contrast, the force required to penetrate with tip growth initially increases with depth before reaching a plateau, probably because friction anchors the tube in the granular medium, thereby damping the penetration force. In addition, the tube tends to bend as it penetrates, a consequence of the interactions between the mechanical behavior of the inflated tube and the mechanical stress in the granular medium. These results suggest that tip growth is an effective anchoring mechanism.

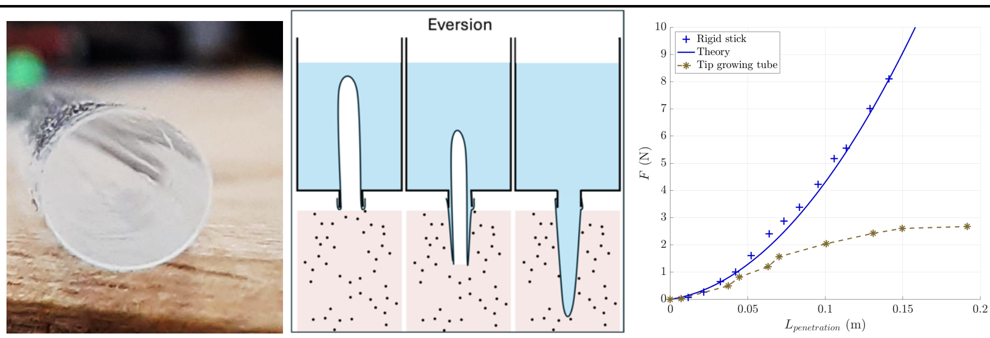

Figure: Photography of a soft tube (left) that has been fabricated in PDMS, with a diameter of 7 mm and a thickness of 150 µm (±10 µm), eversion principle (center) and penetration force as a function of depth (right) for a rigid stick and a tip-growing tube.

Study of a stationary bedload transport by a laminar shearing flow across viscous to inertial regime

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Preference: TALK & preferred session: 'Granular media and dense suspensions: from micro (friction/adhesion/entanglement) to rheology'

Keywords (5 max): Erosion, granular rheology, refractive index matching

Abstract: Erosion is a natural phenomenon deeply involved in geo-morphology such as the formation and evolution of systems like channels, fans, and dunes. Two-phase modeling has been recently developed to describe sediment transport using a continuum description of the particulate phase stemming from recent developments made in dense suspension and granular flows, and has been successfully compared with experiments in a laminar viscous regime. This study aims to combine experiments and theoretical approaches to gain a better understanding of the sediment transport by a shearing fluid. In particular, considering a tilted channel, we design a configuration that allows to obtain a stationary flow. Using a refractive index matched combination for particles and fluid, the objective is to acquire detailed measurements of fluid and granular motions for various regimes, from viscous to inertial, to infer the rheology of the sediment.

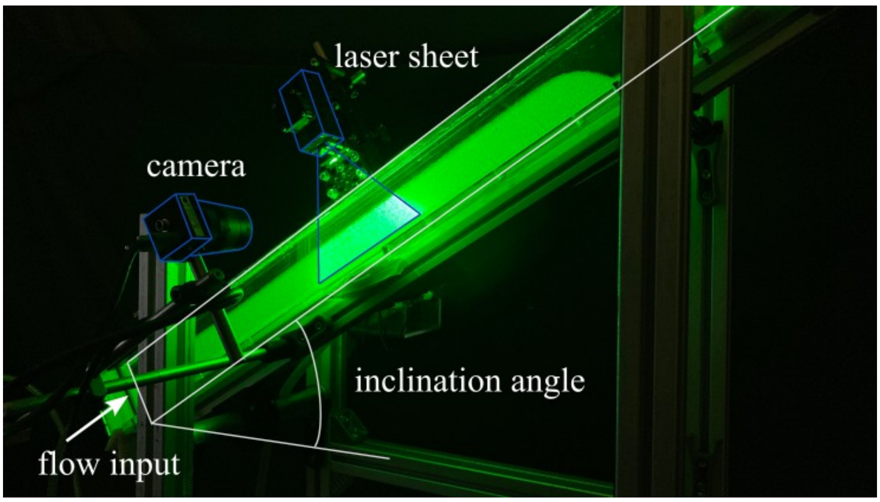

Figure 1: Experimental apparatus

Shear-thickening suspensions in pipes: A frictional soliton controls the flow resistance

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Preference: Talk - S2/ Granular media and dense suspensions: from micro to rheology

Keywords : Shear-thickening suspension, Pipe flow, Friction, Jamming, Soliton

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Abstract : Suspensions of non-Brownian microscopic particles shear-thicken when sheared strongly. While this behavior has been understood as a grain-scale frictional transition [1, 2, 3], and extensively studied in rheometric (simple shear) configurations, it is not even known how shear-thickening suspensions flow through pipes. We experimentally address this question using a gravity-driven pipe flow, for which the mean shear stress at the wall is precisely controlled. For large particle volume fractions, we find that the flow rate actually saturates at high driving stress. Local measurements of pressure and near-wall velocity reveal that this saturation is associated with the emergence of a *frictional soliton*: a unique, localized, back-propagating and superdissipative flow structure, which coexists with the laminar frictionless flow over the remainder of the pipe. We characterize the remarkably steep effective rheology of the frictional soliton and show that it sets the resistance law at the whole pipe scale. The phenomenology is observed for varied shear-thickening suspensions, confirming its universality for industrial and environmental applications.

References

[1] Mari R., Seto R., Morris J. & Denn M. *Shear thickening, frictionless and frictional rheologies in non-Brownian suspensions*, J. Rheol., **58**, 1693–1724 (2014).

[2] Wyart M. & Cates M. E. *Discontinuous shear thickening without inertia in dense non-Brownian suspensions*, Phys. Rev. Lett. **112**, 098302 (2014).

[3] Clavaud C., Bérut A., Metzger B. & Forterre Y. *Revealing the frictional transition in shear-thickening suspensions*, Proc. Natl. Acad. Sci. **114**, 5147–52 (2017).

Reconfiguration of drag of a Flexible Ribbon sedimenting in a viscous Fluid

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Preference: TALK or Poster & S4 Gels, polymers, foams and rheology at/with interfaces

Keywords (5 max): Drag reconfiguration, fluid-structure, low Reynolds, deformable objects

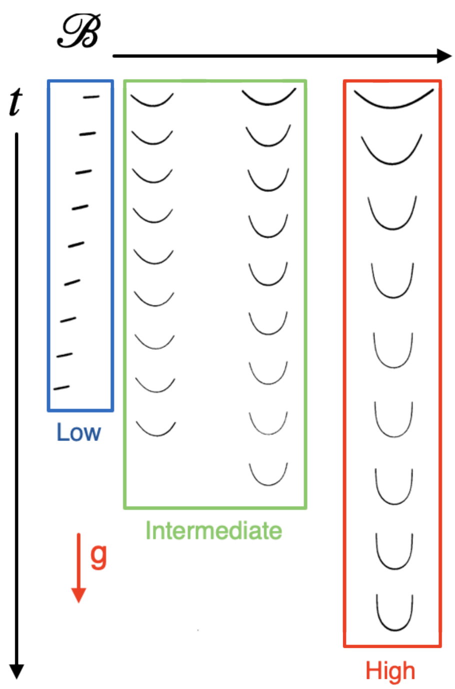

Figure 1: Ribbon sedimentation chronophotographies of increasing $\mathcal{B}$

Abstract (250 Words Max): The motion of a deformable elastic structure in a viscous fluid is of fundamental importance, from flagellar propulsion of micro-organisms and small flying insects, to biopolymer (e.g., DNA or actin microfilaments) or polymer science. The interaction between internal elastic forces and hydrodynamic forces results in deformations of the object that govern its velocity.

Inspired by previous studies on the settling of elastic cylindrical fibers [1,2] or rigid slender ribbons [3], we investigate the dynamics of the deformation, the drag, and the settling velocity of elastic ribbons, at low Reynolds number combining experiments and a simple bead-spring modeling of the ribbon.

We show that the deformation of the ribbons is governed by the competition between the torque applied by gravity to the ribbons and the typical elastic resisting torque, captured by a nondimensional number $\mathcal{B}$ (see chronophotography on fig1). Depending on the value of $\mathcal{B}$, i.e. the relative magnitude of these two effects, we observe three regimes of deformation, characterized by the length and the thickness of the ribbon, and independent of its width. These regimes can be classified as low and high deformation regimes, characterized by a drag proportional to the settling velocity, and an intermediate regime, which exhibits a non-linear drag-velocity relationship.

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[1] Marchetti B., Raspa V., Lindner A., Du Roure O., Bergougnoux L., Guazzelli E, Duprat C. *Deformation of a flexible fiber settling in a quiescent viscous fluid*, Phys Rev Fluids, **3**, 104102, 2018

[2] Delmotte B., Climent E., Plouraboue F. *A general formulation of Bead Models applied to flexible fibers and active filaments at low Reynolds number*, Journal of Computational Physics, **286**, 14-37, 2015

[3] Koens L., Lauga E. *Analytical solutions to slender-ribbon theory*, Phys Rev Fluids, **2**, 084101, 2017

Granular aqueous suspensions with controlled inter-particular friction and adhesion

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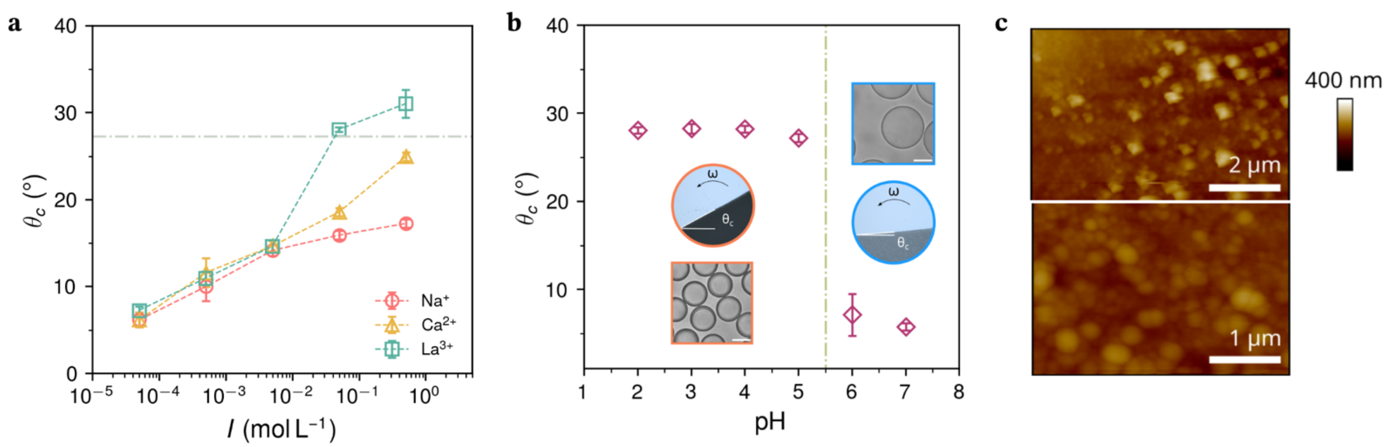
Preference : TALK

Keywords (5 max): suspensions, friction, stimuli

Abstract: In this talk, I will describe recent work we carried out on the design of stimuli-responsive non-Brownian particles with the aim of controlling inter-particle friction and adhesion. I will start with a description of the chemical reaction that allows us to produce up to 50 g of non-Brownian frictionless particles from commercial frictional particles. I will then focus on the response of suspensions of these modified particles in a rotating drum. Their flow will be discussed in the light of a characterization of their surface with an AFM, and I will show that the particles respond to physico-chemical stimuli that act as a proxy to their frictional state. I will finish with preliminary pressure-imposed measurements in a rheometer, the capillarytron.



Revisiting the role of friction in transient granular flows through non-smooth simulations and experiments

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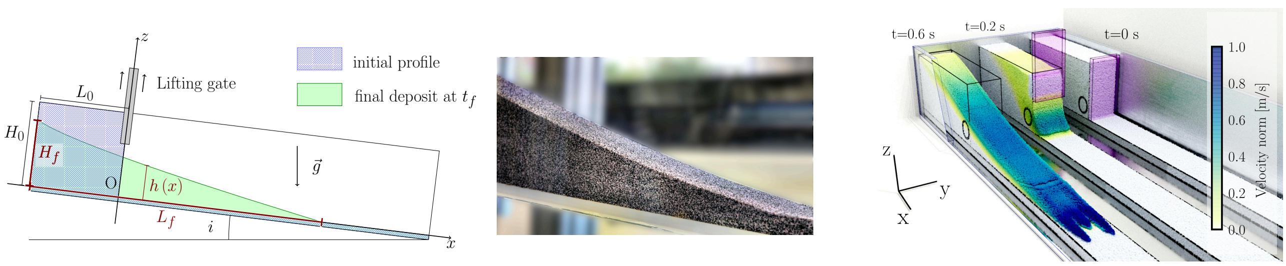
Preference: Talk (session S2 "Granular media and dense suspensions")
Keywords: transient granular flows, non-smooth, friction



(a) Experimental setup of the granular collapses onto inclined erodible beds.

(b) 3-D simulation of a granular column collapse on a 15°-tilted bed.

Figure 1: Inclined granular column collapses: experiments and simulations [1].

We confront experiments of granular column collapses with the corresponding 3D continuum-based numerical simulations to carefully investigate the role of friction in transient granular flows. We carry out the collapses with different bed slopes, ranging from 0° to 20°, different channel widths, and different materials, and analyse the impact of frictional dissipation within the material or with its enclosing walls by comparing experimental data to numerical simulations performed with different friction coefficients and models.

Our simulation method leverages the non-smooth MPM-based continuum framework introduced in [2] to accurately resolve the plastic Drucker-Prager threshold without regularisation, and carefully accounts for all the experimental setup (c.f.fig. 1), including friction with the lateral walls and the lifting gate. We notably compare simulations obtained with the fully plastic Drucker-Prager and the viscopastic $\mu(I)$ [3] rheologies, and compare both the resulting transient and final states with experimental measurements of the free-surface profiles and material velocities measured at the side wall.

While our results (e.g. fig. 2a) confirm the weak impact of the viscous effects introduced by the $\mu(I)$ rheology in this regime, as previously suggested in [4, 5], they also stress the

Influence of temperature on the flowability of powders

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Preference : TALK (S2/ Granular media and dense suspensions: from micro (friction/adhesion/ entanglement) to rheology)

Keywords (5 max): Powder, temperature, flowability, rheology, rotating drum

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Abstract : Numerous applications involve processing granular materials or powders at elevated temperature. This can be due to requirements of the process or variations of the environmental conditions especially for production sites located around the world. Temperature elevation can induce different mechanisms that will change the powder properties. The moisture content will usually decrease at elevated temperature, the oxidation at the surface of the particles will be modified, the stiffness of the particles will change, … All these particle properties modifications will lead to a variation of the powder cohesiveness and subsequently will influence the flowability [1]. Therefore, it is essential to evaluate the powder behavior at a temperature close to the one seen in the process in order to provide reliable predictions. In this study, we propose to investigate the influence of temperature on the flowability and rheology of powders in a rotating drum geometry (Granudrum, Granutools). A cylindrical cell containing the powder rotates at different speeds while being maintained at the target temperature (from room to 200°C). Snapshots of the powder bed are taken and analyzed to recover the powder to air interface. The Cohesive Index metric [2] is used to evaluate the influence of temperature on the cohesive behavior of the materials. A significant impact of the temperature elevation on the powder flowability is observed, even for the metal powders.

[1] G. Lumay, F. Francqui, C. Detrembleur, N. Vandewalle, Influence of temperature on the packing dynamics of polymer powders, Advanced Powder Technology (2020), 4428-4435, 31(10).

[2] A. Neveu, F. Francqui, G. Lumay, Measuring powder flow properties in a rotating drum, Measurement 200 (2022), 111548.

Tribocharging of flowing granular materials: experiments and DEM simulation with patchy particles

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Preference : TALK, S2

Keywords : tribocharging, cohesiveness, adhesion, granular flow

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Abstract : When two objects are rubbed against each other, they charge electrostatically due to the triboelectric effect. This effect is significant in flowing granular materials due to the large rate of collisions between grains and between grains and surfaces. Measuring and understanding this phenomenon, and its consequences, remains a challenge. For example, the reason why large particles tend to charge positively while small ones charge negatively in binary mixtures is still a matter of debates. We investigated a model based on the existence of acceptor and donor sites (also called patches) of charges at the surface of the grains and show that the experimental measurement of binary mixtures' charging can be retrieved using customized DEM simulations. The patches at the surface of spherical particles are defined using a Voronoi tessellation. To compare with experiments, simulations were performed in the rotating drum geometry and with grains flowing in an inclined tube. In the rotating drum, the charge buildup during the flow induces avalanches and intermittent flow as for cohesive powders in experiments. In the inclined tube, we recover the influence of the angle on the total charge that is measured in experiments. Finaly, this model is used to improve the understanding of the measurements performed with the GranuCharge laboratory instrument.

Tribocharging of granular materials and influence on their flow, Soft Matter **19**, 8911 (2023)

Figure: (Left) Simulation of flowing grains with charge donnor/acceptor patches in a rotating drum. (Center) Simulation in a tube. (Right) Experiments with GranuCharge.

Exploring the degradation of cationic polyacrylamide flocculants during rheological measurements

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Preference : TALK
Keywords (5 max): Flocculating polymer, Cationic polyacrylamide, polyelectrolyte rheology, Wastewater treatment.

Abstract: In wastewater treatment operations, polymers are commonly used as flocculating agents to agglomerate particles into large flocs. Optimizing the flocculation process remains a significant financial, operational, and environmental challenge. High molecular weight cationic polyacrylamide (CPAM) polyelectrolytes are widely used as flocculants due to their effectiveness in forming robust flocs, aiding separation, and enhancing sludge thickening and dewatering. Since flocculation heavily relies on the rheological characteristics of CPAMs, precise measurement of their properties is crucial for scaling installations. This research shows that obtaining the intrinsic rheological properties of these polymers is challenging due to the lengthy time needed to acquire low shear viscosity and relaxation time data. Indeed, our study demonstrates that CPAMs are susceptible to degradation when in contact with various metallic surfaces. This conclusion is drawn from observing significant changes in CPAM's rheological properties during measurements using metallic Couette tools, where a shift from elastic to viscous behavior is evident.[1] The low shear viscosity drops drastically over time by several orders of magnitude, and the reptation time similarly decreases during the degradation process. This degradation is especially pronounced with metallic surfaces, while thermoplastic surfaces have a substantially lesser effect on CPAM. Key findings indicate that chemical interactions, rather than mechanical stress, primarily drive the degradation process, with temperature acting as a catalyst. This research offers essential insights into the interactions between CPAM and metal surfaces, bearing significant environmental and industrial implications. Additionally, it establishes a protocol for accurately characterizing the intrinsic rheological properties of these materials.

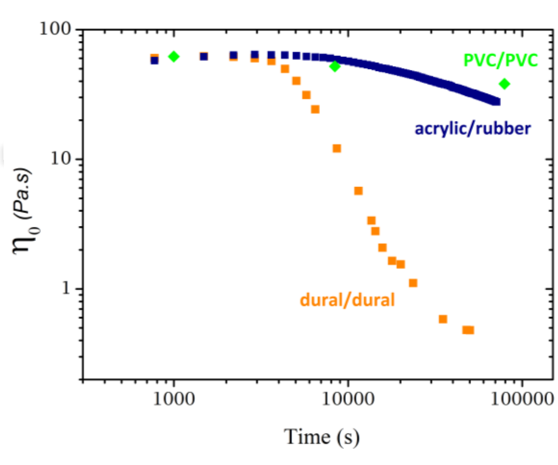

Figure: Impact of rheometry tools materials on reducing viscosity of cationic polyacrylamide.

[1] Loukili, N., Chitanu, A., Jossic, L., Karrouch, M., Oliveira, M., Guerin, S., Fayolle, Y., Ginisty, P., …& Rharbi, Y. (2024). "*Degradation of Cationic Polyacrylamide Flocculants upon Contact with Metal Surfaces during Rheological Measurements*". https://assets-eu.researchsquare.com/files/rs-4188757/v1_covered_7899260a-5e8f-460b-a590-7cc18cce88ac.pdf?c=1712178498

Insights into the rheological behavior of mineral suspensions used in cement industry

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Preference : TALK

Keywords : Viscoelasticity, Solid volume fraction, Particle size distribution, Percolation threshold, Structural build-up

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Abstract : Mineral suspensions like cement paste exhibit complex rheological behavior due to particle polydispersity and chemical reactivity. Understanding this behavior is of great interest for modern cementitious materials, such as low carbon cements and printable materials, which face challenges in their application (multi-layer casting, SCMs..).
This study focuses on how the type and granular properties of mineral powders, commonly used in cement formulations, affect viscoelastic behavior and structural build-up. Using a small amplitude oscillatory shear (SAOS) procedure, the effects of solid volume fraction, particle size, and reactivity on deformation capacity and network percolation/rigidification were examined. Four types of mineral suspensions: a Portland cement, a limestone filler (LF1), a crushed limestone filler (LF2), and a Fly ash (FA).
Results show that granular properties significantly impact the percolation of a network able to withstand minimum shear stress. Cement paste and fly ash showed a percolation volume around 35%, while limestone filler suspensions (LF1 and LF2) had about 25%. The deformation capacity was slightly influenced by the type of mineral suspension and solid volume fraction once the particle network was formed, with critical strain at the end of the LVED being similar (approximately 10^-4). However, the crossover strain (or transition solid/liquid strain) was notably affected by solid volume fraction.
Moreover, structural build-up varied significantly with the type of mineral suspension and solid volume fraction. Cement pastes with 50%, 48%, and 45% solid volume fractions exhibited structural build-up rates of 195.6, 150.5, and 95.8 Pa/s respectively, with cement paste showing the highest rigidification rate due to enhanced flocculation from particle dissolution.

Jet instability of magnetorheological suspensions exhibiting discontinuous shear thickening

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Preference : TALK or **Poster** & preferred session: S2

Keywords: discontinuous shear thickening; magnetorheological fluids; jets; flow instability

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Abstract: Instability of jet flowing out from a vertical tube under gravity stretching is one of the striking features of the discontinuous shear thickening (DST) phenomenon. This instability is manifested through self-excitation of bending waves [Fig. 1] appearing even for free ended jets [1,2], as opposed to classical rope-coiling instability. It has been recently shown that the bending waves appear only if the peak tensile stress in the jet overcomes the DST threshold stress [2], while the wave dispersion relation is nearly linear for silica and calcium carbonate concentrated suspensions [1,2]. In this work, we explore concentrated suspensions of iron particles whose viscosity can be tuned by application of external magnetic fields **B**. Unexpectedly, we observe at least two zero group velocity modes of the bending waves propagation, while, depending on **B** orientation, the applied magnetic field either stabilizes the jet or amplifies the amplitude of the jet bending. These results will be discussed in connection with DST phenomenon and suspension microstructure, both affected by the applied field.

1. Liard, M., et al. (2020). Eur. Phys. J. E, 43, 1-6 (2020).
2. Meloussi, M. et al. J. Rheol., 66, 1005-1026 (2022).

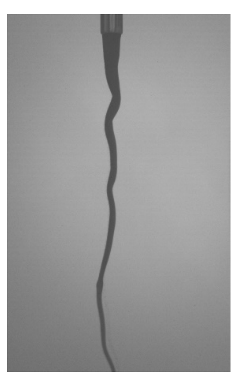

Fig. 1. Bending waves of the iron suspension jet flowing out from a vertical tube (B=0)

Slip velocity at high slope angles in dry granular flows over a rough incline

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Preference: Poster & session S2, Granular media and dense suspensions

Keywords: Dry granular flow, Rough incline, Slip velocity, Experiment, Discrete numerical simulation

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Abstract: Granular material flowing on complex topographies are ubiquitous in industrial and geophysical situations and exhibit non-trivial rheological properties, which we attempt to better understand thanks to model materials and appropriate rheometers. A widespread model configuration relies on steady and uniform dry granular flows over a rough inclined plane. However, we observe the emergence of a slip velocity between the granular layer and the rough bottom of the inclined plane at high slope angles, even before the instability of longitudinal vortices, well known in the literature. We investigate the effects of the emergence of a slip velocity on the estimation of the apparent friction coefficient as a function of the inertial number. In particular, we study the amplitude of the error induced by the slip velocity, thanks to the comparison between three dimensional experimental and two dimensional discrete numerical results.

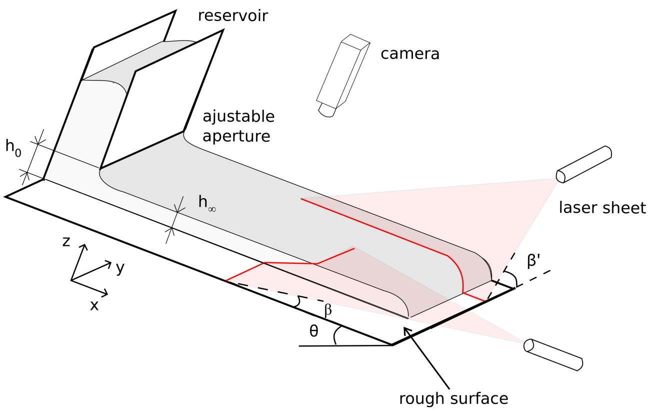

Figure 1: Schematic representation of the inclined plane setup

Laboratory landslides

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Preference: Poster & S2

Keywords (5 max): Granular media, Laboratory experiments, Landslides

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A main objective in landslide research is to predict how far they will travel. A well-known feature first reported by Albert Heim in 1932 is the positive correlation between landslide volume and landslide runout, so that larger landslides can travel many times further than one can naively predict using the energy balance between initial potential energy and frictional dissipation. Here, we used a simplified geometry for granular landslide laboratory experiments to study these complex phenomena. Focusing on the maximum travel distance, we were able to reproduce at the laboratory scale the positive correlation between landslide volume and its runout. Then by using scaling analysis, we found that correctly accounting for the fall height and the granularity not only yields an improved correlation of normalized runout, but also quantitatively unites experiments and field data.

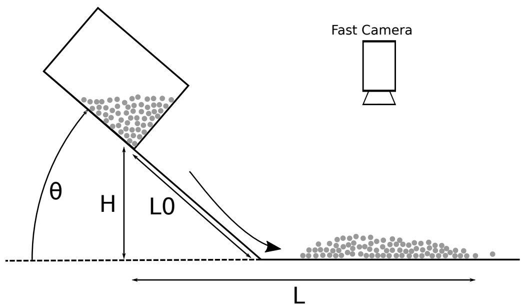

Figure 1: Side view schematic of the experimental setup.

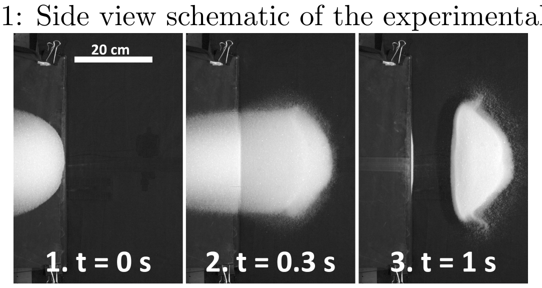

Figure 2: Motion of a mass of grains.

Rhéologie des Granulaires Partiellement Mouillés

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Mots-clés : LAOS, Granulaires non saturés, Cohésion, Rhéologie – $\mu(I)$

Résumé :

On étudie le comportement non linéaire lors de grande amplitude oscillatoire (LAOS) de matériaux granulaires humides non saturés en utilisant des mesures rhéométriques sous contraintes normales contrôlées. En dehors de la limite quasi-statique, on montre que l'énergie dissipée par unité de volume au cours d'un cycle LAOS, qui peut être visualisée par la surface incluse dans la courbe de Lissajous de contrainte par rapport à la déformation, est une fonction croissante de la viscosité du liquide mouillant et est également influencée par la pression réduite $P*$ (comparant les forces cohésives aux forces de confinement) et la fréquence. En introduisant le nombre inertiel I et le nombre visqueux I_v comme cela a été fait précédemment, il est montré que l'influence de la tension superficielle, de la viscosité, du et de la fréquence d'excitation peut être capturée en traçant l'énergie dissipée par unité de volume en fonction de I_v : un bon ajustement est obtenu. Un modèle théorique, introduisant la rhéologie $\mu(I)$, permet également de prédire les résultats de cette étude.

Discharge Flow of a Granular Media from a Silo: Experimental investigations and continuum modeling

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Preference: TALK session S2

Keywords: granular media, visco-plastic frictional rheology

Abstract : Silos are widely used in the industry. While empirical predictions of the flow rate, based on scaling law, exist for more than a century, recently advances have been made on the understanding of the control parameters of the flow. In particular using a continuum model together with a visco-plastic frictional rheology seem to be successful in predicting the flow rate.
In order to gain a better understanding of the physical mechanisms at play during silo discharge, we are conducting experiments considering different unconventional geometries (lateral orifice, corner orifice, presence of an obstacle, cohesive materials...) and testing the ability of a continuum model to predict observations.

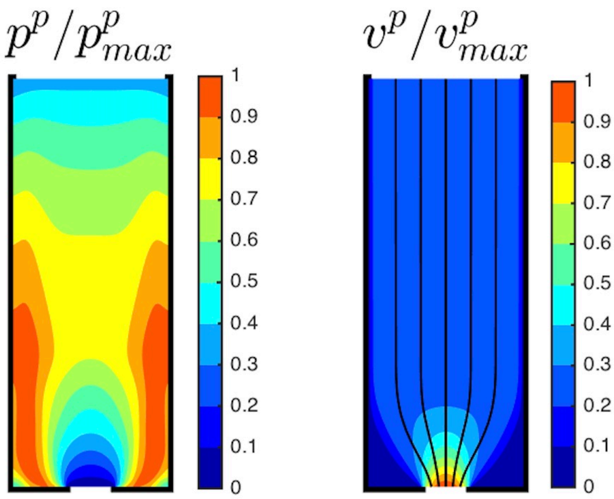

Figure 1: Continuum simulation of a silo discharge using a visco-plastic frictional rheology $\mu(I)$, pressure and velocity fields.

Mechanics of active fibers assemblies : Fitting a poplar tree in the lab

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Preference: Poster, Session 2

Keywords (5 max): Active fibers, cohesion

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tecnic **Abstract:** We study the opening of fruits from the poplar tree. Seeds from this tree are wind carried thanks to cotton-like fibers, deployed when the fruit dries. These fibers are initially packed inside the fruits and unfold to occupy a much larger volume. Using active fibers made of memory shape alloy we try to reproduce this physics in the lab in a controlled model experiment. Our fibers are highly deformable and plastic at room temperature, but recover their initial straight shape and become stiffer when heated. We aim to characterise the change in volume as well as cohesive effects that emerge when an assembly of active fibers undergoes a rise in temperature.

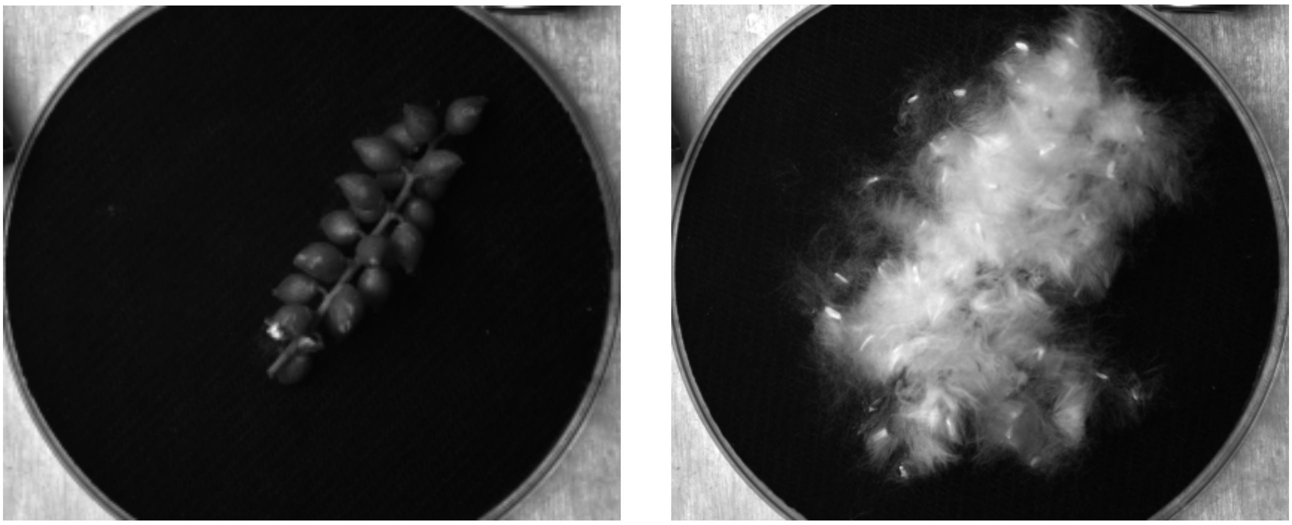

Figure 1: Branch of the poplar tree. Initially the fruit are closed (left). After drying over one night (right), the fruits are open and an assembly of cotton-like fibers is deployed.

GRAIN DISPERSION IN SMOOTH GRANULAR FLOWS

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Preference: TALK or Poster & preferred session

Keywords (5 max): Chaotic flows, Granular dispersion, mixing

Abstract: Mixing is crucial in industries like glass and concrete manufacturing, where inadequate homogenization affects quality. Chaotic flows enhance mixing at low Reynolds numbers through advection and diffusion (Aref, 1984), a quantitative analysis can be done via concentration fields (Villermaux, 2019). Despite many studies on fluid mixing, granular mixing in smooth flows is less understood, complicated by differences like discrete nature and lack of thermal agitation (Ottino & Khakhar, 2000).

We developed a 2D dry granular experiment in a closed setup, using a figure-eight protocol to stir the grains. By tracking each grain, we quantify Lagrangian trajectory separation and the evolution of tagged particles towards homogeneity, focusing on global system rotation. Our results suggest potential improvements in dispersion models for smooth granular flows through further variance decay analysis.

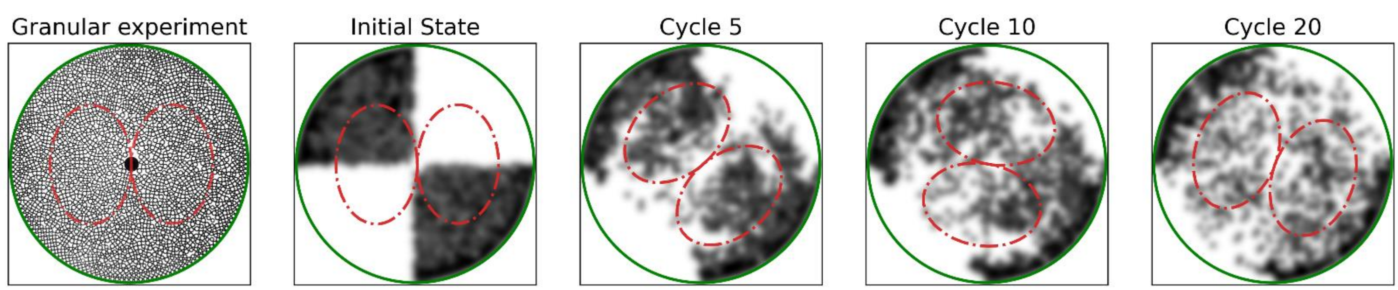

Figure: 2D granular experiment confined in a circular configuration (green line), where grains are stirred by a rod using a figure-eight protocol (red line). Tagged particles are spread by the rod, which rotates 10° each cycle to enhance global rotation.

A gluey contact model with friction for the numerical simulation of immersed granular media

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Preference : TALK S2 : Granular media and dense suspensions: from micro (friction/adhesion/ entanglement) to rheology

Keywords : Friction, Viscosity, Numerical Simulation, Contact, Granular Media

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Abstract :

In this presentation, we focus on the simulation of dense granular media made up of macroscopic particles coated with a viscous fluid. These systems reveal physical phenomena such as lubrication (effect of interstitial fluid) and solid contact, which are also existing in the more general context of suspensions. The macroscopic behavior of such systems (concentration instabilities or flow-blocking, for example) is particularly complex and still poorly understood.

Numerical simulation of these systems should provide a step forward in our understanding of these phenomena. The modeling of contacts between grains is very important for the macroscopic behavior. These contacts lead to singular interactions for which suitable numerical schemes need to be developed. In this context, we consider the approach of the "Contact Dynamics" models developed by J.J. Moreau.

Such schemes have been developed to take account of dry contacts with friction [1] or lubricated contacts [2] . At each time iteration, a discrete energy minimization problem is solved, under a constraint that depends on the chosen model. Experimental results show that it is essential to take into account both the effects of lubrication and frictional contact [3]. Based on the above formulations, this talk presents a new model to represent the transition between viscous and frictional contacts. The corresponding scheme involves solving a new constrained optimization problem at each point in time. The results of multi-particle numerical simulations of granular media flowing on an inclined plane with the code SCoPI [4] illustrating the macroscopic differences induced by the choice of contact model will be presented.

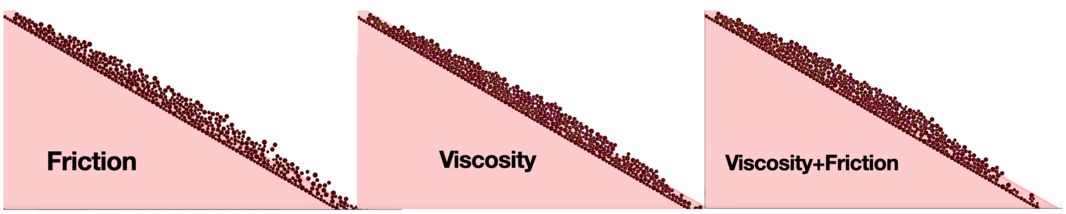

Figure: Simulations of particles flowing on a plane for various contact models

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