PhD position in Material Physics (2020-2024)

Rheology and Microstructure of unsaturated wet granular materials

Context and Goal

The Rheophysics group of NAVIER Laboratory (https://navier-lab.fr, a joint research unit between Ecole des Ponts-ParisTech, IFSTTAR and CNRS) is looking for an excellent, highly motivated PhD candidate who will discover the physics of unsaturated wet granular materials.

How does liquid expand in wet granular material under shear? We know from everyday experience that mixing powders and liquid is a challenging task. The main reason is the internal cohesion due to capillary forces arising from liquid bridges between the grains [1]. This simple description occurs to numerous materials in civil engineering. For instance, capillary cohesion plays a central part in unsaturated soils [2]. The elaboration of cements involves a critical step of mixing of constituents, in which the material is close to a wet powder [3]. Bituminous concrete [4] is assembled by mixing and compacting solid grains with a viscous unsaturating binder. Beyond civil engineering, one may cite other industrial fields: food, pharmacy, powder sintering or wet granulation [5], the physical properties of the triphasic system of early stage of glass manufacturing [6], and environmental issues such as the flow of liquefied soils or wet snow [7]. As a general research field, it is relevant to a variety of industrial processes and engineering problems in which the grains and the fluid are mixed in the elaboration or assembling stage, and then processed, handled, and/or transported according to practical needs. In view of its industrial applications, mixing process has repeatedly been investigated, but the detailed mechanisms at the grain level remain unclear. Any improvement in the understanding of mixing mechanisms would provide better predictions of the material heterogeneities. On a more practical level, mixing processes are time and energy consuming. Understanding the evolution of heterogeneous granular materials may also help in reducing the cost of stirring processes and the amount of materials, while keeping the same mechanical properties. Improved manufacturing processes of industrial materials require a good knowledge of the rheology of non-saturated granular materials, which should be based on a good understanding of the microscopic structure and mechanisms leading to liquid distribution.

The Navier Laboratory is strongly involved in this research; both experimentally and numerically, through two theses recently funded by Ifsttar (Saeed Khamseh 2011-2014 and Michel Badetti, 2014-2017) and an ANR project 'RheoGranoSat' (2017-2021) [8 – 12]. These preliminary works led to the formulation of viscoplastic constitutive laws adapted to the homogeneous material in pendular state (low liquid contents), for which a good quantitative agreement is obtained between the numerical simulations (DEM / or discrete, at the grain scale) and experiments.

Next steps will be to account for the viscosity of the wetting liquid, to address the regime of higher liquid content and to apply constitutive laws of such materials to progressively more complex configurations such as inclined plane flows. To do so, we dispose of powerful skills, tools and methodologies, including specifically dedicated advanced experimental devices (rheometry, X-Ray microtomography, MRI) and numerical simulation tools (discrete simulation, computer clusters).

Project description

This project addresses the rheology of unsaturated granular materials, in a generic framework, using model materials. These model systems will first be slightly polydisperse assemblies of macroscopic spherical grains (with diameters between 0.1 and 1 mm), mixed with (mostly) non-volatile, wetting, Newtonian liquids. In a second step, we will study complex shaped grains, a wider polydispersity of grains, and non-Newtonian liquids.

Thus, within a multi-scale approach, our goal is to establish the fundamentals of the capillary and/or viscous phenomena involved in these materials. Our project is structured around three components objectives of which is to:

- define the different rheological regimes in the parameter space.
- set up an experimental methodology allowing for the detailed characterisation of the microstructure of such materials in the various regimes previously established. To do so, a rheometer inserted into the X-ray microtomography setup available at laboratoire Navier and specific image processing tools will be developped.
- apply constitutive laws of such materials therefore described and predicted to progressively more complex configurations such as inclined plane flows. The experimental results will be confronted with predictions from continuous numerical simulations integrating the previously identified rheology.

Requirements

- Master in Physics,
- Experience in the following fields: Rheology, Soft Matter.
- Good communication skills.
- Some skills in image processing would be appreciated

Further information

For more information, please contact
Dr. Abdoulaye Fall, e-mail abdoulaye.fall@ifsttar.fr ;
Dr. Camille Chateau, e-mail camille.chateau@enpc.fr
Dr. Jean Noël Roux, e-mail jean-noel.roux@ifsttar.fr

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https://navier.enpc.fr/CHATEAU-Camille?lang=en

Références:
[1] T. Mikami, H. Kamiya, and M. Horio, Chem. Eng. Sci. 53, 1927 (1998). J. N. Israelachvili, Intermolecular and Surface Forces (Academic, London, 1991), 2nd ed. D. J. Hornbaker, R. Albert, I. Albert, A.-L. Barabasi, and P. Schiffer, Nature (London) 387, 765 (1997). T. C. Halsey and A. J. Levine, Phys. Rev. Lett. 80, 3141 (1998). L. Bocquet, E. Charlaix, S. Ciliberto, and J. Crassous, Nature (London) 396, 735 (1998). N. Fraysse, H. Thomé, and L. Petit, Eur. Phys. J. B11, 615 (1999).
[2] J. K. Mitchell and K Soga, Fundamentals of Soil Behavior, John Wiley & Sons (2005). D. G. Fredlund and H. Rahardjo, Soil mechanics for unsaturated soils (Wiley-IEEE, 1993).
[3] B. Cazacliu & N. Roquet, Cement and Concrete Research, Vol. 39, Issue 3, pp. 182-194 (2009).
[4] M. Duriez and J. Arrambide, Nouveau traité des matériaux de construction, Vol. 3: Liants et bétons hydrocarbonés, Dunod, Paris (1962). Z. You and Q. Dai, Canadian Journal of Civil Engineering 34, 239-252 (2007).
[5] S. J. R. Simons and R. J. Fairbrother, Powder Tech., 110, 44-58 (2000).
[6] D. Bouttes, E. Gouillart, E. Boller, D. Dalmas, D. Vandembroucq, Phys. Rev. Lett., 112, (2014).
[7] P. G. Rognon et al., Europhysics Letters 74, 644-650 (2006). P. G. Rognon, Thèse ENPC (2006)
[8] M. Badetti, Rhéolohie des matériaux granulaires non saturés: Expériences et Simulations, Thèse de Doctorat, Université Paris Est-Marne, (2017). M. Badetti et al., European Physical Journal E 41 (5), 68 (2018)
[9] A. Fall et al., Journal of Rheology, 59, 4, 1065-1080 (2015)
[10] 1. M. Badetti et al., Journal of Rheology 62 (5), 1175-1186 (2018)
[11] S. Khamseh, J.-N. Roux, and F. Chevoir, Phys. Rev. E, 92:022201 (2015).
[12] http://www.agence-nationale-recherche.fr/projet-anr/?tx_lwmsuivibilan_pi2%5BCODE%5D=ANR-16-CE08-0005