Université Gustave Eiffel

ANR AGENCE NATIONALE DE LA RECHERCHE

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PhD offer : Coupling between rheology, particle breakage and size segregation in dense granular flows

Laboratory : Université Gustave Eiffel, IFSTTAR, Campus de Nantes, laboratoire MAST/GPEM Allée des Ponts et Chaussées, 44344 Bouguenais ;

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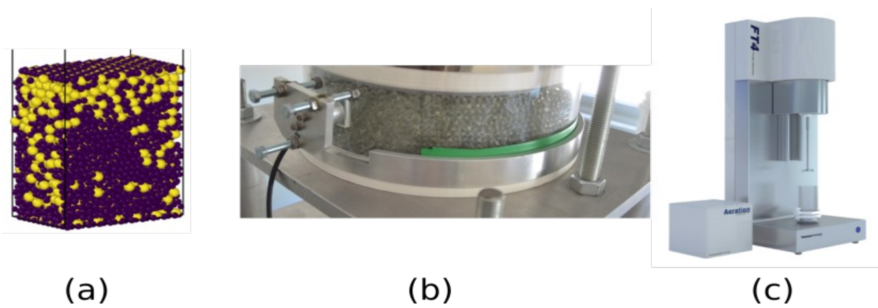
Context: Granular materials (powders, grains) are ubiquitous in industry but often problematic to handle as they easily agglomerate and jam: this yields excessive energy and resource demands. The processes associated to flows of these materials often involve phenomena like agglomeration and particle breakage. In addition, the materials treated in these processes are intrinsically polydisperse, and the mechanisms cited above may be accompanied by spatial transport according to particle size (size segregation). Whether the occurrence of such phenomena is sought (as in granulation or milling processes) or unwanted (attrition during mixing, caking of powders, blocking of silos, product separation), there is a strong need for understanding the complex mechanics of such particulate flows.

In order to sustainably optimize processes involving the flow of powders and grains, reliable numerical models are strongly needed. It is evident that critical aspects for the modeling are (1) the generality of the constitutive laws, i.e. their validity in realistic geometries, (2) the treatment of polydispersity and consequent segregative transport, (3) of the possibility of particle size evolution for example through breakage. In order to feed and validate such models, experiments on heterogeneous flows combining particle velocity and force measurements are needed. Due to the nature of the materials, experiments have to be supported by detailed particle scale simulations via the discrete element method (DEM). This method, originating from the work of Cundall & Strack (1979), allows to obtain micromechanical information on the behavior at the grain scale and in particular on the possible mechanisms of energy dissipation (friction, internal dissipation, fracture, attrition), depending on stress level and confinement conditions.

This PhD thesis will be carried out in the framework of the ANR PRCI project « MoNoCoCo : Nonlocal Models for Complex, Cohesive granular flows » (2021-2014), which is an international collaboration with the group of Prof. F. Yang at the National Taiwan University (NTU), in Taipei, Taiwan, focused on the development of a modeling framework involving (1) nonlocal rheological laws supplied with correct boundary conditions, and (2) population balances to describe the spatiotemporal evolution of the particle size distribution (via segregation and particle breakage).

Topic : This PhD project will combine experiments and discrete numerical simulations in order to study the relation between flow rheology, particle fracture and size segregation in dense granular flows. This relation will be explored in two phases, the first one being focused on segregation of unbreakable polydisperse particles, the second on systems of brittle grains.



Numerical and experimental tools: (a) discrete numerical simulation, (b) annular shear cell, (c) FT4 powder rheometer.

In the first part, controlled systems of polydisperse spheres will be prepared and tested in (1) an annular shear cell (Artoni et al 2018), for coarse grains, and in (2) a powder rheometer (Freeman FT4), for powders. In particular the evolution of the system will be characterized by the measurement of the torque, the velocity profiles obtained by PIV, the analysis of the particle size distribution profile (by splitting of the cell in layers, retrieving the material layer by layer and sieving). In this phase, experiments will be supported by DEM simulations of polydisperse materials in similarly confined flow configurations. The simulations will be validated against experimental results, and will allow to directly quantify segregating fluxes as a function of shear, pressure, particle size and amount of cohesion.

In the second part of the thesis, at first, simple aggregates will be prepared by gluing spheres together in dimers and studying their fracture, segregation and rheology in the annular shear cell, with the methods described above. These tests will constitute a benchmark for simplified (bidisperse) population balances. Then, brittle agglomerates (e.g. granulated lime, cemented glass beads) will be prepared and used for tests in both set-ups cited above. Also in these cases different techniques will be employed (torque, PIV, sieving) in order to record the evolution of both the rheology and the particle size distribution. These experiments will allow to study the effect of material and system parameters on the different mechanisms of spatiotemporal evolution of particle size. In parallel to the experiments, discrete element simulations will be performed for homogeneous shear with irreversible, brittle contact laws (Neveu et al 2016, Artoni et al 2019b) in order to further quantify the extent of shear induced breakage in 3d, while simulations of heterogeneous flows (ex. inclined plane flow, annular shear flow) will allow to study the joint effect of fracture and segregation.

The results will be employed to feed and validate a population balance model being developed at Univ Eiffel under the framework of the MoNoCoCo project. In addition, they will be compared to results obtained in other flow configurations obtained by the taiwanese group. Yearly visits to NTU are thus planned.

The results of the research will be published in international journals in physics (for the more fundamental aspects), granular materials (for the technical aspects of simulations), powder technology (for the applications). At least two articles should be submitted before the end of the thesis. It is also envisaged that the doctoral student will present his work at thematic conferences.

Profile: Applicants must hold a Master 2 in physics, mechanics, chemical engineering, or equivalent. They must be motivated by approaches combining experiments with numerical simulations.

References:

Artoni, R., Soligo, A., Paul, J. M., & Richard, P. (2018). Shear localization and wall friction in confined dense granular flows. Journal of Fluid Mechanics, 849, 395-418.
Artoni, R., Neveu, A., Descantes, Y., & Richard, P. (2019). Effect of contact location on the crushing strength of aggregates. Journal of the Mechanics and Physics of Solids, 122, 406-417.
Cundall, P. A., & Strack, O. D., (1979). A discrete numerical model for granular assemblies. Geotechnique, 29(1), 47-65.
Neveu, A., Artoni, R., Richard, P., & Descantes, Y. (2016). Fracture of granular materials composed of arbitrary grain shapes: A new cohesive interaction model. Journal of the Mechanics and Physics of Solids, 95, 308-319.