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PhD thesis proposal : Fracture of model fibers in a granular flow

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Context. Due to the inner complexity of granular materials, industrial processes associated with them are often rudimentary, based on poorly optimized rules of thumb. It is expected that mathematical modeling may help in designing new processes and operations, yet to date no reliable models exist for a number of observed behaviors. This is even more true when the particle shape is complex, as in the case of rigid fibers, which are found in a myriad of applications ranging from the food industry to the pharmaceutical industry and, in civil engineering, from concrete to raw earth construction.

Among the issues that constitute a real challenge for the modeling of granular flows, the change in grain size stands out for its complexity [1]. However, it is present in numerous industrial operations which concern a wide range of fields: (1) crushing/grinding processes, where size reduction is sought (but poorly controlled and subject to significant losses in resources and energy) , (2) granulation where agglomeration and fracture mechanisms contribute to the evolution of the size of the grain, (3) mixing/transport/storage operations of granular products, where grain wear (attrition) with formation of fines is always present and can represent a danger for process control [2]. But this is not limited to industrial applications. To give an example, grain fracture is present in geophysical flows (landslides, flows), and certainly influences rheology and associated risks [3]. To go further, fracture and agglomeration phenomena have also been put forward to explain the size distribution of the particles forming the rings of Saturn [4]. The evolution of grain size in different processes is often modeled using statistical approaches such as “population balances” [5]. These models describe the evolution of the particle size distribution (PSD) and the composition of the particles. They require several choices for modeling the fracture process. It should be noted that, in polydisperse granular flows, size segregation phenomena can take place: these phenomena can also influence the local rheology [6,7], and therefore increase the complexity of the problem via the coupling of the phenomena involved.

Objectives: The objective of this thesis is to study the coupling between fracture and flow for a particular class of granular materials, fibers. The thesis will be divided into three parts: experimental, numerical and modeling.

From the experimental point of view, model fibers will be prepared in the laboratory by solvent welding of plastic beads. The resistance of the joints will be tested by different methods (impact tests, press). Then the fibers will be placed in an annular shear cell [8] in which the grains are sheared by the rotation of the bottom wall and compressed by a load acting on the upper wall. In this cell, flow profiles will be determined by particle image velocimetry on videos recorded by a high-speed camera. Grain fracture, as well as possible size segregation, will be evaluated at different flow times, by image analysis and by direct inspection.

From a numerical point of view, simulations with a “discrete element” code (DEM) will be carried out in order to characterize - at the grain scale - the confined flow of elongated grains [9] and its coupling with the fracture. These simulations can take into account contact models developed in the laboratory [10] and can be analyzed using averaging methods taking into account micropolar effects [11, 12].

The experimental and numerical results will allow to construct a continuum model composed of constitutive laws for rheology and for fracture, integrated into momentum conservation equations and population balances for grain size. The results will also be compared to calculations carried out with a simplified kinetic theory taking into account grain fracture, established in collaboration with professors Michele Larcher (Univ Bolzano Italy) and Jim Jenkins (Cornell, US).

Références

[1] A. D. Salman, M. Ghadiri, and M. Hounslow (2007). Particle breakage, volume 12. Elsevier.
[2] J. Moreno Juez et al. (2016). Construction and Building Materials, 116:299-309.
[3] T. Davies and M. McSaveney (2009). Engineering Geology, 109(1):67-79. ; V. J. Langlois et al. (2015). Journal of Geophysical Research: Earth Surface, 120(9):1866-1880.
[4] N. Brilliantov et al. (2015). Proceedings of the National Academy of Sciences, 112(31): 9536-9541.
[5] D. Ramkrishna (2000). Population balances: Theory and applications to particulate systems in engineering. Academic press.
[6] Rognon, P. G., Roux, J. N., Naaïm, M., & Chevoir, F. (2007). Dense flows of bidisperse assemblies of disks down an inclined plane. Physics of Fluids, 19(5), 058101.
[7] Gray, J. M. N. T. (2018). Particle segregation in dense granular flows. Annual Review of Fluid Mechanics, 50, 407-433.

[8] 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.
[9] Pol, A., Artoni, R., Richard, P., da Conceição, P. R. N., & Gabrieli, F. (2022). Kinematics and shear-induced alignment in confined granular flows of elongated particles. New Journal of Physics, 24(7), 073018.
[10] Neveu A., Artoni R., Richard P. and 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.
[11] Artoni R. and Richard P. (2015) Average balance equations, scale dependence, and energy cascade for granular materials, Phys. Rev. E 91, 032202
[12] Artoni R. and Richard P. (2019) Coarse graining for granular materials: micro-polar balances, Acta mechanica, 230, 3055-3069