VICI 10828: Bridging the gap between particulate systems and continuum theory

Saeed Khamseh, September 2014

Rheology of wet granular materials: effect of rolling resistance

Project description

The flow properties of particulate systems has been the focus of intense research in physics, engineering and geomaterial researches. The mechanical properties of dense flow of granular materials is widely studied, especially by means of modern numerical and experimental techniques, which permit to investigate the microscopic origin of macroscopic behavior of such materials. It should be noted that in the industrial applications of granular materials the particles often have irregular shapes and asperities on the surface. These surface asperities will lead to tangential forces and also torques, concentrated in the contact area of two particles, which resist rolling at the contacts. Recent studies show that the rolling resistance has an important influence on the mechanical properties of granular materials [1]. The contact models are appropriately developed in order to include the rolling resistance effect [2] and the influence on the mechanical properties of dry [3] and cohesive [4] granulate systems are studied. However, despite the wide application of wet granular materials, their properties and particularly the effect of the rolling resistance on those materials is less understood. The main objective of this postdoctoral research is studying the effect of the rolling resistance on the dense flow of wet granular materials by means of discrete element simulation. Furthermore, beside the main plan of the project, many interesting features of such materials could be investigated which are explained more in the following.

Background and ongoing efforts

This research program could be also considered as a natural continuation of my studies and the researches of the VICI project team on the flow properties of cohesive [5] and wet granular materials. Within my PhD studies I investigated the plane shear flow of dense granular materials, under constant normal stress, by using a 3D DEM simulation of an assembly of rigid, frictional, spherical grains, either dry or in the presence of a small amount of water which gives rise to an interstitial fluid and hence capillary forces between particles [6]. My simulations find an important influence of capillary forces on the macroscopic properties of the material. We observed and measured several important features of those materials, such as localization tendencies for strong capillary forces, the role of particle agglomeration and the dependence of macroscopic behavior to microscopic parameters. On the other hand, the rheological properties of cohesive and wet granular materials is recently studied by VICI project team by using a DEM simulation in a split bottom Couette cell configuration.

Comparing the results of the two different methods can provide a better understanding of the materials behaviour, which also may give rise to some new ideas and approaches to the problem. Some of the ideas which are partly investigated within the last two months are as the following:

1. **Rolling resistance**: The simulation code for the plane shear flow of wet grains is appropriately developed to include the rolling resistance effect. At the moment we attempt to obtain the initial results with this model. It is also interesting to study the effect in the

split bottom Couette cell configuration. It should be noted that our previous studies have shown a strong influence of the capillary forces on the aggregation effect, which may also enhance the influence of the rolling resistance on the system behaviour.

2. **Localization effect:** Singh *et al.* [5] have performed a detailed study on the effect of the cohesive forces on shear banding using the split bottom Couette cell. The plane shear flow simulations also reveal that the system can strongly localize when, comparing to the force due to confining stress, the capillary force is large enough. More results in the plane shear flow should be obtained in order to compare the results of the two different configurations.
3. **Rheology within the shear bands:** The plane shear flow simulations suggest that when the capillary force is strong enough, the shear bands can form in which the thickness of the bands vary for different flow rates. These results can be extended and compared to those by Singh *et al.* [5].
4. **Agglomeration effect:** We have already studied the influence of the capillary force on the agglomeration effect by measuring the size and durability of clusters. Those methods can be employed to examine the agglomeration phenomena in the Couette cell within the shear bands.
5. **Comparing results and models:** Comparing the two approaches and the results is instructive. It improves our knowledge of the material behavior and on the other hand it reveals the advantages and the disadvantages of the employed methods. This is partly done and we found some good agreements. For instance, our results for macroscopic properties of dry grains is quite close to those obtained by Weinhart *et al.* [7] in an inclined plane configuration. Our results in wet grain simulations suggest a Coulomb-like criterion which is not a straight line as in the dry systems. These results are remarkably in agreement with those obtained in Couette flow configuration.

References

[1] F. A. Gilabert, J.-N. Roux and A. Castellanos, "Computer simulation of model cohesive powders: Influence of assembling procedure and contact laws on low consolidation states," *Physical Review E,* vol. 75, no. 1, p. 011303, 2007.

[2] S. Luding, "Contact models for very loose granular materials," in *Eberhard P. (ed) Symposium on Multiscale Problems in Multibody System Contacts*, Heidelberg, 2007.

[3] A. Mohamed and M. Gutierrez, "Comprehensive study of the effects of rolling resistance on the stress–strain and strain localization behavior of granular materials," *Granular Matter,* vol. 12, no. 5, pp. 527-541, 2010.

[4] F. A. Gilabert, J.-N. Roux and A. Castellanos, "Computer simulation of model cohesive powders: Plastic consolidation, structural changes, and elasticity under isotropic loads," *Physical Review E,* vol. 78, no. 3, p. 031305, 2008.

[5] A. Singh, V. Magnanimo, K. Saitoh and S. Luding, "Effect of cohesion on shear banding in quasistatic granular materials," *Physical Review E,* vol. 90, p. 022202, 2014.

[6] S. Khamseh, J.-N. Roux and F. Chevoir, "Flow of dry and wet granular materials: numerical simulation results," in *Powders and Grains,* Sydney, 2013.

[7] T. Weinhart, R. Hartkamp, A. Thornton and S. Luding, "Coarse-grained local and objective continuum description of three-dimensional granular flows down an inclined surface," *Physics of Fluids,* vol. 25, no. 7, p. 070605, 2013.