Discrete element modelling of grain size segregation in bi-disperse granular flows down chute

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ABSTRACT

Grain size segregation in dense granular chute flows is generally explained by the mechanisms of kinetic sieving and squeeze expulsion (after [1]). The basic idea is that small grains preferentially fall through the underneath local voids, which are randomly opened by the shearing developed with the grains flowing down chute. The imbalance in contact force and the mass conservation normal to the base lead the larger grains to drift towards the top of the flow. In addition to extensive experimental studies, some theories have been proposed to describe the size segregation in bi-disperse flows [2]. Recently, discrete element (particle) modelling have been reported, which allows a more detailed description of particle velocities, volume fractions and contact forces. The results from this sort of modelling are also interpreted in the macroscopic perspectives, e.g. the rheology of the flow [3].

In this paper, three-dimensional DEM simulations are presented. Different cubic bi-disperse samples are generated in pluviation, on the rough base formed by randomly located particles. Periodic boundaries are applied to the flow direction, while two different types of boundary conditions are imposed on the sides, i.e. periodic boundaries and rigid walls. Parametrical studies, involving slope, width, volume fraction, and coefficient of friction, are systemically performed. In all presented cases, steady, fully developed (SFD) flows are achieved, that the kinetic energy and fractional volume distribution keep constant. Segregations are completed with slightly different extents, in the sense that a thick layer of pure coarse grains appears on the top of the flow.

From the macroscopic view, the profiles of volume fraction, mean velocity and shear stress are calculated and interpreted by performing averaging in space. The rheology of binary granular system is presented. On the other hand, one of the major objectives is to provide microscopic evidences for the reviewed mechanisms (i.e., kinetic sieving and squeeze expulsion), since the discrete element modelling produce more detailed information on the individual particles. The trajectory of each particle is tracked and analysed, showing clearly the contact conditions and shear history that one single particle has experienced. It has been found that the connectivity of small particles are at a lower level than that of the large ones, indicating that the probability of their dropping into voids under gravity is higher. The large particles see a significant increase of connectivity when they are migrating through the layer of small particles. The upward forces exerting on the coarse grains become dominant at the same time with the highest rate of segregation of the entire flow. For the periodic side-boundary cases, when the width of the sample is increased, diffusion and re-mixing are observed in the minor direction (i.e. the transverse dimension). The percolations of small particles occur in either directions, instead of just in the direction normal to the base. Velocity fluctuations with slightly higher probability towards the top lead to the upward movement of the coarse layer. When the sample is narrow, or is confined by sidewalls, pure upward/downward movements are observed and the shear stress plays an important role in the process of segregation.

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