Size segregation in confined granular shearing flows: a two-dimensional process

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Abstract

Granular materials are important in many industrial and geophysical processes, but they are often a problem to handle as they are intrinsically polydisperse in size, leading to segregation when dense mixtures are sheared. While existing models can represent particle transport in simplified flow configurations, describing the interplay between collisional and gravitational segregation in more complex granular flows remains a challenge.
In this paper, we experimentally and numerically studied the coupling between size segregation and granular flow rheology in bidisperse mixtures of spheres that have the same density but different sizes. These mixtures are subjected to non-uniform shear rates and confining pressure, with systematic variations in mixture concentration and size ratio. The experiments are conducted in an annular shear cell with rotating bumpy bottom, while simulations are performed in a linear cell with a moving bottom base, using the open-source discrete element method (DEM) code LAMMPS. Additionally, we worked with an extension of kinetic theory for dense binary mixtures to predict the concentration and velocity profiles of the mixtures.

In experiments and simulations, a cell is initially filled with lower layers of large particles and upper layers of small particles, confined at the top by a bumpy wall, with a mass equal to the total mass of the mixture. In the experiments, the segregation process is filmed through transparent sidewalls, and the evolution of particle concentration in space and time is evaluated by means of post-processing image analysis. At the end of some experiments, grains are carefully removed by layers and then sieved to determine the particle concentration within the flow. In the simulations, we collect particle-level information, including instantaneous velocity, position, and normal and tangential inter-particle forces. This data is then filtered to obtain particles concentration in space and time, as well as other local parameters, such as granular temperature, packing fraction, coordination number and force chain network.
Both experiments and simulations demonstrated that vertical segregation fluxes are proportional to the size ratio between large and small particles, and the quantity of large particles within the mixture. It was observed that the segregation process takes place in two dimensions, not only in the vertical direction but also in the horizontal direction. The two dimensional nature of segregation was evident in the cross-section of the simulated cell, where small particles accumulate next to the sidewalls, displacing large particles toward the interior. These large grains form a persistent, dense core, preventing complete vertical segregation. Force chains were observed to extend along and across the flow, indicating enduring

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contacts. The presence of these force chains suggests that collisional models, such as kinetic theory, may not be adequate to describe deep and highly loaded granular flows.