Unsteady rheology of dense inertial granular flows

Jin Sun
University of Glasgow (UK)

Dense granular flows occur widely in nature—such as in debris flows—and in industrial applications like powder spreading in 3D printing. Their transition from quasi-static to inertial behaviour is characterized by the inertial number (I), defined as the ratio of the microscopic rearrangement timescale to that of macroscopic deformation. In steady inertial flows, the μ (I) rheology successfully describes both the shear stress-to-pressure ratio (μ) and the solid volume fraction as functions of I. However, applying μ (I) rheology directly to unsteady flows assumes that stresses adjust instantaneously to changes in I, thereby neglecting any history-dependent effects. This raises an important question: are history effects significant in unsteady inertial flows?

To address this, we investigate the relaxation behaviour following abrupt perturbations in flow conditions using discrete element simulations of simple shear in a system of monodisperse spheres. We introduce step changes in volume fraction, inertial number, and flow direction, and observe complex evolutions in stress and microstructure post-perturbation. Notably, the relaxation period correlates with the magnitude of the imposed changes. These findings clearly indicate that history effects are crucial for accurately describing unsteady inertial flows. However, the optimal method for incorporating these effects into predictive models remains an open question.