Jamming-originated large frictional force exerted on a rod withdrawn from granular layer

Takatsune Furuta[1], Hirofumi Niiya[1], *Hiroaki Katsuragi[1]

1. Graduate School of Environmental Studies, Nagoya University

Frictional property is one of the most important characteristics for characterizing mechanical properties of granular matter such as regolith layer found on various solid bodies. Granular frictional force depends on grains size and shape, packing fraction, slip rate, and so on. In this study, we particularly focus on the effect of packing fraction and grains size to characterize the low-speed withdrawing of a rod from a granular layer. Specifically, a vertical rod of diameter D is slowly withdrawn from a granular layer consisting of glass beads of diameter D_g. The packing fraction of granular layer is controlled by air fluidization and mechanical vibration applied to granular layer. After preparing the granular layer, a rod is vertically withdrawn. During the steady withdrawing state, pulling force is measured by a load cell. The main control parameters in this experiment are size ratio D_g/D and packing fraction. By a systematic series of experiments, we find that the steady withdrawing force F depends on D_g/D with a power-law manner. At the same time, F shows a critical divergence towards the critical packing fraction value about 0.62. The latter comes from the shear-induced jamming transition of granular layer. By considering a simple model of local jamming, an empirical form for the growth of jammed region can be built. When the initial packing fraction is close to the critical value, a part of the mass of jammed region is reoriented to the normal force acting on the rod. As a result, very large frictional force can resist the withdrawing. Combining all the experimentally obtained data, we propose a simple form (constitutive law) for slow granular frictional drag. In addition, we find that the granular friction is significantly reduced if the perturbation (air fluidization or mechanical vibration) is continually applied to the granular layer during the withdrawing. This is a natural result since the perturbation works to unjam and fluidize the granular layer. This experimental setup is very simple to discuss the frictional property of regolith layer which has rough shape and wide size distribution. However, the current result is suggestive to consider the penetration and withdrawing some probes on the surface of regolith layer.

Keywords: granular friction, jamming

