Granular friction: high speed friction and critical slip distance in DEM simulation

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In a microscopic view, natural faults generally consist of gouge layers, the frictional properties of which are much richer than the celebrated rate-state friction law. One of such examples is intermediate-to-high slip velocity (mm/sec-m/sec) regime, where anomalous weakening and, at the same time, strengthening are reported; namely, the results differ from experiments to experiments. In order to understand such a complicated phenomenon, one must carefully control the physical processes that potentially affect the frictional properties. In this paper, we adopt a standard model for granular materials to investigate the frictional properties in a wide range of slip rate, focusing on two situations: (a) stationary sliding with velocity control, (b) unstable slip with a spring-block system on granular layers.

In the stationary sliding system, it is found that the friction is velocity-strengthening in a wide range of shear rate; up to four orders of magnitude. Furthermore, the parameter-independent master curve is found, in which the friction coefficient increases as the power of the slip rate with a nontrivial exponent. This is mainly due to the increasing random motion of gouge particles, which increases the dissipation in sheared granular layers. Furthermore, the density and granular temperature (a quantity that describes the random motion of particles) also obey power-law master curves with different exponents [1].

Even though the stationary friction law is velocity-strengthening, slip can be unstable due to the static friction. The critical slip distance, over which the frictional strength decrease, is investigated as a function of the system parameters. It is found that the critical slip distance strongly depends on the maximum slip rate and can increase by several orders of magnitudes than that for stationary sliding. This means that the critical slip distance cannot be determined solely from the surface roughness and is essentially coupled with the slip dynamics.

As a closing remark, an ongoing experiment on granular friction is introduced, in which the temperature and the (internal) shear rate is strictly controlled. It is found that the power-law dependence of the friction coefficient on slip velocity overwhelms the logarithmic rate dependence which originates from the rate-state friction law.

[1] T. Hatano, Power-law friction in closely packed granular materials, Phys. Rev. E. 75 (2007) 060301(R).

Figure: Velocity dependence of friction coefficient in stationary sliding granular layers. The horizontal axis is nondimensional shear rate and the vertical axis is the friction coefficient. The inset illustrates the computational system.