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Granular Friction: Constitutive Law and Slip-Weakening Mechanism

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In a microscopic view, slip bands of a natural fault 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 have been reported; i.e., 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. To this end, we adopt the standard numerical model of granular materials to investigate the frictional properties in a wide range of slip rate. We focus on two situations: (a) stationary sliding with velocity control, (b) unstable slip with a spring-block system on gouge layers.

In a stationary sliding system, the parameter-independent 'master curve' is found, in which the friction coefficient increases as the power of the slip rate with a nontrivial exponent [1]. This is mainly because the random motion of particles, which leads to the dissipative collisions, is enhanced as the sliding velocity increases. Furthermore, quantities that describe the random motion of particles and the dilatation also obey power-law master curves with different exponents.

In unstable slip regime, the system undergoes sudden acceleration, which is responsible for seismic wave radiation. However, the following deceleration process is much gradual, resulting in afterslip. Thus, a fault consisting of granular layers can be an asperity which also exhibits afterslip. It is also found that the critical slip distance is equal to the total slip distance, which depends on the unloading rate. This indicates that the critical slip distance cannot be determined solely by the surface roughness and essentially depends the slip dynamics.

[1] Takahiro Hatano, "Power-law friction in closely-packed granular materials", Physical Review E 75, 060301(R) (2007).