New atomistic mechanism for velocity-weakening friction

*Takahiro Hatano[1], Akio Ishii[2], Tomoaki Niiyama[3], Tomotsugu Shimokawa[3], Shigenobu Ogata[2]

1. Department of Earth and Space Science, Osaka University, 2. Department of Mechanical Science and Bioengineering, Osaka University, 3. Department of Mechanical Engineering, Kanazawa University

The extent of slip acceleration is crucial to the understanding of “science of slow earthquakes”, and it is mainly determined by the law of friction. A necessary condition for slip acceleration is the negative velocity-dependence of friction force: i.e., the frictional force decreases as the slip velocity increases.

To the current popular belief, the physics behind the negative velocity-dependence of friction is the time-dependent growth of the real contact area. This has been actually verified in laboratory experiments on brittle, dry, and transparent materials.

In actual seismogenic zones, however, such experimental conditions may not be so relevant due to the existence of gouges, fluid, and high pressure. For instance, at the depth of 40 km, the pressure is expected to be 1 GPa. Even if the fluid may support the pressure in part, the nominal normal stress may exceed the compression strength of quartz, and therefore one can expect that the real contact area may equal the nominal contact area. In such cases, the time-dependent growth of the real contact area is less likely.

Here we propose a completely different mechanism for negative velocity-dependence of friction by assuming a time-dependent process at the atomic scale. Namely, the atomistic rearrangement (or a plastic event) by the shear “activates” the system and therefore a subsequent plastic event can occur more easily. This is effectively described by introducing the time-dependent activation energy for plastic events. The activation energy decreases immediately after an atomistic plastic event and slowly relaxes to the original value unless another plastic event occurs. We show that the negative velocity dependence is derived if the relaxation time of the time-dependent activation energy has a certain distribution width. Since this velocity-weakening mechanism does not require any concepts on real contact area, this may be applicable to a wider class of earthquakes, such as intermediate depth earthquakes.

Keywords: friction law, hysteresis

