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Atomistic origin of velocity-strengthening friction

HATANO, Takahiro[1*]

[1]ERI, Univ. Tokyo

Since the discovery of non-volcanic deep low-frequency tremor (Obara 2002), various kinds of slow earthquakes (or slow slips) have been discovered. However, the underlying physical mechanisms that yield such diversity of slow slips are still not known. Because the slow slips play an essential role in the stress accumulation processes in subduction zones through the cycle of slow slips and the moment release dynamics, various models have been proposed that address to reproduce slow slips and their cycle. In most of the models, friction laws are employed that possess positive velocity dependence. It is natural because the slow slips involve some kinds of stability, which may be represented as positive velocity dependence. However, from materials science point of view, it is not generally understood that under what conditions friction can have positive velocity dependence.

Here we report the atomistic nature of the rate- and state-dependent friction law, which is often adopted in modeling slow earthquakes. We begin with the creep constitutive law that describes the deformation process of a true contact junction and derive the rate- and state-dependent friction law. As a result, the empirical parameters (generally denoted by a, b, and L) are expressed in terms of atomistic parameters (activation energy, temperature, etc). By virtue of these expressions, one can determine the velocity dependence of friction from materials constants, and the length constant from the surface topography. We further discuss these results that are relevant to slow earthquakes: in particular, 1) crossover from negative to positive velocity-dependence. 2) role of water in velocity dependence.

Keywords: friction, rate- and state-dependent friction, creep