Dependence of the Constitutive Parameters of RSF Law on Slip Velocity and Temperature at Subseismic Slip Velocities

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1. Introduction

The behavior of frictional resistance at intermediate ($10^{-3} < v < 10^{-1}$ ms^{-1}) to high slip velocities ($>10^{-1}$ ms^{-1}) are quite different from that at low slip velocities ($<10^{-3}$ ms^{-1}); at low slip velocities the value of steady-state friction coefficient tends to be between 0.6 and 0.85 [Byerlee, 1978], at intermediate slip velocities steady-state friction resistance exhibits velocity-weakening or velocity-strengthening, and at high slip velocities it shows dramatic velocity-weakening. The cause of this weakening/strengthening behavior is considered to be frictional heating (temperature) during the slip on a fault. For better earthquake prediction, it is required that earthquake simulations considering this behavior are performed. However, previous friction constitutive laws cannot explain the behavior efficiently.

One of the most useful friction constitutive law is rate- and state-dependent friction constitutive law (RSF law), developed by Dieterich [1979] and Ruina [1983]. RSF law was originally described to explain the behavior of frictional resistance at low slip velocities, and it has not been clarified whether this law can also explain the frictional behavior at intermediate to high slip velocities. In addition, the behavior of frictional resistance depends not only on slip velocity but also on temperature, so it is required to clarify the relationship between RSF law and temperature.

In this study, we carried out friction experiments at intermediate to high slip velocities, and estimated the constitutive parameters of RSF law from the experimental results considering the variation of temperature on the frictional surface.

2. Method

We conducted slip velocity step tests using a rotary-shear, intermediate- to high-velocity friction testing machine in Kyoto University at a normal stress of 1.5 MPa under room temperature and room humidity conditions. As a sample, we used a pair of hollow cylindrical Zimbabwe gabbro with an inner/outer diameter of 26/40 mm without sandwiching gouges. For the step, we defined two parameters, IRPM and ΔRPM; IRPM is the value of rotation rate of the servo-motor installed in the machine before stepping, and ΔRPM is one of slip velocity stepping. We selected all the combinations of IRPM and ΔRPM throughout the experiment: a value of IRPM of either 10, 20, 50 or 100 RPM, and a value of ΔRPM of either 80, 150, 200, 300 or 400 RPM. Note that we performed the next combination after the temperature on the frictional surface went down to the room temperature.

To estimate the values of constitutive parameters of RSF law and temperature on the frictional surface, we used the Levenberg-Marquardt method modified by Sakamoto et al. [2005] with a quasi-static spring-slider model and the FEM produced by Kuroda [2005], respectively.

3. Results

As a result of the experiments, the value of steady-state friction coefficient decreases with increasing slip velocity, which is consistent with Tsutsumi and Shimamoto [1997]. In the combination of (IRPM, ΔRPM) = (100, 400) frictional melting could be observed, and obvious slip-strengthening was observed until the molten layer was completely created. This result is also consistent with Hirose and Shimamoto [2005], which mentions that initial melting may act as a stopping mechanism for fault slip.

On constitutive parameters, the trends against slip velocity and temperature are similar; the value of each

constitutive parameter linearly increases with increasing slip velocity/temperature. This trend is consistent with Nakatani [2001] and Nakatani and Scholz [2004]; they suggest that the constitutive parameters a and b have a linear dependence on the absolute temperature. However, our discussion on the relationship between the constitutive parameters and slip velocity/temperature is not enough because temperature on the frictional surface increases with increasing slip velocity. Therefore, it is needed to perform a further experiment in which the dependence of temperature on the constitutive parameters can be divided from that of slip velocity.

Keywords: friction, rate- and state-dependent friction constitutive law , intermediate to high slip velocity, temperature

