Frictional strength at subseismic slip rate

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Sliding velocity of faults ranges from micron m/s to m/s during earthquake rupture. While the friction at slow slip rates (under 1 mm/s) depends on contact state of asperities on the opposite fault surfaces and its behaviors are well described as the rate and state variable friction law [e.g., Dieterich, 1979], the friction at higher rates of - 1m/s is not well investigated at present. Friction at high slip rates generates heat that raises the temperature of slip zones, melts the surrounding rocks if temperature exceeds the rock melting point, and causes thermal pressurization if pore fluid exists. The frictional behavior of faults below the melting temperature is very complicated because many thermally activated phenomena occur, such as mineral dehydration, mineral decomposition, silica gel lubrication, flash asperity heating, and moisture draining. Here, we systematically investigate friction on simulated faults under dry (room-humidity) and wet conditions at normal stresses of between 0.5 and 3 MPa and slip rates between 10^{-4} and 10^{-1} m/s. Under this condition, visible frictional melting does not occur.

The experiments were conducted using a new rotary-shear friction apparatus made in 2007 at National Research Institute for Earth Science and Disaster Prevention (NIED), whose design is based on that of Prof. T. Shimamoto of Hiroshima University [Shimamoto and Tsutsumi, 1994]. Our apparatus is composed of a 5kW electric servo-motor with a speed between 0.5 and 3000 rotation per minute and a maximum torque power of 15 N$*$m, a rotation reduction gear system with a ratio of 1/100, two sample holders, a torque gauge, an axial displacement transducer, an axial load transducer, and an air-driven load actuator with a maximum load of 20 kN. A pair of cylindrical specimens of gabbro or granite was prepared for each run. The contacting end surfaces between two cylindrical specimens of gabbro correspond a simulated fault plane, which was sheared by rotating one with respect to the other in atmospheric environment and a water-saturated opened vessel for the dry and wet experiments.

The coefficient of friction for the dry (with room humidity) gabbro at low slip rates of - 10^{-3} m/s and at low normal stresses of - 1 MPa decreased gradually from an initial peak value of 1.0 down to a constant value of 0.8 with increasing displacement up to 100 m. In contrast, the friction coefficient at high slip rates of - 0.1 m/s and at high normal stresses of 3 MPa decreased dramatically from the same initial level of 1.0 down to a low value of 0.4 - 0.6 at displacement of less than 10 m. The steady state friction was dependent on both slip rate and normal stress. However it did not decrease linearly with increasing these parameters. The friction coefficient at intermediate slip rate or normal stress initially decreased to 0.4 then started to oscillate between 0.4 and 0.8 with displacement. Increasing slip rate / normal stress values resulted in more chances to stay at the lower value (0.4) than the higher one (0.8). During slip, the axial length of the specimens shortened due to the production of wear materials and its extrusion from the fault. The shortening rate was high when slip rate / normal stress was high. For the wet gabbro experiments, although slip weakening behavior was observed that depended on slip rate and normal stress, the steady state friction coefficient at low slip rates for the wet gabbro was lower than for the dry gabbro and the oscillation frequency was one order of magnitude less for the wet gabbro than for the dry gabbro. We will also present the friction behavior for the dry and wet granite to compare the results with that of gabbro.