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Dynamic permeability change caused by high velocity friction

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Understanding changes of permeability during shear deformation is crucial to explain the dynamic hydrological and mechanical processes that occur during earthquakes at shallow and deep crustal levels. Permeability can be dramatically changed by the formation of the wear materials, frictional heating and chemical reactions under high velocity friction during large earthquakes. In our study, we measured permeability after friction tests at constant velocity from 0.00013 to 1.3 m/s. Thermal pressurization, which is one of the possible dynamic weakening mechanisms, was numerically analyzed by using laboratory data, and we estimated the influence of shear induced permeability on the mechanism.
We used three rock samples in our laboratory tests: Berea sandstone (porosity = 20-22 %), Indian sandstone (10-15 %), Aji granite (<1 %). We performed constant-velocity rock-to-rock friction tests by using the rotary shear testing apparatus with a wide range of speeds in the Kochi Core Center. We rotated at constant speed from 0.15 to 1500 rpm and applied a constant normal stress of around 2 MPa during slip. After the friction tests, we measured permeability at room temperature under uniform (isostatic) confining pressure from 5 to 120 MPa in a high-pressure oil apparatus. Permeability of permeable Berea sandstone and Indian sandstone was measured by the steady-state flow method, and that of impermeable Aji granite by the transient pulse method, with distilled water used as the pore fluid.
Permeability in Berea sandstone decreased as slip rate increased, and the permeability decreased by 1 order of magnitude ($5*10^{-15} m^2$at 10 MPa) from initial permeability ($4*10^{-14} m^2$). Permeabilities in India sandstone and Aji granite did not change much below slip rate of 0.1m/s, though the sharp increase of permeability was observed at high slip rate. Permeability in India sandstone increased by 5 times after high velocity test from $2*10^{-17} m^2$to $10^{-17} m^2$, and that in Aji granite increased by 3 orders of magnitude from $4*10^{-20} m^2$to $4*10^{-17} m^2$. After shear displacement at high slip rates (1.3 m/s), permeability in Berea sandstone decreased by about one order of magnitude after 2 m of slip displacement, with little further change after 3 m of displacement. Permeability of Indian sandstone and Aji granite changed slightly within the first 4 m of slip displacement, and then increased rapidly as slip displacement approached 4 m.
A fine-grained gouge layer of thickness developed during slip, and the wear rate was increased abruptly at high slip rates. Microcracks and mesoscale fractures formed at slip rates above 0.13 m/s. Numerical modeling showed that the slip surface temperature increased by several hundred degrees for slip velocities above 0.13 m/s and exceeded the alfa-beta phase transition temperature of quartz at 1.3 m/s. Both temperature rise and the temperature gradient at the slip surface were high at fast slip rates. We attributed reduced permeability after slip in porous sandstone to the low permeability gouge layer. An abrupt permeability increase in low permeability rocks at high slip rates was caused by heat-induced cracks. An increase in the rate of wear of gouge with increasing slip velocity was caused by frictional heating that reduced rock strength.
The modeled results of pore pressure rise by thermal pressurization for Indian sandstone and Aji granite show sudden pore pressure rise during the first second of slip, though pore pressure decreases immediately after sudden permeability increase by thermally induced cracks. The modeled result for Berea sandstone shows very slight influence of shear induced permeability on

thermal pressurization. Our results show that thermal pressurization may not always occur within relative impermeable faults if permeability enhancement by thermal cracks was effective.

Keywords: permeability, thermal fracturing, friction coefficient, thermal pressurization, wear rate