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Real-time monitoring of flow rate through simulated fault rock after friction test

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Fluid pressure cycle as a result of fault-valve behavior, which gives rise to large variations in fault strength, can play a very important role for earthquake recurrence process (Sibson, 1992). Transport properties within fault zone can vary through both coseismic and interseismic periods, and this evolution of transport property is a key to understand the fluid pressure cycle. Here we tried to estimate the evolution of permeability over the coseismic and the beginning of the interseismic periods based on laboratory experiments.

We prepared a set of hollow cylinders of quartz-rich Indian sandstone (outer diameter = 25 mm, inner diameter = 9.5 mm, porosity = 12 ~ 14 %, permeability = 10^{-15} ~ 10^{-16} m^2) for laboratory experiments. To produce a shear deformation in a fault surface, we rotated a part of the cylinders, and the other cylinder was fixed and loaded at a constant normal stress. We increased a pore pressure at an inner cavity of hollow cylinder to force fluid flow from the inner wall to the outer wall. Nitrogen gas was used as a pore fluid, and gas permeability was measured by monitoring the volumetric gas flow rate continuously. We performed friction experiments at 2MPa of normal stress and 3m of slip displacement. Constant rotation speed was applied during sliding, and the rotation speed was changed from 0.00022 to 0.22 m/s to observe the influence of the slip velocity on the permeability evolution.

At the sliding velocity from 0.00022 to 0.022 m/s, gas flow rate was suddenly decreased, and gradually reached a stable rate with sliding. The flow rate was decreased with an increase in sliding velocity. After sliding was stopped, the flow rate was gradually increased, and then reached a stable value. The recovery rate was increased with increasing sliding speed, though it did not recovered the initial value before sliding. At a high velocity of 0.22 m/s, a recovery rate was much larger than that in slow-velocity tests, and flow rate was exceeded the initial value. In some high velocity experiments, flow rate was increased rapidly soon after sliding. We also measured lengths of specimen during experiments, and these results indicate that, in slow slip experiments, a length of a specimen was increased by thermal expansion and gouge formation, and it was gradually decreased after slip stopped, which might be caused by the cooling of a specimen. On the other hand, in high-velocity experiment, a sudden shortening was observed due to thermal cracking and leaking of gouge.

Our experimental results suggest that a fluctuation of flow rate in the fault zone by the shear deformation is mainly induced by two processes. One is a change in the pore fluid viscosity by the temperature change caused by the frictional heating. The other is a permeability evolution of specimen which is caused by gouge formation and crack enhancement that are related to the mechanical deformation. The former process can strongly influence on the change in flow rate in the slow slip shear deformation, and the latter one can be dominative in the high velocity shear deformation.

Keywords: permeability, permeability evolution, fault zone, fault-valve model, Fluid pressure