Friction experiments on Nojima gouge: Dynamic weakening at seismic slip rates and a new textural evidence for earthquake faulting

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Recent high-velocity friction experiments revealed several important aspects of fault at high slip rates, such as the fault weakening mechanism associated with frictional melting (Tsutsumi and Shimamoto, 1997; Hirose, 2002). However, the previous high-velocity friction experiments were performed on intact rock samples that need no seal. We thus developed a new seal to keep fault gouge on simulated fault, and examined high velocity frictional properties of Nojima fault gouge.

The fault gouge used in the experiments is blue gray gouge derived from granodiorite collected at the Hirabayashi trench along the Nojima fault. All experiments were conducted using a rotary-shear, high-speed frictional testing apparatus described by Shimamoto and Tsutsumi (1994). The fault gouge is placed between a pair of solid-cylindrical granite specimens. One of the pair was rotated by servo-motor and the other was fixed. Normal stress was applied to the gouge from the stationary side by an air-driven actuator. Hollow-cylindrical Teflon (a PTFE material) was used to keep the fault gouge at the artificial fault. A series of experiments were performed at a constant normal stresses of 0.3 - 2.1 MPa and a constant equivalent slip rates of 1.03 m/s (1200rpm), with different displacements of 0 - 60 m under room temperature, unconfined and dry conditions.

The representative mechanical behavior and axial shortening of a simulated fault are as follows. At the initiation of a run, friction coefficient rapidly increased to about 0.8 - 1.0 and then gradually decreased. The friction coefficient finally attained to nearly constant [0.2 - 0.6]. The steady state fiction level was strongly dependent on normal stress and the value at the maximum stress 2.1 MPa was lower than 0.25. This suggests that frictional strength of a fault might become lower at deeper depth.

Initially, the axial length of the fault gouge decreased rapidly and then became nearly constant. The initial axial shortening may be due to compaction, grain size reduction and rearrangement of the fault gouge. The fault gouge did not leak so much from the artificial fault during the experiments. The overall frictional behavior is reproduced reasonably well in these runs.

Laboratory experiments on bare-rock or gouge at low slip rates [- 1 mm/s] yield values of the steady-state frictional coefficient μ in the range 0.5 - 0.8. On the other hand, the frictional coefficient inferred from the heat flow measurements along the San Andreas Fault was lower than 0.2 and this inconsistent with the laboratory tests confuses many seismologists for a long time. Thus some dynamic weakening mechanisms [thermal pressurization, rock melting, acoustic fluidization, elastohydrodynamic lubrication] were proposed to explain the stress/heat flow paradox. However our results indicate that frictional strength of a fault at rapid slip rates might be enough low without an action of the weakening mechanisms.

We observed thin sections of experimental specimens stopped at various displacements to investigate the relationship between mechanical behaviors and microstructures. Grain size reduction by comminution occurs along the rotational side just after the beginning of the experiments, and then a deformation zone [DZ] formed along the rotational side. The boundary between the DZ and non-DZ could be obviously recognized. The DZ became wider and a strong preferred orientation formed along a Y shear plane in the DZ with increased displacement. The above microstructures were observed at the friction weakening stage. At the steady state friction, a wavy boundary between the DZ and non-DZ, folding and fluttering structures in the DZ, were observed. The structures at the steady state friction have not reported in other experimental studies of fault gouge and might be textural characteristics of seismic fault motions.