Spontaneous Slow Slip and Runaway Slip in Laboratory

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Earthquake nucleation and propagation involves the acceleration of slip on a fault from a background, quasi-static, low-velocity state towards meter-per-second values. From shear experiments using brine-saturated simulated gouge composed of 80:20 wt.% mixtures of halite and muscovite (following e.g. Niemeijer & Spiers, 2007, JGR), Takahashi et al., [2017, G-cubed] recently reported a switch in the dominant deformation process, from distributed viscous flow (pressure solution creep) to localized brittle deformation, at a critical velocity V_c (~20 μm/sec). The direct effect which is normally observed upon perturbations in sliding rate disappears for $V > V_c$, suggesting that runaway fault-slip may be achieved when the sliding velocity exceeds V_c.
At relatively low shear stress, flow mechanisms, such as pressure solution creep and dislocation creep, will be fast enough to effectively suppress slip acceleration. However, with increasing the shear stress, there may be a velocity range in which flow mechanisms still works but not as effective. Hypothesizing that, under constant shear stress boundary conditions, this may lead to spontaneous acceleration followed by deceleration, analogous to a slow slip event. Moreover, imposing the constant shear stress with equal or larger value of the maximum strength of the simulated gouge, I also hypothesize that slip acceleration may proceed as $V > V_c$, inducing a dynamic weakening.
To address these hypotheses, I conducted torque-controlled rotary shear experiments, using brine-saturated, 80:20 wt % mixtures of halite (grain size < 75 μm) and muscovite (grain size < 33 μm) powders. Approximately 1.65 g of the gouge mixture was sandwiched between two teethed steel piston rings, forming an initially 1 mm thick layer. The piston rings had an inner diameter of 38 mm, and an outer diameter of 50 mm. I used a high-velocity rotary shear apparatus designed by T. Shimamoto [e.g., Togo and Shimamoto, 2012], and now installed at the Geological Survey of Japan (GSJ). The apparatus was modified to enable torque control with an accuracy of ±0.002 in the friction coefficient (μ), at a normal stress of 5 MPa. Rotation displacement is measured using a potentiometer installed close to the piston ring at the rotating side.
A preliminary result shows the velocity evolution after stepwise changes in the shear stress. At low shear stresses, corresponding to the pressure solution creep-controlled regime, transient increasing velocity towards a steady-state values suggests stable sliding. At $\mu \approx 0.6$, the simulated gouge shows spontaneous acceleration to $V \approx 1$ μm/sec, followed by deceleration. Lastly, under a constant shear stress condition equivalent to $\mu = 0.67$, spontaneous slip acceleration occurred followed by dynamic weakening at $V \approx V_c = 20$ μm/sec. More experiments and microstructural observations will help to elucidate the relationship between the critical velocity and the switch among dominant deformation mechanisms.

Keywords: shear stress control test, spontaneous acceleration/deceleration, dynamic weakening

