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Frictional strength evolution during earthquake-like shear experiments

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We experimentally investigated two central factors of fault frictional strength: 1) the effect of loading style on the friction constitutive relations; and (2) the suitable parameters to represent the constitutive relations. We present a series of 42 experiments conducted on granite samples sheared in a high-velocity rotary apparatus. Three modes of velocity history were applied: (a) constant velocity mode; (b) ramp-mode in which the sample is subjected to continuous, gentle acceleration followed by a similar rate of deceleration; and (c) quake-mode in which the sample is initially subjected to intense acceleration that is followed by a gentle deceleration. In the 34 runs of constant velocity, the velocity was 0.0006-0.23 m/s, and the normal stresses 1.5-11 MPa. In the four runs of ramp-mode, the maximum velocity range was 0.7- 1.0 m/s, and normal stress 2.2 - 2.6 MPa. The third set of four quake-mode experiments, the maximum velocity was = 0.79-0.94 m/s, and normal stress 2.2 MPa. The steady-state friction coefficients of the constant velocity runs are related to both slip-velocity and normal stress, and thus the constitutive relations are presented with respect to mechanical power-density: PD= [shear stress x slip velocity], with units of power per area (MW/m2).
The experimental constitutive relations strongly depend on the loading mode. Constant velocity mode displays initial weakening with increasing PD that is followed by strengthening for PD = 0.02-0.5 MW/m2, and abrupt weakening at PD > 0.5 MW/m2. Both ramp and quake modes display gentle strengthening for PD < 0.2 MW/m2 that is followed by abrupt weakening as PD reaches 0.7-0.8 MW/m2. Beyond this level of power-density, the two loading modes diverge: in quake-mode the experimental fault continues to weaken with friction coefficient approaching 0.2, whereas in ramp-mode the fault strengthens with friction coefficient approaching 1.0. This strong dependency of the friction constitutive relations on the loading mode is not unique to the present experiments (e.g., Sone and Shimamoto, 2009; Chang et al., 2012). The evolution of slip-velocity and fault weakening during runs of quake-mode is similar to the expected evolution of a slip-pulse during natural earthquakes (Heaton, 1990). We thus propose that quake-mode loading is a promising experimental approach to capture the dynamic response of a fault patch during earthquakes.