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Frictional behavior and BET surface-area changes of SAFOD SDZ gouge at intermediate to high-velocity regimes

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San Andreas Fault Observatory at Depth (SAFOD) Drilling site is located at near the southern end of the creeping section of the San Andreas fault and SAFOD drill cores may provide a clue for the cause of diverse fault motion. We were provided with precious core sample (Phase III core; Hole G-Run 2-Section 8) from southwest deformation zone (SDZ) where creep is confirmed by the borehole casing deformation. Sample for this study was limited to about 6 grams and 6 runs were done at intermediate to high slip rates (10^{-5} to 1.3 m/s) and a normal stress of about 1 MPa and under both dry (room humidity) and wet (with 25 wt% of H_2O added, drained tests) conditions, using a rotary-shear low to high-velocity friction apparatus at Hiroshima University at. One gram of gouge was placed between host rock of Belfast gabbro of 25 mm in diameter with Teflon sleeve outside to contain gouge. Slip rates was decreased first and was increased in step-wise manners to obtain steady-state friction for two runs at intermediate slip rates. Friction coefficient increases from about 0.2 to 0.37 as the slip rate increases from 0.8 x 10^{-5} to 9.7 x 10^{-3} m/s, connecting reported data at the low and high slip rates. Data shows pronounced velocity strengthening at intermediate slip rates which should act as brake for a rupture to grow and this may be a reason for having creep behavior. On the other hand, the steady-state friction markedly decreases at high velocity. Four experiments were conducted at subseismic to seismic slip rate both at dry and wet conditions demonstrating marked slip weakening of gouge at high slip rate. The results agree with reported results for central deformation zone (CDZ). The property of high-velocity weakening may allow earthquake rupture to propagate into the creeping section, as in the case of 1857 and 2004 ruptures, once the intermediate strength barrier is overcome.

BET surface area of gouge (A_{BET}) was measured before and after deformation to determine the energy used for grain crushing. The initial specific surface area (2.6-3.4 m^2/g) increases to 14-24 m^2/g for gouge deformed dry at intermediate slip rates and to 45-60 m^2/g for most gouge deformed at subseismic to seismic slip rates (Fig. 1). The results indicate that about 2 % and less han 1 % of the frictional work is absorbed in grain crushing for dry and wet gouges, respectively, if the fracture surface energy of muscovite (0.38 J/m^2) is used as the surface energy of phyllosilicate-rich SAFOD gouge. Thus grain crushing cannot be an important energy sink during seismic fault motion. The surface area tends to be lower for gouge deformed at high slip rates for both dry and wet gouges. This results and SEM observations of gouge strongly suggests that welding of grains takes place at high slip rate due to frictional heating and counteracts the surface-area increase due to grain crushing. Thus intrafault processes are more complex than in a simple scenario of "grain crushing and surface-area increase" assumed in recent studies. Surface area is greater for wet gouge than for dry gouge suggesting that pore water separating gouge particles suppresses grain welding. Surface-area measurements are useful to monitor the grain-scale processes during fault motion.

Keywords: BET surface area, Intermediate to high-velocity friction, SAFOD, Energetics of seismic fault motion