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Frictional behavior and BET surface-area changes of SAFOD gouge at intermediate to seismic slip rates

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The San Andreas Fault Observatory at Depth (SAFOD) Drilling site is located near the southern end of the creeping section of the San Andreas fault. Experimental studies on the frictional properties of fault gouge from SAFOD drill cores may provide valuable information on the cause of diverse fault motion. We conducted friction experiments on gouge from the southwest deformation zone (SDZ, Phase III core; Hole G-Run 2-Section 8) where creep is confirmed by ongoing borehole casing deformation, at intermediate to high slip rates (10^{-5} to 1.3 m/s), at a normal stress of about 1 MPa, and under both dry (room humidity) and wet (25 wt% of H_2O added, drained tests) conditions. Experiments were performed with two rotary-shear friction apparatuses. One gram of gouge was placed between specimens of Belfast gabbro 25 mm in diameter surrounded by a Teflon sleeve to confine the gouge. Slip rate was first decreased and then increased in a step-wise manner to obtain the steady-state friction at intermediate slip rates. The friction coefficient increases from about 0.13 to 0.37 as the slip rate increases from 0.8 x 10^{-5} to 9.7 x 10^{-3} m/s. Our results agree with frictional strength measured at higher effective normal stress (100 MPa) by the Brown University group in the same material. Data shows pronounced velocity strengthening at intermediate slip rates, which is unfavorable for rupture nucleation and may be a reason for having creep behavior. On the other hand, the steady-state friction markedly decreases at high velocity, and such weakening may allow earthquake rupture to propagate into the creeping section, once the intermediate strength barrier is overcome. Gouge temperature, measured at the edge of the stationary sample during seismic fault motion, increased to around 175^{o}C under dry conditions, but increased up to 100^{o}C under wet conditions.

We measured BET surface area of gouge 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 dry gouge deformed at intermediate slip rates and to 45-60 m^2/g for wet gouge deformed at subseismic to seismic slip rates. The results suggest that approximately 2 % and less than 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.