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Weakening mechanism of faults during frictional melting

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Pseudotachylytes have long attracted structural geologists as an evidence of seismic fault motion in exhumed fault zones and have been receiving increasing attention recently from seismologists in relation to the effects of frictional heating on the earthquake generating processes. However, how frictional heating affects mechanical properties of faults has still remained unclear. This paper reports experimental and field studies on the frictional melting processes along faults attempting to single out physical processes involved in the frictional melting and to evaluate its effects on fault mechanics.

In order to explore the overall frictional behavior of faults at a high velocity and large displacements, hollow-cylindrical specimens of Indian gabbro with inner and outer diameters of 15 and 25 mm were deformed dry to 3.6-156 m in displacements at slip rates of 0.85-1.60 m/s and normal stresses of 1.25-2.19 MPa using our rotary-shear apparatus. Experiments have consistently revealed two stages of slip weakening; one following the initial slip, and the other immediately after the second peak friction. The first weakening is probably associated with flash heating of asperity junctions, and the second weakening is due to the formation of molten layer along simulated faults. The two stages of weakening are separated by a marked strengthening regime in which melt patches grow into a thin, continuous molten layer at the second peak friction. The occurrence of pseudotachylites along some natural faults suggests that the second weakening may cause at least some large earthquakes.

After the second peak friction the country rocks are separated completely by a molten layer and the shear resistance along a fault must be determined by the gross viscosity and shear strain rate of the molten layer. The viscosity of the molten layer was determined from the measured shear stress and the average shear strain rate (slip rate / molten layer thickness). The melt viscosity rises dramatically from about 45 Pa-s at the second peak friction up to 145 Pa-s soon after the initiation of the second weakening, and it decays gradually to 90 Pa-s at the nearly steady state or residual friction. The fault weakens despite this increase in melt viscosity, and the weakening during frictional melting is caused by the growth of molten layer, i.e., by the reduction in the shear strain rate. Very thin melt cannot be squeezed out easily from a fault zone so that the rate of melting would be the most critical factor in determining the slip weakening distance during frictional melting.

The experimental results provide two ways of estimating the slip weakening distance during frictional melting from natural pseudotachylyte-bearing faults. One is based on the systematic correlation of fractal dimension of the host rock/molten layer interface with mechanical behavior of the fault during the frictional melting. The other is using the overall shape for the pseudotachylyte-thickness versus displacement curves which can be compared with the slip weakening during frictional melting. A similar shape of curve such that the pseudotachylyte thickness declines with increasing fault displacement is reported from natural pseudotachylytes by Sibson (1975). His data yields the weakening distance of the order of several hundreds of millimeters, very close to seismically determined weakening distance.

Present experiments clearly brought about the highly nonlinear nature of high velocity friction because the slip weakening distance is not a material constant, but it changes dramatically with the heat production rate. Fault displacement itself changes largely its mechanical properties and future work should find a way to analyze this nonlinear behavior quantitatively.