Understanding the frictional properties of fault gouge is crucial to understanding the generation and nature of earthquakes. Clay minerals are a major constituent of fault gouge and are of particular interest because they may exhibit exceptionally low friction. Previous work has demonstrated that at shear strains up to ~15, clay-rich gouges are velocity strengthening (stably sliding) over a wide range of normal stresses and sliding velocities. However, it has been hypothesized that shear localization at high strains may cause a transition from stable to unstable frictional behavior in such gouges. Here, we report on laboratory experiments that investigate in detail the relationship between shear strain and sliding stability for a suite of clay-rich gouges. We studied six fault gouge compositions: kaolinite and sand-sized quartz, and a 50%-50% mixture of montmorillonite and silt-sized quartz. We conducted experiments in a servo-controlled apparatus using the double-direct shear configuration under constant shear velocity boundary conditions. To achieve intermediate to high shear strain, we employed a new technique in which shear displacement is unlimited via use of a replaceable centerblock. Layers were initially 5 to 5 mm thick with nominal contact dimensions of 5 cm by 5 cm. For each gouge mixture we measured frictional properties at normal stresses of 15, 50, and 100 MPa and conducted velocity stepping experiments in the range 1-300 mm/s at strain intervals of ~10-20. We report values of (a-b) as a measure of gouge stability; a positive value of (a-b) indicates velocity-strengthening behavior associated with stable sliding, whereas negative values indicate velocity-weakening behavior associated with instability and potentially seismic slip.

Abstract

Experimental Setup

- Servo-controlled biaxial testing apparatus
- Horizontal ram applies normal load
- Vertical ram induces shear
- Double-direct shear configuration
- Contact area: 5 cm x 5 cm
- Grooved contact area to ensure slip within layer and not at contact boundary
- Two center blocks allow infinite displacement

Experimental Procedure

- One normal stress in each experiment
- Velocity stepping sequence: sliding velocity is increased from 1-3, 3-10, 10-30, 30-100, and 100-300 mm/s and then back to a background velocity of 10 mm/s
- Velocity stepping sequences run at strain intervals of 10-20
- Coefficient of friction values taken before each velocity step sequence
- Shear strain calculated as $\gamma = \frac{\Delta L}{h} = \frac{L_t - L_0}{h} = x$ (displacement, h=layer thickness)
- Friction rate dependence (a-b) values are computed as: $(a-b) = \Delta \mu \ln(v/v_o)$

Conclusions

- Clay-rich fault gouge exhibits mostly velocity-strengthening behavior; quartz gouge is mostly velocity-weakening.
- At low normal stress, (a-b) increases with increasing velocity. At high normal stress, (a-b) is independent of velocity.
- At low normal stress, chlorite and illite gouges are velocity-strengthening with no dependence on strain. At high normal stress, increasing shear strain tends to make the gouge less velocity-strengthening.
- For most gouge materials, shear strain does not have a strong influence on fault gouge stability; factors such as normal stress, sliding velocity, and gouge mineralogy may be more important.
- In natural faults, high shear strain may make a limited contribution to the onset of seismic slip in chlorite- and illite-rich gouge.