Constitutive Properties and Frictional Behavior of Simulated Fault Zone of Halite Developed in Granular Medium

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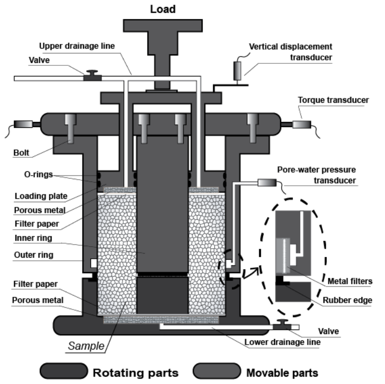
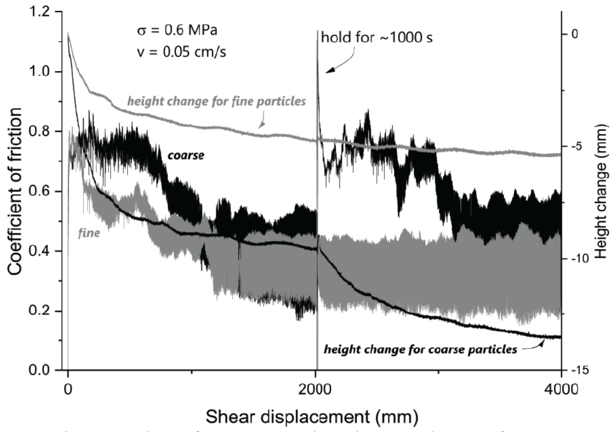
Tectonic faults and landslides exhibit an extensive spectrum of velocities. A key motivation of this study is to better understand the physical processes that dictate the slow-to-fast transition of frictional behavior in earthquakes and landslides by combining the friction measurements and microscopic analysis of the experimental fault zone. We simplify the questions as (1) the effect of the comminution rate and segregation of granular material in determining the friction coefficient; (2) the connection between the frictional parameters and the development of shear fabric with the increasing displacement of shear. We employ a unique ring-shear configuration that has a large shear box (18.0 cm in outer diameter, 12.0 cm in inner diameter, and 10.9 cm of available sample height) to contain a larger volume of granular particles than that of conventional rotary or direct shear configurations for fault mechanics. It could produce experimental shear zones of large dimensions at significantly great shear displacements (Figs. a-c). The ring-shear apparatus is in Kyoto University and has been used in studies of landslide behavior. It should be emphasized that a shear zone is developed within the granular medium. In most of the previous friction experiments, a simulated shear zone of a millimeter scale is defined by the amount of gouge sandwiched between hard host rocks and cannot grow to be thicker. We use analog granular materials with two initial size distributions, i.e., coarse and fine halite particles, to examine the constitutive properties and frictional behavior. We vary the total normal stress from 0.2 to 1.0 MPa and the slip rate from about 0.001 cm/s to 10 cm/s for velocity-step tests. We begin with a run-in process for materials to reach a steady state of friction, and a substantial weakening ($\mu \approx 0.4$) is observed at a low slip rate (0.05 cm/s) under higher normal stress (e.g., 0.6 MPa as shown in Fig. d). We stop and hold the tests for about 1,000 seconds and the fine halite weakens rapidly once the shear is resumed. We then perform velocity-step tests and reproduce unstable stick-slip and stable sliding behaviors at relatively low and high slip rates, respectively (Fig. e). The experimental shear zone is observed after the shear test (Figs. b-c). The thickness of the shear zone is tens of millimeters The thickness of the shear zone is from several millimeters to tens of millimeters and it is larger in coarse granular media. A spring-slider model is used to fit the stable velocity-step tests to obtain the frictional properties in a rate- and state-dependent friction law. Finally, we combine the measurements of frictional parameters, observation of shear zone development, and comminution and packing of particles to dissect the key issue that how they interact and regulate slow and fast motion.



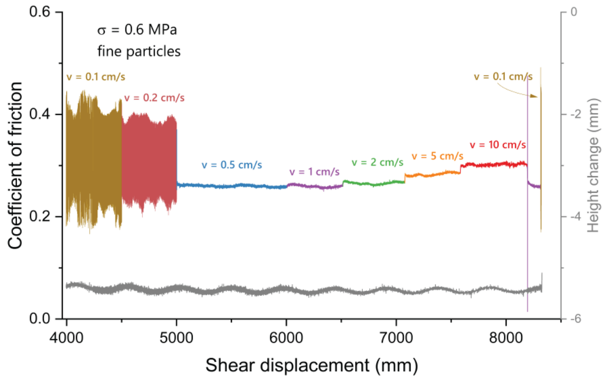
(a) The ring-shear configuration

(b) A photo of an experimental shear zone in coarse halite particles (thick)

(c) A photo of an experimental shear zone in fine halite particles (thin)



(d) Run-in phases for two materials under normal stress of 0.6 MPa. We stop and hold the tests for ~1000 s and the fine material shows rapid weakening when the shear is resumed



(e) Results of velocity-step tests on fine particles under normal stress of 0.6 MPa, showing unstable stick-slip and stable sliding