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New Experimental Constraints on Frictional Instability of Simulated Halite Shear Zones

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1. Introduction

It is widely believed that the frictional properties of granular materials provide many fundamental insights into geophysical processes such as landsliding and earthquake faulting. Some previous experimental studies have shown that the mineralogy of constituent materials plays a first-order control on the transitions of frictional behavior, including sliding stability or instability [Shimamoto and Logan, 1981]. Other laboratory studies have demonstrated the importance of shear rate as a primary control on frictional properties, leading to rate-weakening or stick-slip instability [Di Toro, et al., 2011; Ferri, et al., 2011]. Field observations have also revealed that the development of internal structures or surface morphologies may excite the unstable frictional slip [Sagy et al., 2007]. Despite these efforts, however, neither the knowledge of general relationships among mechanical conditions, material properties and frictional behavior nor the underlying processes are well understood. For instance, the geo-materials interact with each other via different grain sizes and shapes, and it is still somewhat uncertain what kinds of physical mechanisms determine the evolution of strength spectrum, and how the slip surfaces infer frictional behaviour. Although our previous results from glass beads have tentatively explored the possible roles of grain size and shear rate in affecting the frictional instability [Jiang, et al., 2016], natural landslide materials could be involved in other process (such as grain fragmentation) and also could be experienced a variety of sliding conditions (i.e., velocities and surfaces) from their initial and long runout paths. Herewith, we report on a suite of ring-shear experiments designed to investigate the influence of grain interfaces on the granular frictional behavior over a wide range of shear velocities.

2. Experimental methods

Samples, consisting of granular halite and mixtures of granular halite and silica sand, were sheared at room temperature and constant normal stress of 400 kPa, and we varied the proportions of halite by weight. In each experiment, the same loading procedures were adopted. We evaluated the frictional behavior following two stages. In the first stage, the samples were initially sheared under high shear velocity approximately 330 mm/s to examine their fast behavior. And then, in the second stage, we gradually stepped the shear velocity following multiple orders of sequence (i.e., ranging from 5 μm/s to 330 mm/s) for the pre-existing shear zones. Additionally, in order to detect brittle events in samples, three equally spaced acoustic emission (AE) transducers were installed near the shear plane during tests, and the AE data were amplified and recorded at the sampling rate of 1 MHz.

3. Results

One selected result is given in Figure 1 to reveal the friction properties as a function of elapsed time for sheared granular materials with different proportions of halite. We find that: (1) the pure halite sample shows stick-slip instability (Figure 1a), but the pure silica sand sample exhibits stable-sliding (Figure 1e); (2) inclusion a low concentration of halite (10%) is strongly to modify the frictional behavior and specifically to reduce its ability to sustain stable-sliding for silica sand sample (Figure 1d); (3) the stress drop and recurrence time of instability events increase with increasing of halite contents (Figures 1a to 1c), but the occurrence of plastic deformation increases the recurrence time (Figure 1d).

Figure 2 illustrates the details of one instability event and the time-frequency spectrum of AE waveforms for halite shear zone. It is noted that the domain frequency band for AE waveforms is distributed from several kHz to hundreds of kHz, and some AE waveforms were captured before the stress drop. The rupture time is approximately 100 millisecond and maximum rupture velocity is approximately 40 times greater than the imposed shear velocity.

4. Closing remarks

Our observations highlight the fundamental aspects among material properties, mechanical conditions and frictional behavior for granular materials. The most important finding of this study is the presence of halite in affecting granular frictional behavior (i.e., stable-sliding or stick-slip instability), even if small amounts of halite were presented. The frictional instability parameters (i.e., stress drops and recurrence time) can be dramatically influenced by the proportion of halite. We infer that the distinct frictional behavior might result from the pressure solution in the halite grains, which is related to accommodate the interconnections between adjacent grains on halite-rich shear surfaces as anticipated for the brittle-ductile transitional conditions at room temperature.

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References

Di Toro, G., R. Han, T. Hirose, N. De Paola, S. Nielsen, K. Mizoguchi, F. Ferri, M. Cocco, and T. Shimamoto (2011), Fault lubrication during earthquakes, Nature, 471(7339), 494-498.

Ferri, F., G. Di Toro, T. Hirose, R. Han, H. Noda, T. Shimamoto, M. Quaresimin, and N. de Rossi (2011), Low- to high-velocity frictional properties of the clay-rich gouges from the slipping zone of the 1963 Vaiont slide, northern Italy, Journal of Geophysical Research: Solid Earth, 116(B9), B09208.

Jiang, Y., G. Wang, and T. Kamai (2016), Effect of particle size and shear velocity on frictional instability in sheared granular materials during large shear displacement. Journal of Geophysical Research (under review).

Sagy, A., E. E. Brodsky, and G. J. Axen (2007), Evolution of fault-surface roughness with slip, Geology, 35(3), 283-286.

Shimamoto, T., and J.M. Logan (1981), Effects of simulated fault gouge on the sliding behavior of Tennessee sandstone: Nonclay gouges: Journal of Geophysical Research: Solid Earth, 86(B4), 2902-2914.

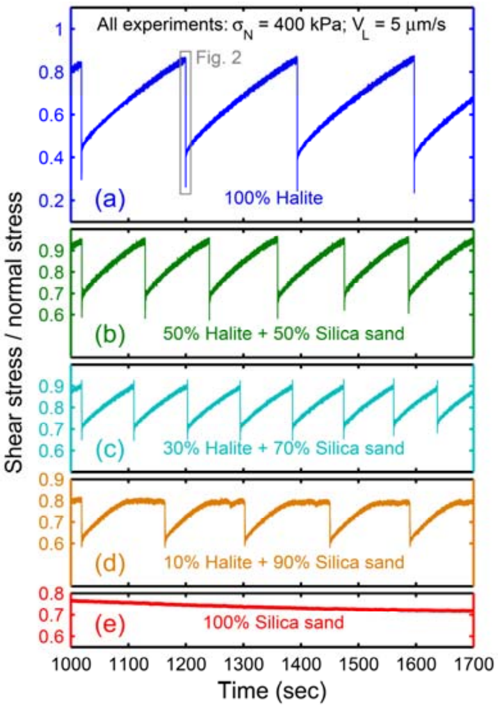

Figure 1. Friction coefficient (the ratio of shear stress and normal stress) taken from sections of experimental data for halite/silica sand samples with halite contents of 100% (a), 50% (b), 30% (c), 10% (d) and 0% (e), respectively. All experiments were conducted under the constant normal stress of 400 kPa and the shear velocity of 5 μm/s. The boxed event is enlarged in Figure 2.

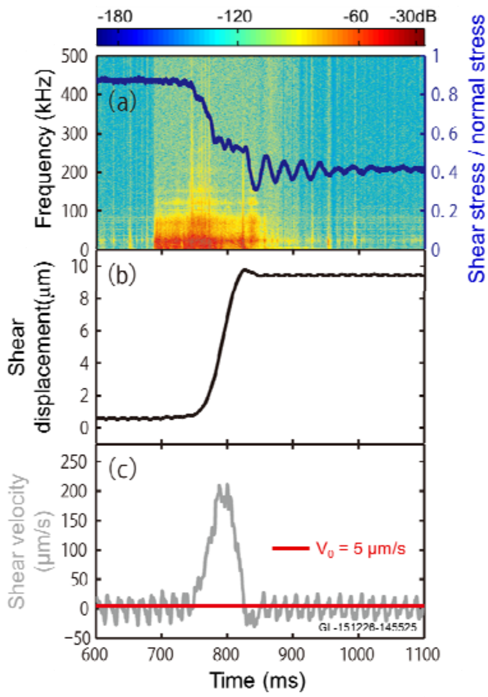

Figure 2. Close-up view of boxed event from Figure 1 illustrating details of instability behavior for halite shear zone. (a) The time-frequency spectrum of AE waveforms (background image) and recorded friction data (blue color). (b) The observed shear displacement for the instability event (black color). (c) The calculated (gray color) and imposed shear velocity (red color).