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Development of Micro-fractures within Shear Zone Revealed by X-ray Micro-CT Scan: Examples from Rock Halite in Ring-shear Experiments

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Introduction

Fractures, generally referring to Riedel shear structures, within shear zones of different scales manifest themselves as a system of fractures/shears on a relatively smaller scale (Tchalenko, 1970), ranging from continental-scale strike-slip faults to shear zones along the sliding surfaces of landslides, and to microscopic deformation bands. They are believed to develop during the early episode of fault motions or landsliding, and can offer some crucial knowledge such as rock properties, fracturing temperature, changes in regional stress field, and activation histories (Anders et al., 2014).

In order to understand the formation mechanism and sequence of fractures with different orientations, various fieldwork and laboratory experiments were performed for several decades around the world, most of which contribute to two-dimensional field mapping and/or thin-section observations under an optical microscope or scanning electron microscope (SEM) besides mechanical behavior studies. Until now three-dimensional microstructural observations on fractures are rare compared to the intense two-dimensional research mentioned above. Thus, the present study tries to render three-dimensional information about fractures within the shear zone and provide a more comprehensive insight into the mechanism behind it.

Methodology

Three sets of ring-shear tests on rock halite materials (grain size > 2 mm) were conducted with two ring-shear apparatuses (producing two different kinds of annular samples in size) in terms of (1) different shear displacements (1, 2, 3, 4, 6, and 8 m), (2) different normal stresses (200, 500, and 1000 kPa), and (3) different shear velocities (0.05, 0.5, and 5 cm/s), respectively. We use halite because it is relatively widely used in the study of tectonics and also enables us to sample the shear zone. The shear tests were conducted by the shear-rate controlled method. In each test, the shear box was opened and the shear zone was observed after the shear test was finished. It is noted that in all the tests, an annular shear zone was formed. The annular shear zone was cut into several segments, which were then scanned using an X-ray micro-CT (XCT) scanner to obtain high-resolution images in three-dimensional space.

Results and conclusions

Fig. 1 shows the frictional coefficient against shear displacement for different displacement (1-8m) tests. It is seen that each test has a consistent trend with each other and also shows the stick-slip and strain-weakening phenomena. Fig. 2 shows an example of the shear zone formed in the shear test. The upper part has been moved. It is noticed that a denser shear zone has been formed and grain crushing has occurred within the shear zone, while the grains in the lower part of the shear zone were less, if any, crushed.

Xu et al. (2013) reported six types of Riedel shear structures, i.e., R and its conjugate R’, passive P, displacement-direction-parallel Y shears, X, tension T; subsidiary fractures in micro-scale, micro-fractures (as shown in Fig. 3). In our tests, preferential orientations of rock halite grains as well as fractures can be recognized in three-dimensional images obtained by non-destructive XCT. The number of Y shear increases as shear displacement becomes larger (see Fig. 4), or the normal stress decreases, or the shear velocity becomes greater.

In conclusion, we found that longer shear displacement, higher shear velocity, or lower normal stress can result in the formation of multi-Y shears within the shear zone. These Y shears are the sliding surfaces that could be observed in the shear zone of a landslide on the field and can be also related to bedding structures as well as repeated seismic slips within strike-slip faults. We infer that the possible formation mechanism of the multi-layered structure can be associated with the film model in tribology. Mechanically-stable thin films (denoted by Y shears) are the product of the process to reach a mechanical equilibrium status in the shear zone, as reported by Stachowiak et al. (2013).

References

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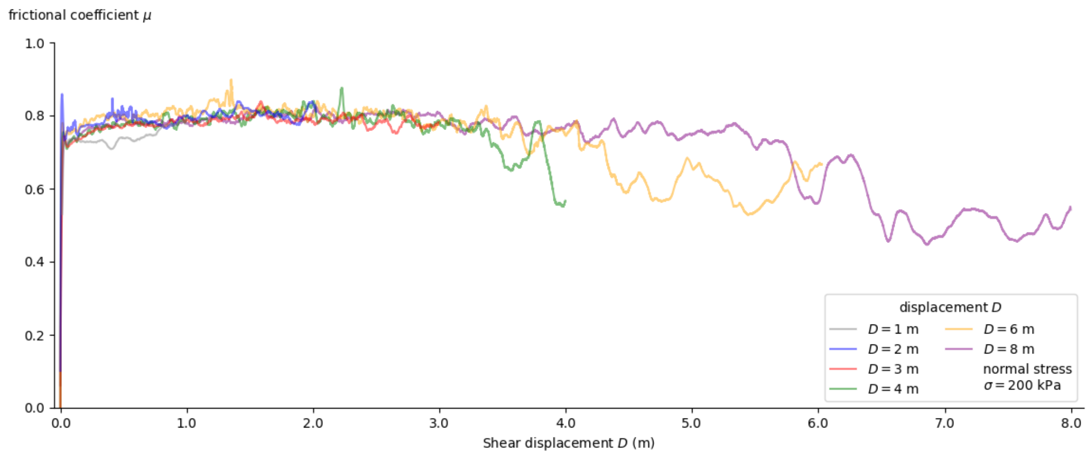

Fig. 1. The frictional coefficient in terms of shear displacement for different shear displacement tests.

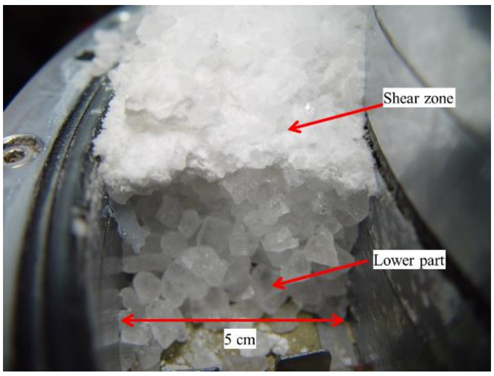

Fig. 2. View of shear zone formed in the test

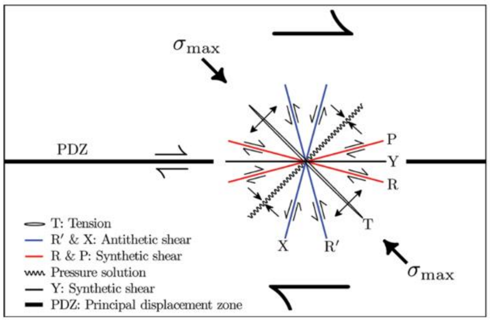

Fig. 3. An idealized Riedel shear system containing six types of shear structures (Xu and Ben-Zion, 2013).

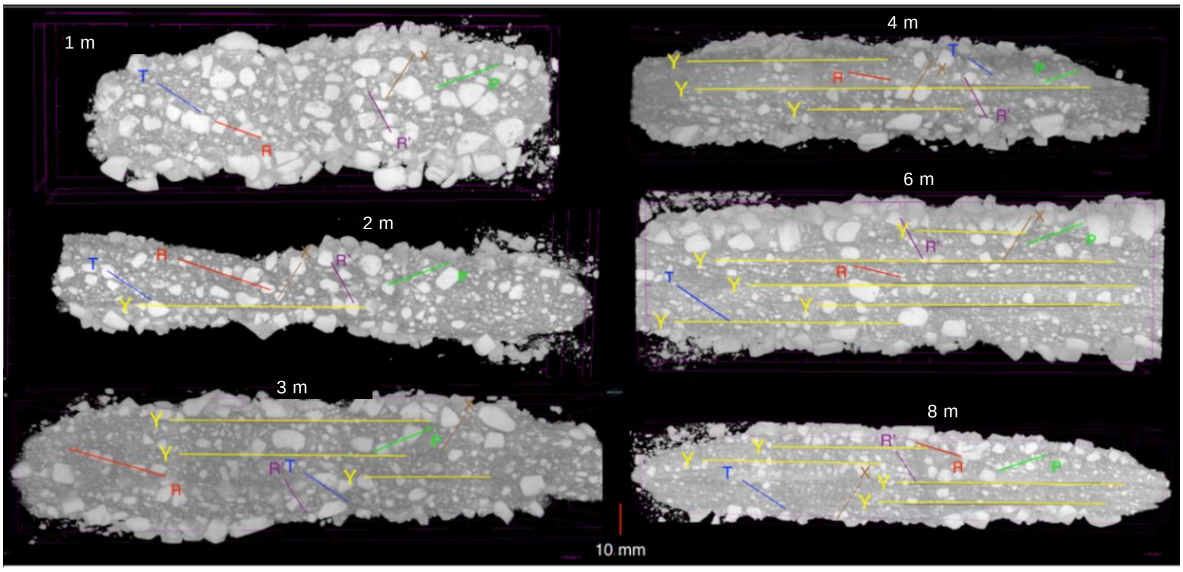

Fig. 4. Six types of Riedel shear structures can be recognized in terms of different shear displacements (1, 2, 3, 4, 6, 8 m) in this study. One interval in all the three-dimensional magenta boxes around the samples denotes 10 mm