University of New Hampshire

IN SITU OBSERVATION OF THE DEVELOPMENT OF SHEAR-ZONE MICROSTRUCTURES AND STRAIN LOCALIZATION USING A TRANSPARENT ROTARY SHEAR APPARATUS

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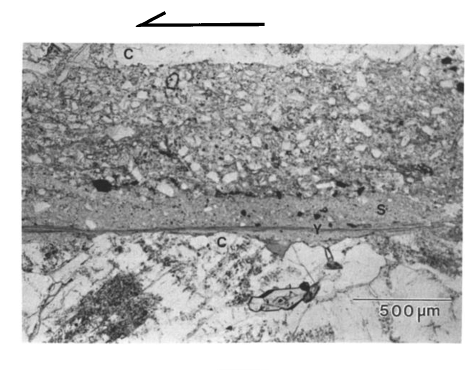
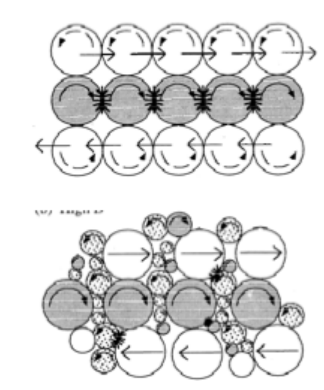
Abstract

Using a transparent rotary shear apparatus and rock-analogue granular materials, we investigate the micromechanics of slip in shear zones. We evaluate the effects of grain size distribution (GSD) on grain kinematics, such as prevalence of rolling and sliding. We track the emergence and evolution of shearing-related microstructures and investigate conditions that lead to strain localization. Our experimental apparatus consists of a ring-shaped transparent sample chamber, with a width of 1.5 cm and a thickness of 2 cm. The upper wall of the chamber functions as a piston and also transmits the shearing force to the sample. An immersion fluid, with an index of refraction similar to that of the transparent sample material, facilitates the observation of individual grains throughout the width of the sample chamber. Normal stresses of up to 344 KPa and slip rates of up to 60 μm/s can be attained. Granulated sugar and potassium alum powder are used as rock analog materials.



Left: This is a microphotograph of a laboratory experiment using simulated granite gouge. Discplacement: 65 mm. From Beeler et al., 1996.



Right: Low GSD (upper image) results in distributed deformation, whereas intermediate to high GSDs (lower image) lead to distinct planes of deformation (i.e. localization). From Morgan & Boettcher, 1999.

Motivation

In most natural faults, a zone of less cohesive material is formed at the interface of the sliding blocks as a result of the damage to the fault walls due to shearing. This granular aggregate, commonly referred to as fault gouge or simply gouge, consists of rock fragments of various sizes and can have a thickness of a few millimeters up to a few meters. It has been found that the existence and frictional behaviour of the gouge layer plays an important role in strain localization and therefore in fault stability. Laboratory experiments[1] as well as numerical simulations[2, 3] have focused on the interactions between the following aspects of a shear zone:

1. Grain kinematics, i.e. rolling and/or sliding
2. Microstructures (e.g. grain bridges, shears) development and evolution
3. Grain size distribution and its evolution due to grain comminution (cataclasis)

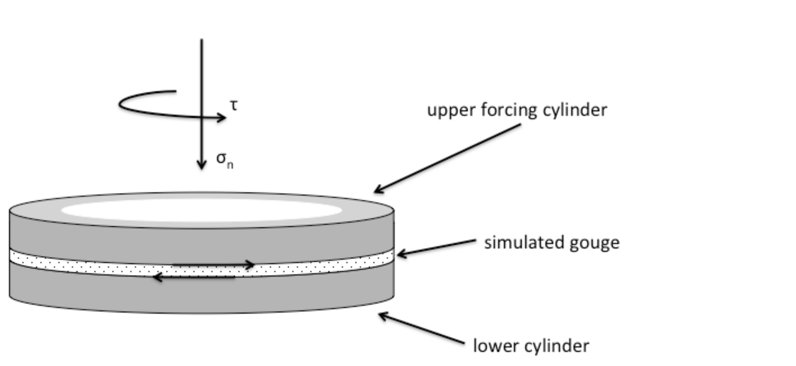
Experimental Apparatus

The rotary shear apparatus presented here was initially developed by Terry Tullis and Margaret Boettcher at Brown University, in 1998. In addition to the advantage of large displacements, this design also features a transparent sample chamber, which allows for direct observation and recording of the deformation process through an attached microscope and camera.

The apparatus is comprised of four main components:

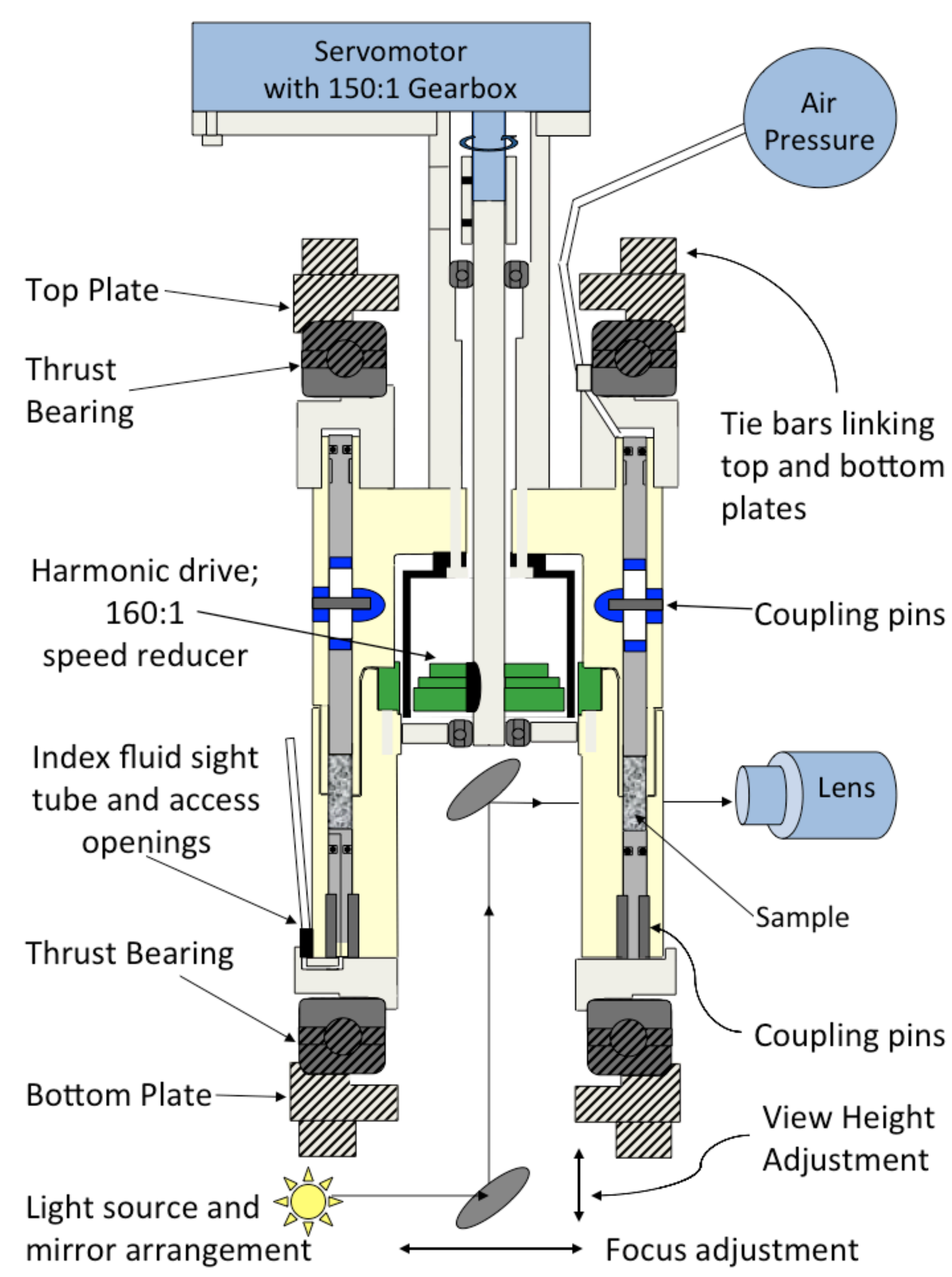
1. The sample chamber
2. The pneumatic system that applies normal stress
3. The electromechanical system that applies shear stress
4. The optical system

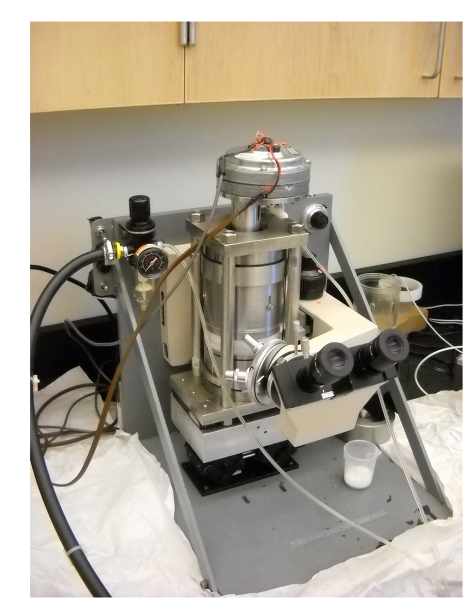
To recreate gouge layers we use granular analogue materials such as sugar and aluminum potassium sulfate ($KAl(SO_4)_2$).



Above: Ring shear concept. A ring-shaped gouge analogue material is placed between two pistons. Air pressure and torque are applied to the upper piston, thus imposing normal and shear stresses on the simulated gouge.

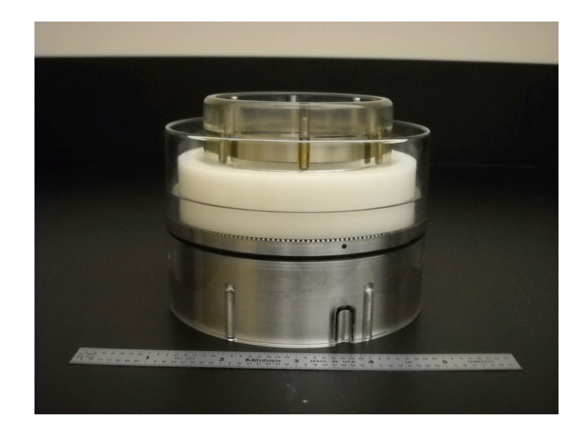
Below: Aluminum potassium sulfate ($KAl(SO_4)_2$) grains.

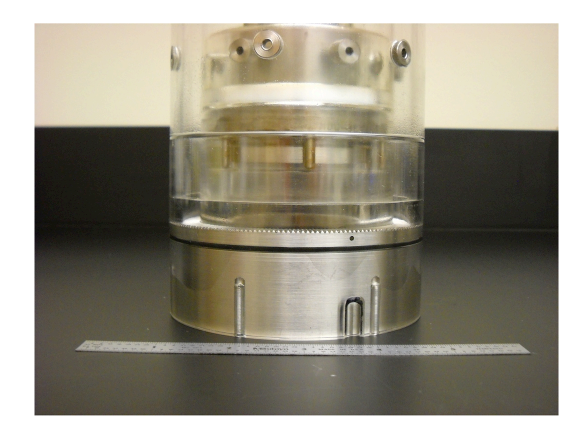




Above: Our apparatus.

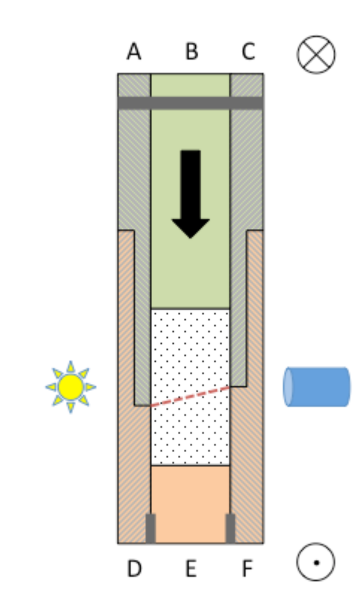
Right: A cross-section of the apparatus used in this project. Courtesy of M.S. Boettcher.





Top: Picture of the two plastic rings and the piston that constitute the lower part of the sample chamber. The white teflon ring shows the approximate size of the sample. Ruler length: 6 in.

Below: The two upper rings have been added and the chamber is ready to be loaded with sample material.



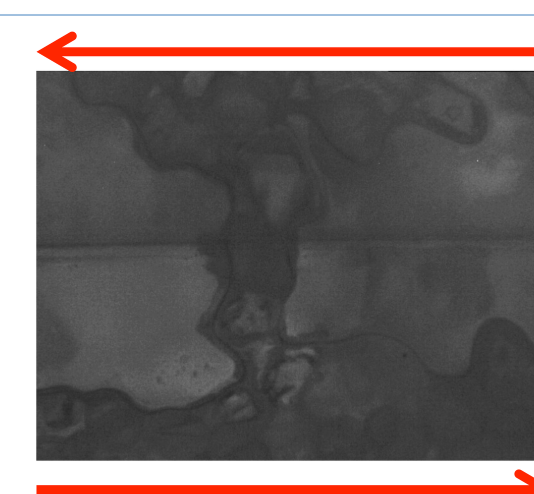
Right: A detailed cross-section of the sample chamber. Note the tilted dashed red line that represents the slip interface.

Experimental observations

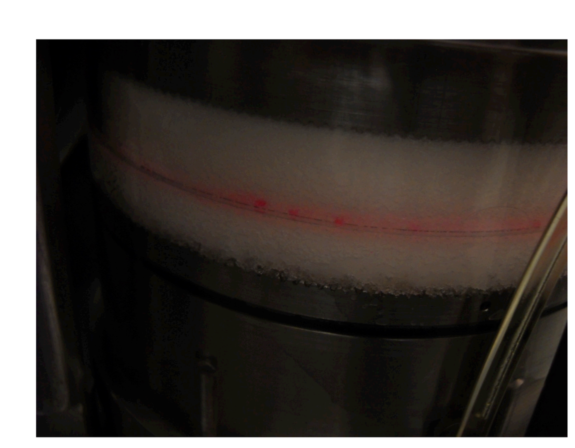
The experiments discussed here have been performed on samples about 2 cm thick, under 138 KPa of normal stress, a 0.023 cm/s slip rate and with unpressurized immersion fluid. The average grain size of the sample materials used is 0.5 mm and the maximum size is 1 mm. A 5x microscope lens has been used for the microphotographs.

We can clearly observe localization of strain within a 1.5 mm thick zone centered at the slip interface. Rolling is the primary mode of grain motion since it is far more prevalent than sliding. Because of the low normal stress applied we do not observe any cataclasis. Grain motion is not restricted in the direction along the slip but also occurs laterally. This is shown in our videos by the gradual fading of individual grains as they move out of focus.

Lastly, we can also observe the development and evolution of grain bridges that form and collapse during our experiments. Y- and synthetic low-angle Riedel shears are also very prominent in our videos.



Above: Another example of a grain bridge.

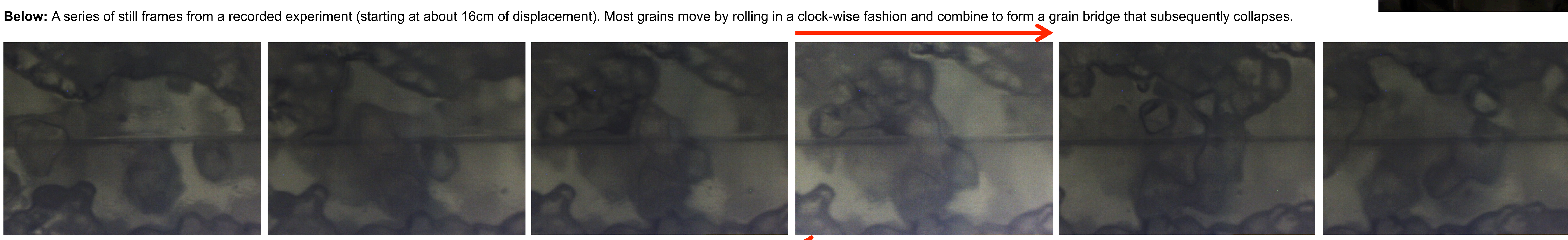


Left: Pictures of the sample chamber during an experiment. Coloured sugar grains have been used to visualize deformation. The top photograph was taken shortly after the start of the experiment, while the bottom one after a complete rotation (27.9 cm).

Future work

We plan to experiment with simulated gouge assemblages of various GSDs and compare our results to those of numerical simulations[2]. Furthermore we intend to perform velocity stepping experiments and attempt to visually observe and record dilation.

Below: A series of still frames from a recorded experiment (starting at about 16cm of displacement). Most grains move by rolling in a clock-wise fashion and combine to form a grain bridge that subsequently collapses.



References

1. Beeler, N.M., Tullis, T.E., Blanpied M.L., Weeks, J.D., 1996, Frictional behavior of large displacement experimental faults. Journal of Geophysical Research, v. 101, p. 8697-8715.
2. Morgan, J.K., 2004, Particle dynamics simulations of rate- and state-dependent frictional sliding of granular fault gouge. Pure and Applied Geophysics, v. 161, p. 1877-1891.
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