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Effect of montmorillonite included in fault rock on frictional strength and fluid flow properties

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Without experimental researches, it is difficult to infer physical properties of fault rocks, such as frictional strength and permeability, because natural fault rocks consist of various minerals having various strengths and various permeabilities. Previous experimental works revealed that a few contents of weak minerals play a critical role to decrease the fault strength. Permeability of fault rocks is also important term to affect the fault strength. The fault rock with low permeability is a candidate to cause the abnormal high pore pressure, because it can hold high pore pressure for long while against fluid flow through the fault and will behave as undrainage at sudden increase of stress relevant to the earthquake propagation. However, effects of clay contents on permeability in fault rocks have not been addressed sufficiently.

We investigated both frictional strength and permeability of artificial fault gouge using a gas-medium, high-pressure and high-temperature deformation apparatus at AIST, Japan. Pressure medium of confining pressure and pore pressure were Ar gas and distilled water, respectively. Initially, confining pressure was raised to 80 MPa, and pore pressure was raised to 5 MPa under the room temperature condition. A specimen assembly (20 mm in diameter and c.a. 40 mm in length) consisted of cylinders of Berea sandstone with a sawcut plane cut at 30 deg. to the loading axis. The sawcut contained a layer of clay-quartz mixed gouge. The confining pressure was controlled to keep the normal stress constant at 80 MPa with increasing axial load. A sinusoidal pressure oscillation was applied on the pore pressure of upstream side of the specimen was for permeability measurement during the deformation. We prepared Na-montmorillonite powder as low-strength and low-permeable minerals and quartz grains sized between 150 and 200 micrometer as hard crusts. Various weight percent of the clay contents of the mixed gouge (1.00 g of total weight) were deformed with a constant axial sliding velocity of 0.001 mm/sec.

On the result of frictional strength of the mixed gouge, the frictional coefficient of the mixed gouge decreased from 0.7 (100 % of quartz) to 0.2 (100 % of Na-montmorillonite) at 2.0 mm of sliding displacement. However the frictional coefficient did not decrease monotonically. There was a sharp decrease in the frictional coefficient at around 40 % of the clay contents. The frictional coefficients with more than 40 % clay were lower than those expected from the monotonic decreasing. Therefore, strength of fault gouge having more than 40 % of clay content would be strongly affected by that of clay.

The permeability of the specimen with mixed gouge decreased continuously as the increase of the sliding displacement. Although that was also found in the case of 100 % quartz gouge, the values of bulk permeability of the specimen assembly were quite higher than the result of 10 % of clay contents case. The permeability of an assembly of 100 % quartz gouge and Berea sandstones initially indicated 3x10ˆ-14 mˆ2 and decreased toward 2x10ˆ-14 mˆ2 at 2.5 mm of the displacement. That small reduction would reflect the comminution of quartz grains during the deformation. On the other hand, before the sliding, the permeability of an assembly of 10 % Na-montmorillonite and 90 % quartz mixed gouge sandwiched by the Berea sandstones showed lower value of 7x10ˆ-16 mˆ2. Additionally, the permeability reduced by 1.8 orders of magnitude, indicating 1x10ˆ-17 mˆ2 at 2.5 mm of the displacement. That mechanism of permeability reduction of the mixed gouge would depend mainly on structural development which fine clay matrix intruded into the pore spaces preventing from fluid flow though the fault.