PERMEABILITY EVOLUTION IN NATURAL FRACTURES SUBJECT TO CYCLIC LOADING AND GOUGE FORMATION


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I. INTRODUCTION
II. METHODOLOGY
III. RESULTS AND DISCUSSIONS
IV. CONCLUSIONS
V. FUTURE WORKS
Processes influent transmissivity:

- Changing normal loads
- Surface deformation
- The formation of gouge and fracture offset

Stress-closure-conductivity ($a_{hyd}$) coupling for a moderately altered, medium rough joint, Barton et al. 1985

Model for joints closure developed by Bandis et al. 1985

Grain size distribution of gouge material after test
Fig. 1 Granodiorite specimen

Table 1 Physical properties of the specimen under

<table>
<thead>
<tr>
<th>Test specimen</th>
<th>Specimen length (mm)</th>
<th>Shear offset (mm)</th>
<th>Eff. length (mm)</th>
<th>Frac. mode (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>0</td>
<td>60</td>
<td>I tensile</td>
</tr>
<tr>
<td>2</td>
<td>62</td>
<td>0</td>
<td>60</td>
<td>II shear</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>0</td>
<td>60</td>
<td>I</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>0</td>
<td>60</td>
<td>I</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>2</td>
<td>58</td>
<td>I</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>2</td>
<td>58</td>
<td>I</td>
</tr>
<tr>
<td>7</td>
<td>60</td>
<td>3</td>
<td>57</td>
<td>I</td>
</tr>
<tr>
<td>8</td>
<td>61</td>
<td>3</td>
<td>58</td>
<td>I</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>6</td>
<td>54</td>
<td>I</td>
</tr>
<tr>
<td>10</td>
<td>62</td>
<td>5</td>
<td>57</td>
<td>II</td>
</tr>
<tr>
<td>11</td>
<td>60</td>
<td>1</td>
<td>59</td>
<td>I</td>
</tr>
<tr>
<td>12</td>
<td>60</td>
<td>1</td>
<td>59</td>
<td>I</td>
</tr>
</tbody>
</table>

Classify:
investigating fracture surfaces for slickensides, plumose structures, mineralization and crack propagation through individual grains
**Fig. 2** Experimental setup of core holder and specimen

**Table 2** Pumps used in the setup with model, minimum and maximum pressures $p_{\text{min}}$ and $p_{\text{max}}$, standard pressure accuracy SPA

<table>
<thead>
<tr>
<th></th>
<th>$P_A$</th>
<th>$P_B$</th>
<th>$P_C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{lp}}$</td>
<td>500D</td>
<td>100DM</td>
<td>100DM</td>
</tr>
<tr>
<td>Min. pressure (MPa)</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>Max. pressure (MPa)</td>
<td>25.9</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>Volume (mL)</td>
<td>507</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>SPA (% FS)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Cubic law:**


\[
Q = \frac{a_h^3 \cdot d}{12 \mu} \nabla p
\]

In which:
- $Q$: Flow rate ($\text{mL/min}$)
- $T$: transmissivity ($\text{mL}$)
- $a_h$: Hydraulic aperture ($\text{mm}$)
- $\mu$: Dynamic viscosity ($\text{Pa.s}$)
- $p$: Fluid pressure ($\text{MPa}$)
- $d$: Specimen diameter ($\text{mm}$)
In which:
- $V_{p,\text{conf}}$: Confining fluid volume ($mL$)
- $p$: Fluid pressure (MPa)
- $a_{\text{mech}}$: Mechanic aperture (mm)
- $d$: Specimen diameter (mm)
- $l$: Specimen length (mm)

$$da_{\text{mech}} = \frac{dV_{p,\text{conf}}}{d \times l}$$
Permeability changes during load cycling & fracture transmissivity

Fig. 4 Tests 1, 4, 7 and 10 are shown in subfigures a-e, respectively. The plots show transmissivity versus effective confining pressure.
2. Aperture changes

Fig. 7 Mechanical versus hydraulic aperture changes.

Fig. 8 Mechanical aperture changes versus effective confining pressure.

Loading  Unloading
3. Surface Scans

CDF: cumulative density functions of asperity height distributions on the fracture surfaces

Fig. 11 CDF of asperity height (a) and asperity height normalized to the maximum asperity height (b) for specimens 1–12 for fracture sides A and B before (left) and after (right) testing

Fig. 9 Specimens from tests 1, 2, 4, 7 and 10 (top to bottom) with apertures before (left) and after (right) testing. Reference figure for the aperture field dimensions and aperture size colorbar is shown in f (color figure online)
● All specimens showed a decrease in transmissivity with increased confining pressure.

● These nonlinear changes in the relationship of mechanical and hydraulic aperture changes can be attributed to increased surface damage and fracture closure for high confining pressures.

● The gouge material produced by asperity damage was collected to study the impact of a gouge layer on transmissivity.

● Fracture surfaces in a reservoir plays a significant role in the evolution of fracture transmissivity after initial stimulation.
• 3D model of mold created discontinuity Surface
• Morphology quantification

Testing with YOKO2

• Pemeability => Hydraulic aperture
• Porosity => Mechanical aperture

Result and compare

Conclusion

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3D Printer
SAMPLE CREATION

- 3D model of mold created discontinuity Surface
- Morphology quantification

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YOKO 2 system
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\[ a_{hyd} = \frac{a_{mech}^2}{JRC^{2.5}} \]

Barton and Bandis, 1985
Thank You