Neutron scattering study of strain behaviour of porous rocks subjected to heating and unconfined uniaxial compression

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Problem statement

- Stress-strain state and rock failure is important in characterisation of fracture and design of a **hydraulic fracturing job** as a means of well stimulation.

- **Predictive fracture growth monitoring** tools is critical in oil and gas, carbon sequestration, shale gas and the geothermal power industry particularly with regards to the high costs associated with field trials in extreme conditions.

- Existing information is limited by inability to experimentally measure micro-scale stress-strain concentrations (leading to failure) within the sample mass near critical potential fracture planes.

- Ability to predict these quantities for identified load conditions, is crucial to all geo-mechanical studies and flow characterisation applications.

- Fracture initiation and propagation models at micro-scale are needed to understand hydraulic behaviour of naturally fractured reservoirs and design efficient hydraulic fracturing treatments particularly in presence of localised in-situ stress concentrations.
Aims

- To better understand the micro-scale localized strain behavior of rocks and relate it to the residual stress distribution.
- Methodologies developed through this work can have a significant effect on developing future strategies in execution of hydraulic fracturing jobs and exploitation of naturally fractured reservoirs.

Fig. ASTM 4543 procedure for uniaxial compression test

Chalk (limestone)  Sandstone
Methodology

Table. Uniaxial compression test matrix.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pressure</th>
<th>Temperature</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>5 MPa</td>
<td>25 °C</td>
<td>d₀</td>
</tr>
<tr>
<td></td>
<td>20 MPa</td>
<td>70 °C</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>35 MPa</td>
<td>70 °C</td>
<td>d</td>
</tr>
<tr>
<td>Chalk</td>
<td>5 MPa</td>
<td>25 °C</td>
<td>d₀</td>
</tr>
<tr>
<td></td>
<td>8 MPa</td>
<td>25 °C</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>12 MPa</td>
<td>25 °C</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>12 MPa</td>
<td>50 °C</td>
<td>d</td>
</tr>
</tbody>
</table>

Gauge volume of $4 \times 4 \times 4$ mm$^3$ (fully submerged)

Rietveld refinement (using GSAS code for ENGIN-X)

$\epsilon = (d - d_0)/d_0$, where $d$ and $d_0$ are the lattice parameter for the sample under stress and unstressed sample (at 5 MPa compressive loading and 25 °C in this analysis)

Fig. (a) Uniaxial compression test (at ENGIN-X) of chalk at 5 MPa, and (b) measurement scheme.
Results

Fig. X-ray diffraction spectrum: (a) sandstone (hexagonal, SiO$_2$), and (b) chalk (rhombohedral, CaCO$_3$).

SANDSTONE: porosity: 0.154, permeability: 315 mD, Young’s modulus: 40 GPa, Poisson’s ratio: 0.14, and compressibility: 3e-10 Pa$^{-1}$

Fig. Scanning electron microscopy: (a) sandstone, and (b) chalk.
Results

Chalk (limestone)

Sandstone
Results

Fig. Neutron diffraction spectrum: (a) sandstone, and (b) chalk.

Fig. Neutron diffraction at the center of the specimens (compressive loading under 5 MPa and room temperature conditions):

(a) sandstone (hkI planes in (ii) R to L: [110], [102]/[102], [111], [200], [201]/[201], [112], [003], [202]/[202], [103]/[103], [210], [211]/[211], [113], [300], [301]/[301], [203]/[203], [104]/[104], [302]/[302], [220], [221], [213]/[213], [114], [311]/[311], [204]/[204], [222], [303]/[303]), and

(b) chalk (hkI planes in (ii) R to L: [110], [113], [202], [204], [10-8], [116], [211], [21-2], [1010], [214], [208], [119], [215], [300], [0012], [217], [2010], [218], [306]/[306], [220], [1112], [223], [311], [312], [2110], [1014], [314], [2111]).
Results

Fig. Uniaxial compression stress of 20 MPa (at 70°C) of chalk sample fracture: (a) multiple failure during compression which includes diagonal shear planes, vertical fractures, vertical splitting, shear, conical and spalling (see inbox), and (b) displacement and stress jump leading to failure.

Fig. Neutron diffraction residual strain (based on Rietveld analysis) comparison during uniaxial compression stress, showing strain variation along the radial direction from the centre of the sample: (a) sandstone, and (b) chalk.
Conclusions

- From comparison of Rietveld refinement for multiple peak of crystalline phases in both samples, it was found that the sandstone has significantly high strain bearing capability when compared with chalk, however, the overall strain profile from the central axis in the radial direction looked very similar.

- Comparison of the residual strain profile between the sandstone and chalk indicate that the average residual strain in both samples are largely tensile with some compressive residual strain in the chalk (near the outer periphery of the cylindrical sample).
Thank you

Questions, Comments, Suggestions?

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