SELF-SEALING OF CLAYSTONE UNDER X-RAY NANOTOMOGRAPHY: A NEWLY-DEVELOPED TRIAXIAL COMPRESSION CELL

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Keywords: x-ray tomography, triaxial compression cell, self-sealing, crack

Summary: We performed a range of self-sealing experiments using a newly-developed triaxial compression cell placed within a GE Phoenix Nanotom S CT scanner, equipped with a 180 kV micro-focus X-ray tube/generator and a CMOS 5MPx detector. The body of the compression cell is X-ray transparent, allowing sample healing to be monitored directly.

1. INTRODUCTION

During resaturation of underground structures in the Callovo-Oxfordian claystone, fractures generated during excavation can self-seal, resulting in a significant decrease in permeability to water in the excavated damaged zone.

The self-sealing is due to mineral rearrangements and associated porosity near fractures. The three main processes involved are (i) interlayer swelling of smectitic phases, (ii) inter-particle swelling by osmotic effect, and (iii) crack obstruction by the aggregation of particles. These structural rearrangements within the self-sealed zone affect both hydromechanical and transfer properties. The Multi-Scale HydroGeoMechanics team at the GeoRessources Laboratory has developed a triaxial compression cell that is transparent to X-rays and allows observation of rock samples placed under mechanical stress [1].

Although self-sealing in argillite has been investigated in several types of tests, performed both in situ and on samples in the laboratory [2, 3], there is little information available on the efficiency of self-sealing in different mechanical (taking into account, for example, the opening of fractures and applied stress), hydrodynamic (considering, for example, a flow of water in the fracture), and, eventually chemical (for example, by varying the composition of the circulating waters) contexts. The main objectives of the use of this triaxial compression cell are to (i) observe in real-time the saturation of a rock sample under mechanical stress, and to (ii) identify the phenomenon of self-sealing.

2. EXPERIMENTAL METHOD

The triaxial compression cell (Figure 1A) is manufactured entirely from PEEK CF30, a thermoplastic of sufficient resistance and that, moreover, is X-ray transparent. The design of the compression cell allows cylindrical samples of 20 mm diameter and 40 mm height to be tested. The tomograph used in the experiments is a GE Phoenix Nanotom S CT scanner, equipped with a 180 kV micro-focus X-ray tube/generator and a CMOS 5MPx detector.

Rock samples are artificially cracked. The samples are sawn in two according to a plane containing the axis of the cylinder. One of the faces is machined so as to obtain a slit across 1/3 of the diameter, the opening of which is precisely controlled (between 100 and 800 µm). Water is then injected into the crack. Variable confinement

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pressure can be applied, allowing uniaxial and triaxial tests to be performed at different confinements. The sample can be fully rotated in the tomograph, allowing 3D reconstruction of images before, during and after the tests (resolution: 24 µm), and thus making it possible to visualize the evolution of the cracked zone. Permeability measurements are made at different times to quantify the influence of self-sealing on the flow of water.

3. RESULTS

The initial results show that when fluid is injected perpendicular to the plane of anisotropy, the rate of flow has no apparent influence on the kinetics of the fracture closure, however the final permeability obtained varies significantly with the different flow rates. For low flow, the final permeability varies considerably, from 2.10^{-14} to $2.10^{-18}m^2$ over 116 hours, whereas for a higher flow rate (x5), it decreases by only one order of magnitude. Observations of the lips of the fracture at the end of the tests show swelling that seems to be oriented perpendicular to the plane of the fracture and thus parallel to the plane of the anisotropy. The first results for an injection parallel to the plane of the anisotropy suggest that, in this case, the rate of flow affects the kinetics of fracture closure. For a flow rate of 0.25ml/min, closure begins after about one minute. In contrast, for a flow rate of 0.05ml/min, it is necessary to wait several minutes before partial closure of the zone is observed. The reduction in permeability at the lowest flow rate is large, decreasing from 2.10^{-15} to $4.10^{-18}m^2$ over 96 hours. After completion of the test, swelling was observed in elongated zones that lie parallel to the plane of fracture and therefore to the plane of anisotropy.

Two facies of claystone were tested. In the UA facies (water content of 6.5%, $CaCO_3$ content of 29.7%), an important but not total reduction in volume after 34 days of injection was observed, as well as a high decrease in permeability, even if safe claystone values were not recovered (Figure 1b). A two-phase kinematic developed: an initial rapid phase of several hours' duration and a subsequent slower phase lasting several weeks. In the USC facies (water content of 2.8%, $CaCO_3$ content of 59.4%), a low volume reduction and decrease in permeability were observed after 10 days of injection, and the kinetics were monotonous.

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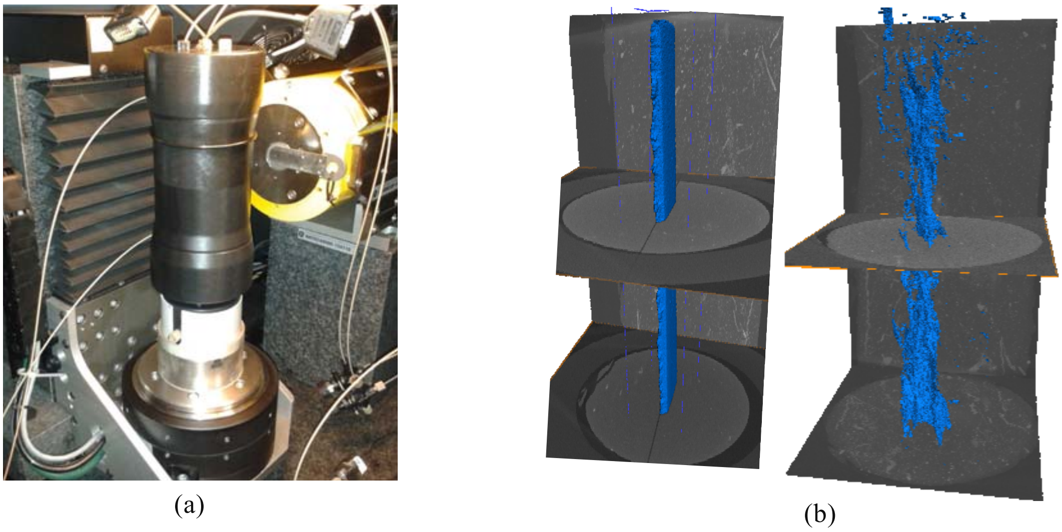
(a) (b)

Figure 1: (a) Transparent triaxial compression cell placed within the GE Phoenix Nanotom S CT scanner chamber. (b) 3D reconstruction 3D of the fracture before and after 34 days of water injection.