DYNAMIC MICRO-CT ANALYSIS OF FRACTURE FORMATION IN ROCK SPECIMENS SUBJECTED TO MULTI-PHASE FLUID FLOW.

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Abstract

In this study, fracture formation in rocks is ~~being~~ studied at the pore-scale through the combination of high-resolution X-ray CT scanning with custom-made add-on modules. The Deben CT5000 system, an in-situ load cell, was used at the scanners at the Centre for X-ray Tomography at Ghent University (UGCT), providing information on mechanical properties of the tested rocks. Micro-CT scans made at the High Energy CT system Optimised for Research (HECTOR) allowed the visualisation of the fractures~~k~~ and their formation as well as the analysis of porosity changes in the material, related to the changes in stress.

Introduction

In geological formations throughout the world, fractures are widespread and contribute significantly to fluid flow and transport (Berkowitz, 2002). Particularly in low-permeable fractured rocks, often referred to as dual-porosity systems, the fractures are considered to be principal pathways for fluid flow and pollutant transport (Berkowitz, 2002; Noiriel, Gouze, & Madé, 2013). More and more often, such low-permeable rock formations in the underground are targeted for exploitation (storage of CO_2, tight oil reservoirs, geothermal energy production). Therefore, the study of ~~the~~ fluid flow behavior in tightly fractured rock formations is of great importance in many fields of geology. However, in numerous investigations, whether ~~it is~~ related to CO_2 sequestration, oil production, or some other applications, direct information from the subsurface reservoir is only available in the form of drill core samples, which are limited in size. Remaining questions in these studies are often related to the pore scale processes in the systems, thus phenomena at the microscopic scale (submicron to approximately 100 µm) are the first which need to be understood in order to determine up-scaled parameters for the reservoir. In this study, the focus lies on the process of fracture formation and its effect on the fluid distribution within rock specimens.

Methods

In order to investigate fracture initiation and propagation in rock samples, as well as the influence on fluid flow through them, different add-on modules are combined with the high-resolution X-ray Computed Tomography (µCT) systems available at the Centre for X-ray Tomography at Ghent University (UGCT, www.ugct.ugent.be).

Primarily, fracture formation in rocks was investigated. An in-situ load cell, the CT5000 system developed by Deben, United Kingdom, was combined with the High Energy CT system Optimised for Research (HECTOR) at UGCT (Masschaele et al., 2013). The load cell allows for both compressive and tensile tests with forces up to 5 kN. Although compressive tests are usually performed on cilindrical rock samples with a length/diameter ratio higher than 1 (Siegesmund & Dürrast, 2014), rock samples with a diameter of 20 mm and a height of approximately 15 mm were used in this study. These dimensions were chosen due to limitations of the current set-up. The CT5000 system consist of a moving bottom jaw, to which a water bath can be connected for compressive tests of saturated samples, and a stationary top jaw. The water bath and outher wall of the load cell is made with glassy carbon (figure 1).

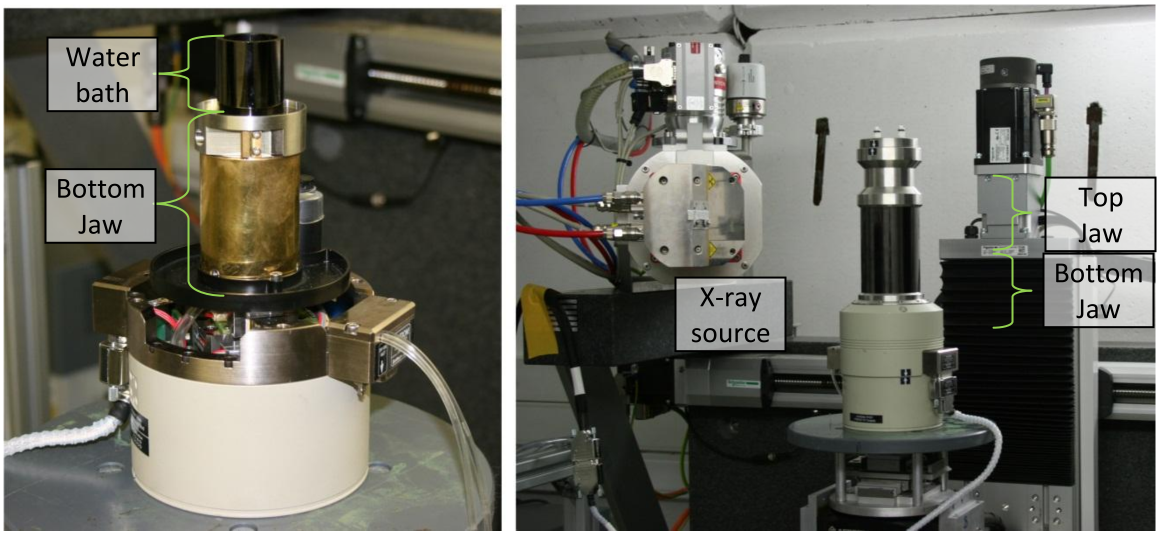

Figure 1 : The Deben CT5000 system fits on the sample stage of the HECTOR scanner at UGCT. The load cell consists of a moving bottom jaw, to which a water bath is connected, and a stationary top jaw.

Using the CT5000 system, both unsaturated and fully water-saturated Savonnières limestone samples were subjected to compressive tests. In order to analyze fracture initiation and propagation, scans were made at different stresses, equal to certain percentages of the compressive strength of the samples. These scans were analyzed for the change in porosity and fracture presence with increasing load.

Results and discussion

Two different types of samples were tested: macroscopically homogeneous (16 samples) and macroscopically heterogeneous (10 samples) Savonnières limestone samples . Their porosity was calculated using the Archimedes method with water saturation at vacuum conditions and linked to their compression strength as tested with the Deben CT5000 system (figure 2). Part of the samples were tested unsaturated, while others were fully saturated and surrounded by water in the water bath. Three macroscopic homogeneous samples were partly saturated (70% to 76% of the pores filled with water) when tested, while two macroscopic heterogeneous samples were fully saturated with water, but not surrounded by water during scanning. As figure 2 shows, there is no clear trend visible in the distribution of compressive strength to the samples' porosity. This is probably due to microscopic heterogeneities within the sample, causing the unpredictable behavior of the samples.

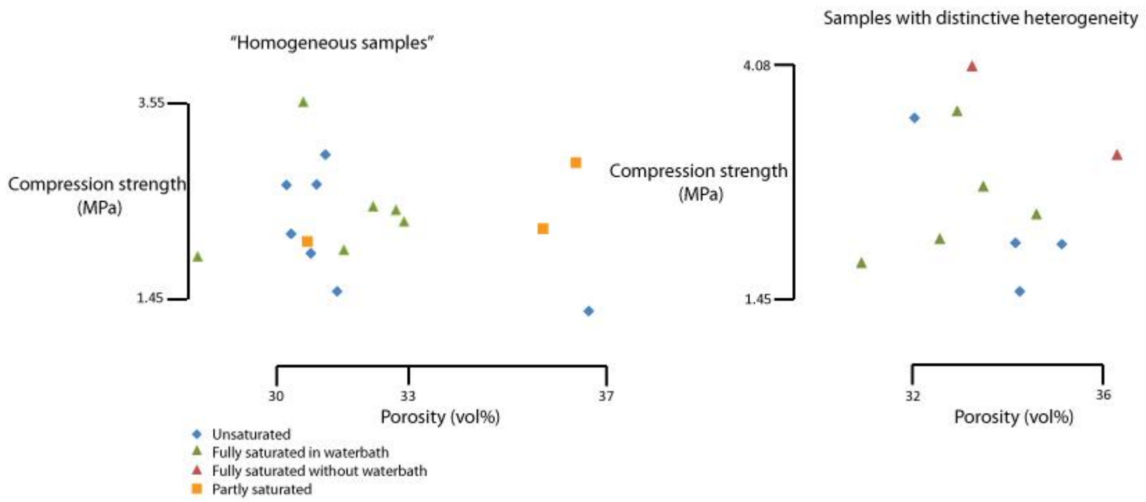

Figure 2: Compressive strength was calculated for different samples, ranging in porosity values. Also, a subdivision was made based on the macroscopic heterogeneity. Because of the microscopical heterogeneity in the samples, there is no clear trend in the distribution of the samples' compressive strength to their porosity.

To elaborate on the experiments, results of sample SL10 are described below. Figure 3a and 3b gives the stress-strain curves obtained during the compressive test of this sample. The vertical strain is constantly measured by the CT5000 system, whereas the horizontal strain can only be measured when a CT scan is made at a certain stress.

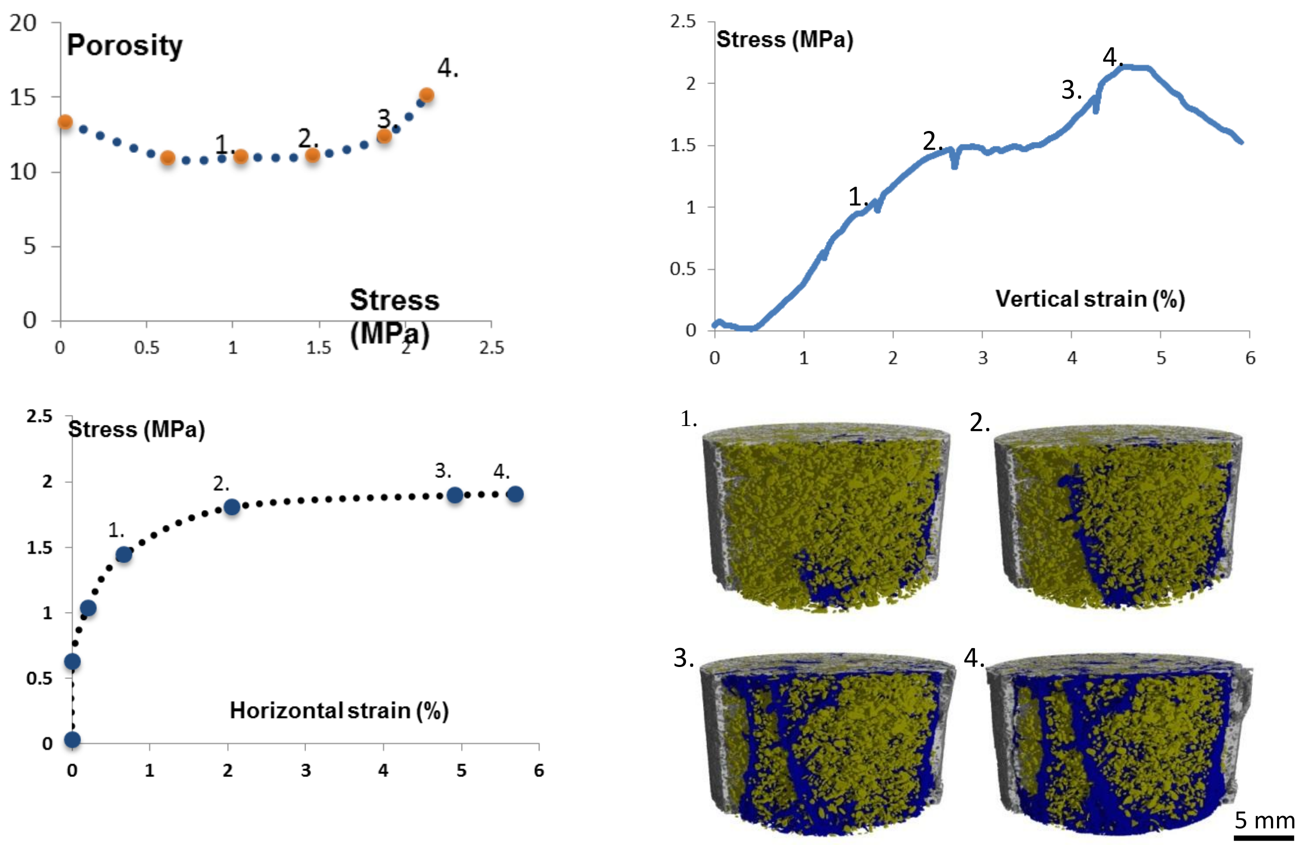

Figure 3: Stress (MPa) – strain (%) curves for both vertical as horizontal strain. Vertical strain is constantly measured in the CT5000 system, while the horizontal strain is measured in the CT scans. Also the porosity changes with stress are indicated and the 3D visualisation of the 4 last scans of this sample (blue = porosity affected by fractures, yellow = porosity unaffected by the fractures).

The stress-strain curve in figure 3 is explained by the 3D images, taken from the last four scans in this test series. These show that the fractures become more and more important as stress increases. They open up more, providing more horizontal strain. The porosity change illustrated in figure 3 tells a similar story: as macro-fractures are formed, porosity increases due to the opening of the fractures. The change in porosity is most distinct just before and at the point of failure (step 3 and 4) in figure 3. This graph also shows an initial decrease in porosity. This is probably related to an early stage of fracturing in the lowermost regions of the sample. Higherup these first fractures cause closing of initial pores, thereby lowering the porosity in the uppermost regions of the sample. The lowermost parts were not taken into account because of metal artefacts due to ~~the closeby~~ lower jaw of the CT5000 system. This could explain the initial decrease in porosity as seen in this sample.

Future outlook

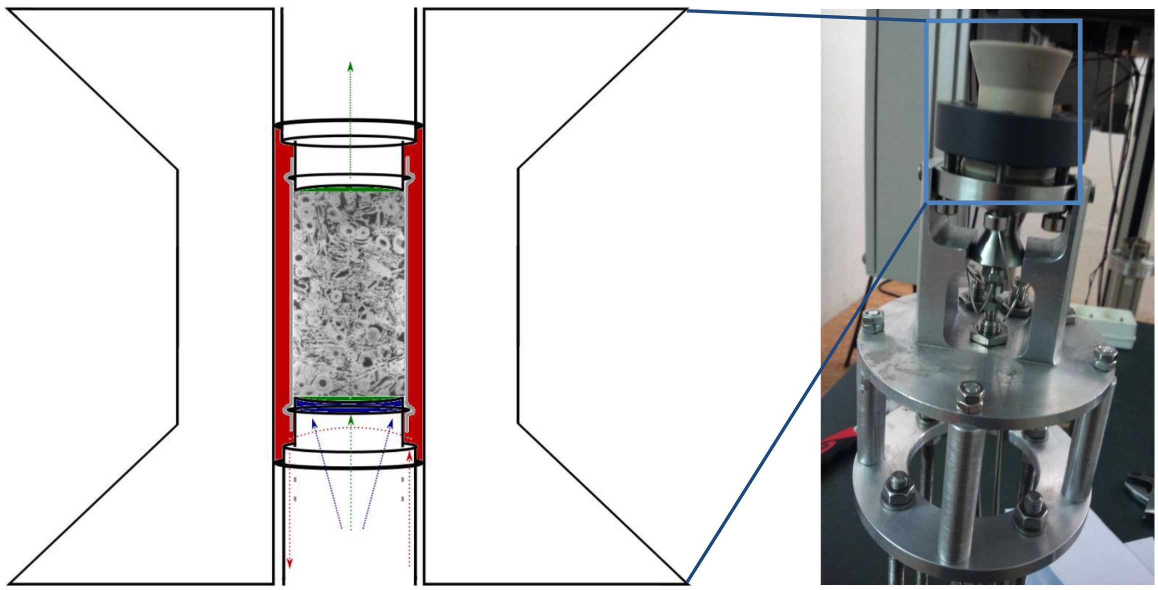

Figure 4: Schematic representation of the experimental set-up in which a Savonnières limestone sample is subjected to a radial pressure (red), multi-phase fluid flow through the sample (green) and an axial pressure is transfered to a mobile piston below the sample (blue). The rock sample is contained in a sleeve and the entire set-up is surrounded by PEEK material.

To incorporate the effect of the fractures on fluid distributions within samples subjected to multi-phase fluid flow, experiments are currently being carried out using an in-situ triaxial flow cell as shown in figure 4. Because of the time-rate related to the propagation of the fractures, scans are performed at the Environmental X-ray CT (EMCT) at the UGCT. This gantry-based system allows CT scans to be made at a time resolution of 12 seconds (Dierick et al., 2014).

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