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Understanding the Mechanical Behavior of Drilling-induced Tensile Fractures through Photoelasticity Lab Tests Conducted on Glass Cubes

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Summary

Photoelasticity tests were carried out on clear glass blocks containing borehole aligned with and at an angle to the applied uniaxial compression in order to visualize the growth of drilling induced tensile fractures. Samples utilized in this study were all illuminated, as such the birefringence, which indicates areas of stress difference, could be detected and video recorded during the whole process. Two types of borehole wall fractures were revealed after cracking, one is the axial drilling induced fracture occurred on a vertical hole, and the other one is the *en echelon* fractures observed from the borehole deviated at 45° to the direction of the compression. In addition, bottom hole fractures were also initiated showing some patterns for 45° inclined holes. These preliminary and currently qualitative results indicate that glass blocks serve as a useful test medium for studies of stress concentration and drilling induced fracture creation under compression.

Introduction

Tensile failure occurs when the effective tensile stress exceeds the tensile strength (T_0) of the rock sample, which is often considered to be nearly zero (Ong, 1994; Fjaer *et al.*, 2008). The relative orientation of the borehole axis with respect to *in-situ* principal stresses plays an important role. If the borehole axis is aligned with one of the *in-situ* principal stresses, drilling-induced tensile fracures (DITFs) tend to grow axially (Fig. 1a); otherwise, *en echelon* tensile fractures (Fig. 1b) will occur (Aadnoy and Bell, 1998; Schmitt *et al.*, 2012; Zoback, 2007). However, since fracture propagation is sensitive to numerous factors, theoretical models always have more or less limitations making them less practical, as such, laboratory simulations become necessary.

Photoelasticity tests allow for direct visualization of the stress state and the growth of fractures inside specimens. This and similar techniques had been utilized in several studies (Galle, 1959; Galle and Wilhoit, 1962; Ito *et al.*, 2004). The objective of this study is to simulate the initiations and propagations of drilling-induced tensile fractures on the borehole wall in the actual fields through conducting photoelasticity tests on various clear glass cubes. First, an overview of our laboratory measurement technique is introduced. Then the preliminary observations from three test samples representing different borehole geometries are summarized qualitatively.

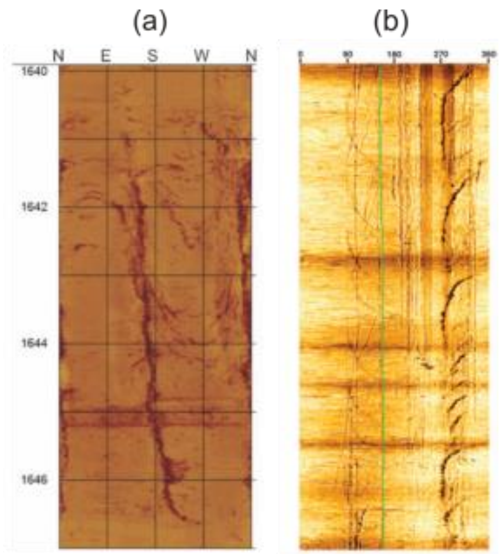

Fig. 1 – a) Ultrasonic borehole televiewer data from the Hunt well, N. Alberta (Chan, 2013) displaying axial DITF. b) *En-echelon* DITFs from formation microscanner data after Figure 8 of Barton and Moos (2010) used with permission under the AAPG fair use policy.

Theory and/or Method

Glass is similar to non-porous rocks in terms of the mechanical behavior. 'Boreholes' with a 0.7 cm radius are drilled into blocks with identical sizes of 7.8cm×5cm×5cm either parallel to the glass face (Sample #1) or deviated (Sample #2 and #3). Each pair of opposing faces of the glass cubes was designed to be parallel so that the external forces could be applied uniformly. Moreover, the diameter of the hole should be large enough in order to see its disturbance on stress distributions, but it also should be small enough compare to the size of the glass; otherwise, boundary effects could influence lab results (Galle and Wilhoit, 1962).

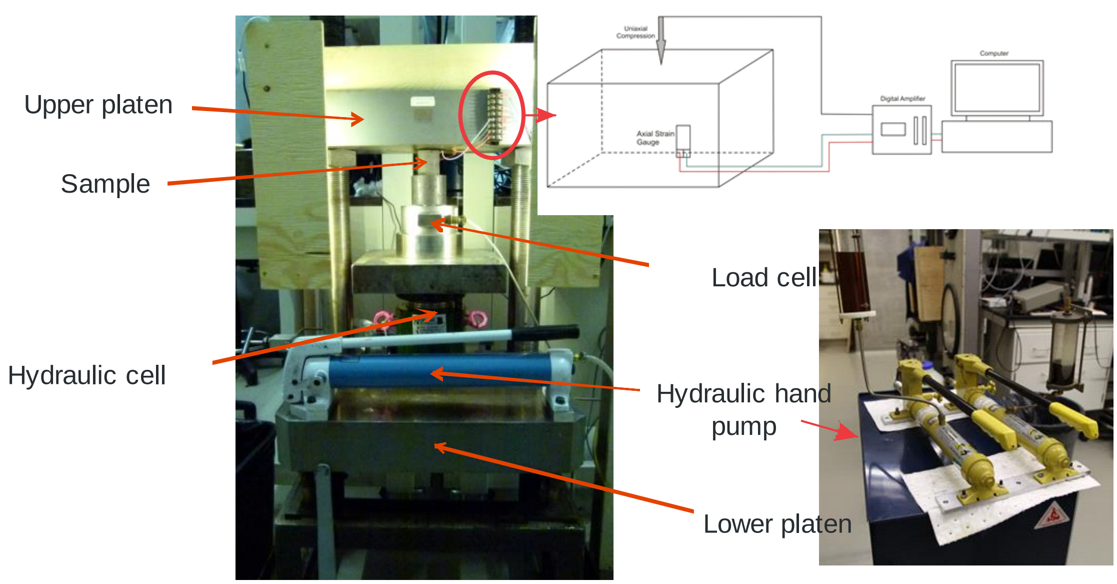

Figure 2 – The experimental setup.

After sample preparations, each block was placed centered on a load cell as illustrated in Fig. 2. The load was applied continuously through the two hand pumps. The specimen was illuminated by the monitor placed behind the sample, and the camera lens located in front of the specimen was covered by a circular polarizer filter. During the experiment, the polarized light is captured by the camera to reveal the birefringence, which shows areas of stress difference in the glass (Hawkes, 1968). Therefore, the manner in which the borehole vicinity and fractures alter the stress pattern can also be observed during the tests. All those birefringence colors constitute 'stress contour lines', and the closer the contour lines are, the greater the stress concentration will be.

Examples

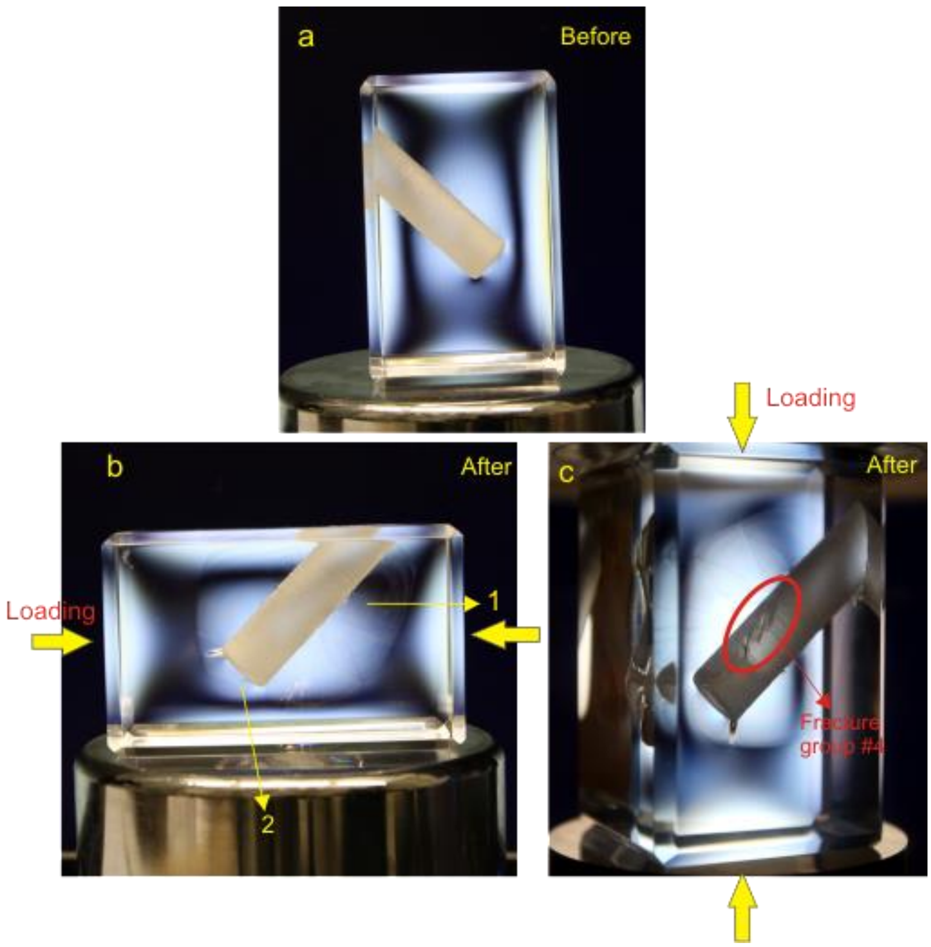

Figure 3 – Sample #2 and its fractures before and after the test.

In this abstract, we only present one specimen (Sample #2), which was drilled with a deviated hole. As shown in Fig. 3a, the hole was not penetrated all the way through the block allowing bottom hole stress and fractures to be observed. The uniaxial load direction is illustrated in Fig. 3b. After this test, three different fractures were created. Note all those fractures penetrated into the 'formation'.

- Fracture #1 (Fig. 3b), which grew twistedly on the 'wall', was the first fracture initiated, and then it propagated until it reached the bottom of the hole forming Fracture #2.
- Bottom hole fractures #2 and #3 (Fig. 4) were first grown in the direction parallel to the borehole axis forming petal fractures, and then Fracture #2 changed its direction to be normal

to the minimum principal stress becoming a centerline fracture (Davatzes and Hickman, 2010; Li and Schmitt, 1997).

- Lastly, three *en echelon* tensile fractures (highlighted in red circle in Fig. 3c) were simultaneously generated, and were eventually linked up together.

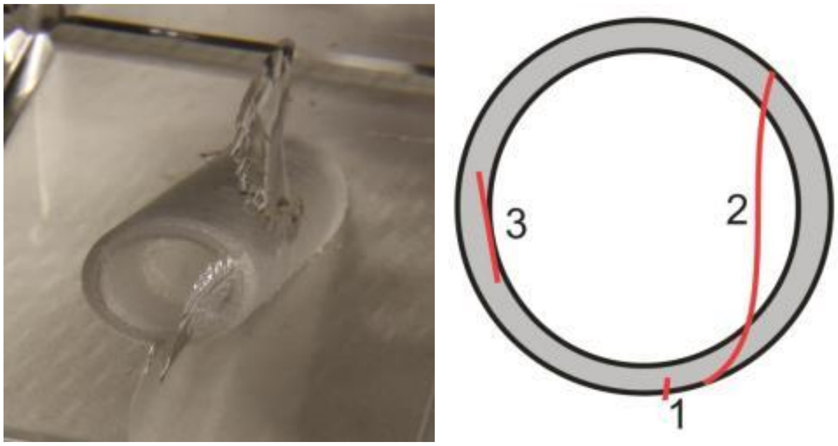

Figure 4 – A closer view of bottom hole fractures for Sample #2.

Conclusions

Photoelasticity experiments were carried out on various glass cubes with holes drilled in different directions. These tests enable us to examine the failure mechanism of tensile fractures. The specimens were subject to continuously increasing uniaxial compression until desired tensile fractures were created. The results of one preliminary test are given in here. Results show both borehole wall fractures and also bottom hole fractures. For wall fractures, three *en echelon* tensile fractures were occurred and they are linked up. However, another sample which is not introduced in this abstract containing a hole drilled parallel to its edge shows axial tensile fractures. This confirms that if one of the principal stresses is aligned with the hole trajectory, axial DITFs can initiate; otherwise, *en echelon* tensile fractures will occur. Regarding to bottom hole tensile fractures, strikes of them are in multiple directions due to the absence of confining pressure. Moreover, they tend to propagate in the direction of hole axis first, and then reorient to be perpendicular to the minimum principal stress.

This study concentrated on the experimental method in order to simulate the behavior of tensile fracture in the real case. There are still some limitations and drawbacks for the experiments. Therefore, for future study, more sophisticated experimental setups are necessary particularly ones in which at least one lateral stress can be applied. An anisotropic material can be utilized to study the effect of anisotropy but such materials are hard to find. Moreover, numerical models can be developed comparing with the lab measurements which can further offer us a more comprehensive view.

Acknowledgements

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