Acoustic Emissions of Hydraulic Fracturing Laboratory Experiment on Montney Shale

Suzie Jia[a], Ron Wong[a], and David Eaton[b]

[a] *Department of Civil Engineering, University of Calgary, Email: qing.jia@ucalgary.ca*

[b] *Department of Geoscience, University of Calgary*

Summary

A laboratory hydraulic fracture experiment conducted on a Montney shale specimen under the conventional triaxial compressional stress condition is present in this paper. Acoustic emissions were recorded on 7 channels throughout the duration of the test to investigate the hydraulic fracture propagation processes. Distilled water was injected at an average rate of 2.5 mL/Min until the sample was failed completely. A hydraulic fracture was formed perpendicular to the external minimum principal stress. Results of the acoustic emission analysis show that numerous event hypocenters are concentrated along the hydraulic fracture plane in the middle of the specimen. Due to the nature of tensile fractures and the Montney shale lithology, the hypocenter location process becomes very challenging comparing to that in granitic materials. A burst of AE energy was released when the injection pressure was changed abruptly and at the peak.

Introduction

Hydraulic fracturing has been widely recognized as the most popular and efficient method in the development of unconventional oil and gas reservoirs. Microseismic monitoring is of great importance for imaging the spatial and temporal changes of fracture network. These two techniques have been used extensively in extracting shale gas from ultra-low permeable shale reservoirs, which usually exhibit transversely isotropic characteristics and complex shale/fluid interaction mechanisms (Lal, 1999) adding complications to the fracture propagation processes. However, current simulation models usually simplify the shale behaviors, which makes it necessary to understand the real shale responses in hydraulic fracturing.

This study aims to simulate the hydraulic fracturing process in a shale material under a controlled laboratory setting while monitoring the crack nucleation and propagation processes using the acoustic emission (AE) monitoring technique. Acoustic emissions are considered to be a proxy of induced microseismicity in a higher frequency (Mogi, 1967), which can provide a further insight on the failure process of hydraulic fractures. Laboratory setup and procedure are introduced in the first section, and then the results are presented including fracture geometry, AE hypocenters and temporal changes.

Experimental Setups

This hydraulic fracturing test was conducted on a Montney sample provided by Seven Generations Ltd. cored from a vertical well located in the Kakwa area at a depth of 3141.36 m. The sample was prepared with 125.8 mm in length and 50.29 mm in diameter, which can be fitted into the triaxial geophysical imaging cell (GIC: A ErgoTech Ltd.) for the triaxial compressional test. Once the sample was polished into an ideal shape, a borehole with a dimension of 6.35 mm diameter and 75 mm in length was drilled along the axial axis using a carbide tipped masonry drill bit (Fig. 1). The bottom of the borehole was sealed by a Design 4 packer, and distilled water was injected by two QuiziX servo-hydraulic pumps with a total average injection rate of 2.5 mL/min but varied with time. A similar experimental setup can be found in Goodfellow et al. (2016).

Seven single-component piezoelectric transducers monitor the AE signals in the normal direction during the entire test procedure. Four of them were mounted in the top loading platen, two of them were located at the bottom platen and the rest one was mounted on the side (Fig. 1). The AE sensors have a calibrated frequency range of 200 kHz to 1 MHz. AE signals were amplified and sampled at a frequency rate of 10 MHz. Once the triggering threshold was met, the AE waveforms were extracted and a length of 1024 sample points was saved for each sensor channel.

The experiment was conducted under a stress condition at $\sigma_1 = 20$ MPa and $\sigma_3 = 10$ MPa, where σ_1 was applied as the confining pressure and σ_3 was applied along the borehole axis (Fig.1). The triaxial system was first loaded gradually to a hydrostatic pressure of 10 MPa under load control. Then the confining pressure started to increase until 20 MPa was reached. Once the desired stress state was achieved and the system was stabilized, the fluid began to be injected. Injection stopped after the sample failed, and the pumping rate is shown in Fig. 2 (c), which varies as a function of time.

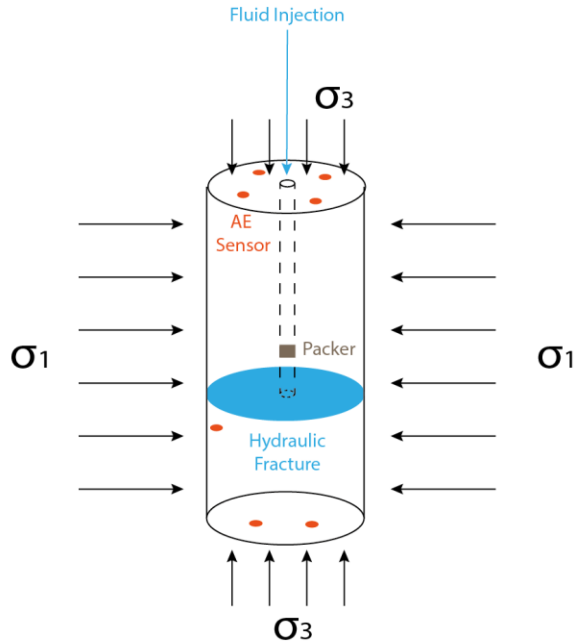

Figure 1. Experimental setup for the hydraulic fracturing test.

Results

The pumping and mechanical data are presented in Fig. 2. The injection pressure started to increase rapidly at approximately 1050 seconds until it reached 17 MPa. To maintain the external stress condition, the sample began to deform as shown by the increase of the axial deformation at around 1250 seconds, and correspondingly, the increasing rate of the injection pressure slowed down. The injection pressure reached a peak plateau of 22 MPa accompanied with a decrease in the rate of deformation implying that the hydraulic fractures had formed completely, and fluid began to leak into the rock surroundings. At around 2000 seconds, the injection was stopped following with the injection pressure and axial deformation decrease (Fig. 2b). The sample images and hydraulic fracture geometry are shown in Fig. 3 (left). A hydraulic fracture formed perpendicular to the minimum principal stress, σ_3.

For acoustic emission results, around 600 events were triggered, but only 38 events were located due to the quality of the signals (Fig. 3 right), and they are located in the middle and the upper end of the specimen. Majority of the events that are positioned at the upper surface exhibits low magnitude. Their locations cannot be explained by the hydraulic fracturing process, so these events could be generated by the pump noise or there could be location errors as seven sensors are not enough to provide sufficient accuracy for those low-energy events. Especially since only one sensor was mounted on the side of the sample, the vertical distance cannot be estimated very precisely.

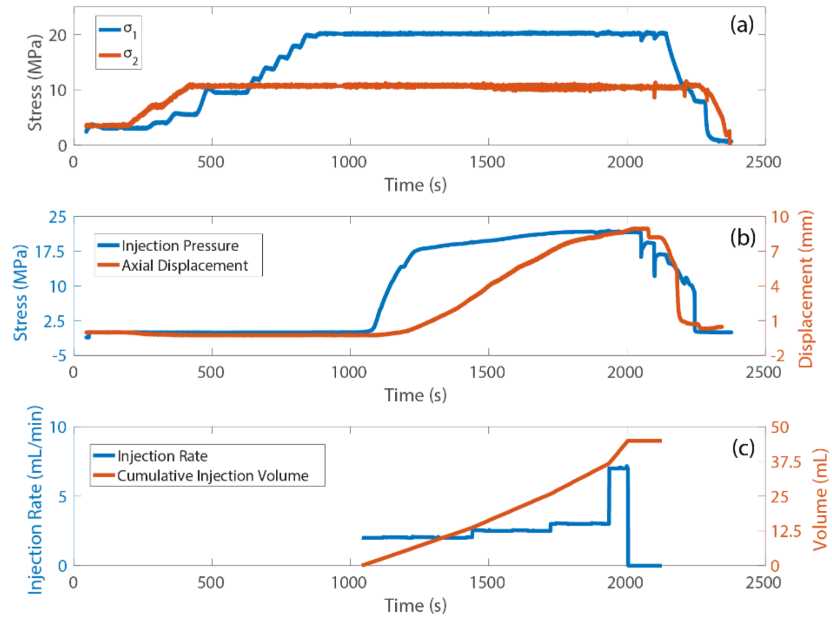

Figure 2. Experimental data plotted as a function of time (all in the same time scale). (a) σ_1 and σ_3 (b) Injection pressure and axial displacement. (c) Injection rate and cumulative injection volume change with time.

Figure 4 shows the cumulative triggered AE event number plotted as a function of time. The AE events began to occur at around 300 seconds indicating the initial crack generations/closure due to the application of the external stresses, and the number of AEs keeps increasing as σ_1 increases. After the external stress condition was stabilized, there was a burst of AE events occurred at around 1200 seconds as a result of the increasing injection pressure. Then, the AE events were less active when the injection pressure reached the plateau. Over a hundred of events were triggered when the injection pressure reached the peak, and more events occurred at the end of the experiment.

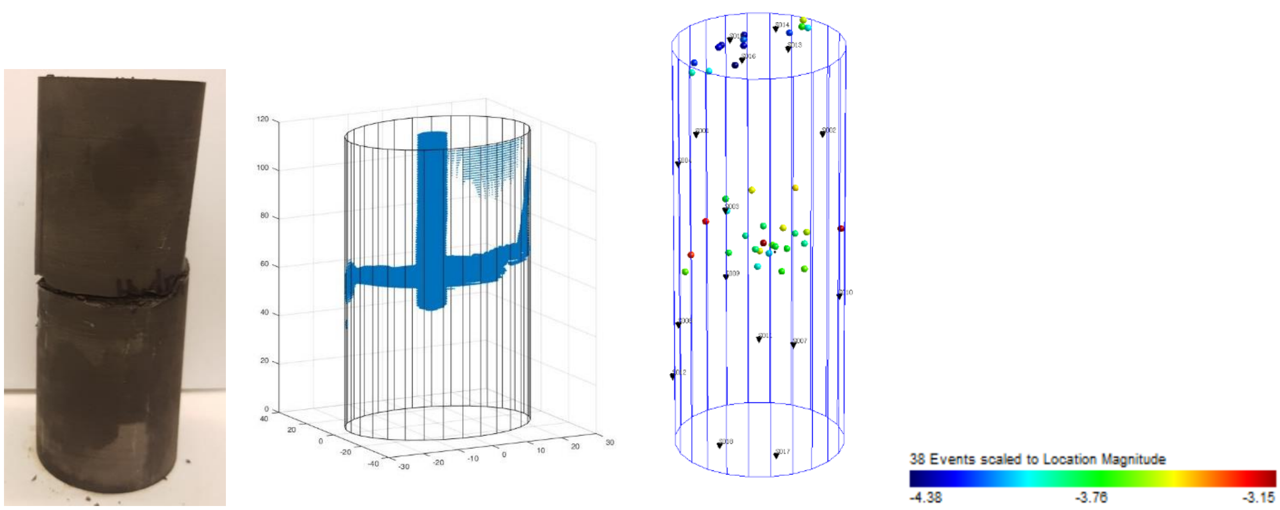

Figure 3. Sample images after the test (left). Processed CT scan using MATLAB shows the hydraulic fracture geometry (middle). AE hypocenters colored by their location magnitudes (right).

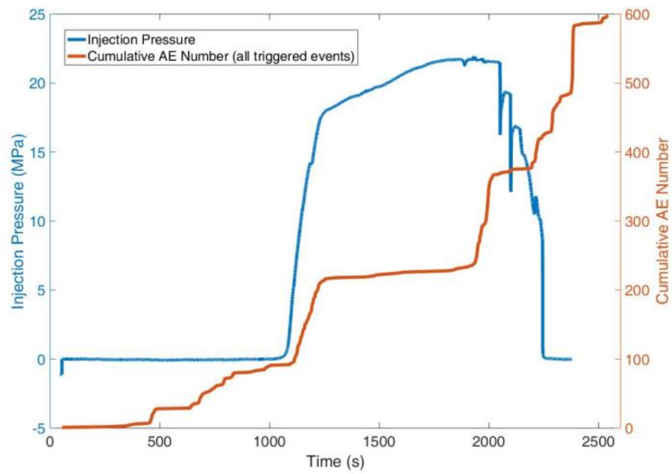

Figure 4. Accumulated AE event number plotted as a function of time (including all triggered events).

Summary

In this paper, we presented the preliminary results of the hydraulic fracturing test on a Montney shale specimen while acoustic emission signal was monitored at the same time. Results show that the AE waveforms obtained from this test have poor signal-to-noise ratios indicating that the hydraulic fracture propagation tends to be an aseismic process. Around 600 events were triggered, but only 38 events can be located. Numerous event hypocenters are concentrated along the central hydraulic fracture plane, and the triggered AE events increased abruptly with an increase of injection pressure and at the peak injection stress.

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