Geomechanical Strength of a Porous Carbonate Saturated with a Highly Viscous Fluid: Implications for Production from the Grosmont Formation

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Summary

We measured the compressive and tensile strengths of carbonate core samples from the Grosmont formation and of a series of Indiana limestone samples. Indiana limestone was tested dry and saturated with parrafin wax to mimick a nearly solid bitumen. The paraffin wax was chosen for its viscous and immobile nature at room temperature being similar to bitumen at the approximately 12°C reservoir temperature in the Grosmont formation. Compressive failure tests were carried out to confining pressures of 30 MPa, a range over which the failure mode evolves from brittle to plastic. Wax saturation does not affect the peak strength but does influence the quasi-static elastic moduli. Due to a limited number of core samples available, only Brazilian tensile strength tests were performed on the Grosmont formation specimens. The tensile strength can be used to update earlier constraints on the stress magnitudes from the unexpected existence of drilling induced tensile fractures in the reservoir.

Introduction

The Grosmont formation is an important carbonate-hosted bitumen reservoir for future energy production in Alberta. The AER [*Alberta Energy Regulator*, 2015] estimates that over 405 billion barrels of crude bitumen is recoverable. The bitumen is highly viscous (~10^6 cP) at the natural in situ conditions with temperatures ~15°C. As such, in-situ production techniques such as steam assisted gravity drainage (SAGD) as employed in the overlying oil sands must be used. There have been a few pilot projects coordinated by the Alberta Oil Sands Technology and Research Authority that pioneered Grosmont bitumen production tests in the 1980's. These efforts were renewed in the last decade with recent tests of the SAGD application described by *Yang et al (2014)*. Although there has been extensive research into the geomechanics of steam injection in the oil sands, we are not aware of any related work in bitumen saturated carbonates. Here we describe some laboratory measurements to better understand failure processes in these rocks particularly.

There are a number of motivations for this work. First, having a better understanding of the behavior of these rocks under varying states of stress leads to risk reduction with regards to inadvertent release of hydrocarbons through borehole failure or flow through fractures. Knowledge of the geomechanics and stress state also allows for the optimization of borehole trajectories and production strategies. The expected strengths of the rock, particularly given the large thermal stresses and pore pressure variations that are anticipated in a SAGD development, are an important component in a geomechanical evaluation.

There are some significant challenges associated with carrying out a laboratory based strength testing. The paucity of actual core from the formation that is available for destructive testing is one limitation. This issue is particularly severe if the reservoir of interest is highly heterogeneous as is the karsted Grosmont Formation. This makes obtaining representative samples for repeatable measurements problematic. One approach to overcoming the lack of actual material is to instead use more readily obtainable proxy materials in testing, while not ideal one can still obtain some insight into the factors that might be important in the failure of such rocks. Here, we chose to carry out an extensive testing program on a suite of samples cut from blocks of Indiana limestone. While not an ideal analog, this limestone does share some similarities in pore structure to the Grosmont rocks under study in our laboratory. Here, we describe a series of compressive and tensile failure tests on cylinders of Indiana limestone both under dry and wax-saturated conditions. The testing program included measurements of i) unconfined compressive strength (UCS), ii) the compressive strength under 'triaxial' loading (to obtain a Mohr-Coulomb frictional failure curve), and iii) Brazilian tensile failure tests.

Theory and/or Method

Cylindrical samples, with a length and diameter of approximately 72 cm and 36 cm respectively, were cored from large blocks of Indiana limestone supplied from a commercial provider. The limestone is primarily composed of calcite and contains a vuggy porosity of ~15.7%. The cylinders were end-ground to be parallel to better than 25μm for proper compression testing according to ASTM standard [*ASTM D4543*, 2008]. Discs were cut from some of these cylinders to allow for tensile Brazilian testing. To saturate Indiana limestone samples with paraffin wax, a prepared sample was placed on top of a solid wax block which then went into an oven under vacuum at approximately 90 °C, for 24 hours. This resulted in saturation values of >85%. A limited number of Brazilian test discs were also cut from cleaned Grosmont Formation cores that had been used for ultrasonic wave speed measurements [Ong et al, 2017, Rabbani et al, 2017]. Strain gauges were mounted to the cylindrical specimens in the axial and radial directions to allow the progressive deformation of the sample to be recorded during the tests.

The compressional strength tests are performed using a hydraulic cell mounted on a load frame (Fig. 1). The cylindrical core specimens are placed in the load frame on a spherically seated platen. The hydraulic cell pressure is increased compressing the sample against the top platen until complete failure occurs. For the UCS tests, an axial stress only is applied such that the principal stresses acting on the sample are σ_1 = axial stress and $\sigma_2 = \sigma_3 = 0$.

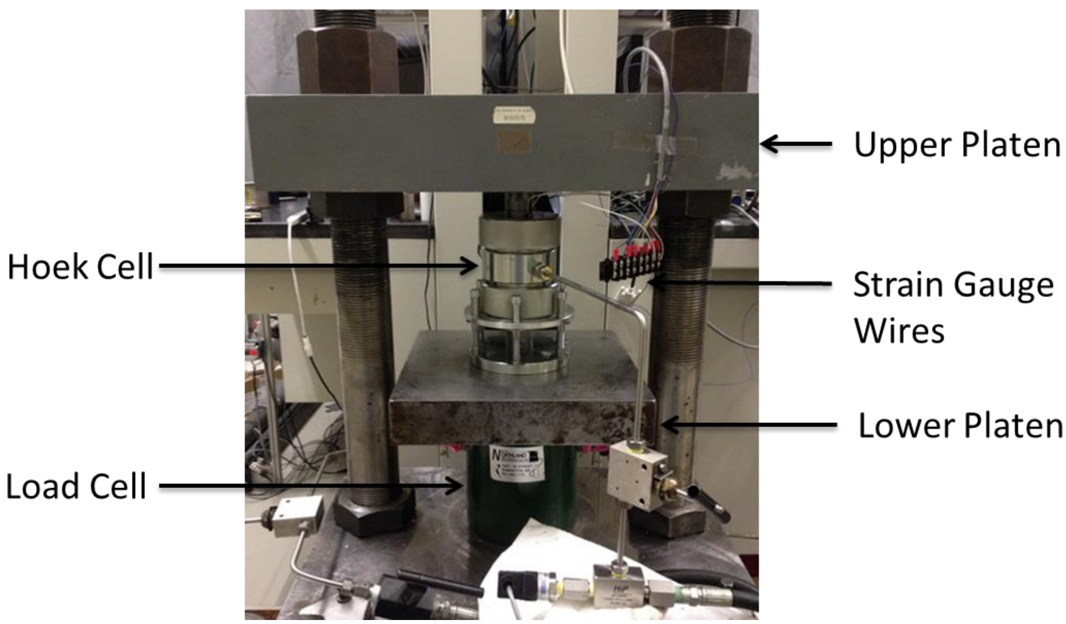

Figure 1: Image of triaxial strength test laboratory set-up. The specimen resides inside the chamber of the Hoek cell.

The triaxial tests are similar to the UCS tests except that the sample is placed within a Hoek Cell which allows a biaxial stress $\sigma_2 = \sigma_3$ to be applied by a confining pressure. Confining pressures from 1 MPa to 20 MPa were used. During this test, the confining pressure was maintained constant while the axial stress σ_1 was slowly increased until the sample completely failed.

The Brazilian tensile test is an indirect method of testing the tensile strength of the rock. The apparatus used for the Brazilian test is similar to that of the UCS test but the specimens are cut into discs and placed so that a compressional load is applied at two opposing points on the circumference of the disc (Fig 2). By applying stress in this way tension is created through the middle of the disc and ultimately results in failure by tension. The Brazilian strength test is commonly used to determine the tensile strength of rocks and other materials due to its simplicity and repeatability. The sample preparation and execution of the test itself for direct methods can be very difficult and time consuming [*Perras and Diederichs*, 2014].

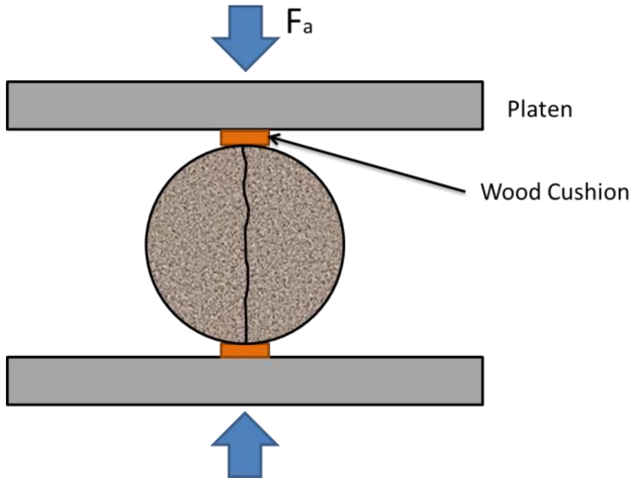

Figure 2: Schematic of Brazilian tensile strength tests (modified from [*Perras and Diederichs*, 2014]). F_a denotes the force applied and the typical failure plane through the sample is drawn.

Results

To date, a total of 40 successful compressive strength tests have been performed on Indiana limestone samples. Half of all Indiana limestone samples tested were saturated with paraffin wax. An additional 20 Brazilian tensile strength tests have been completed. The peak axial stress (σ_1) at which failure occurred in the compressive tests (Fig. 3) shows the compressive strength increasing from ~45 MPa to nearly 110 MPa with confining pressure as is expected.

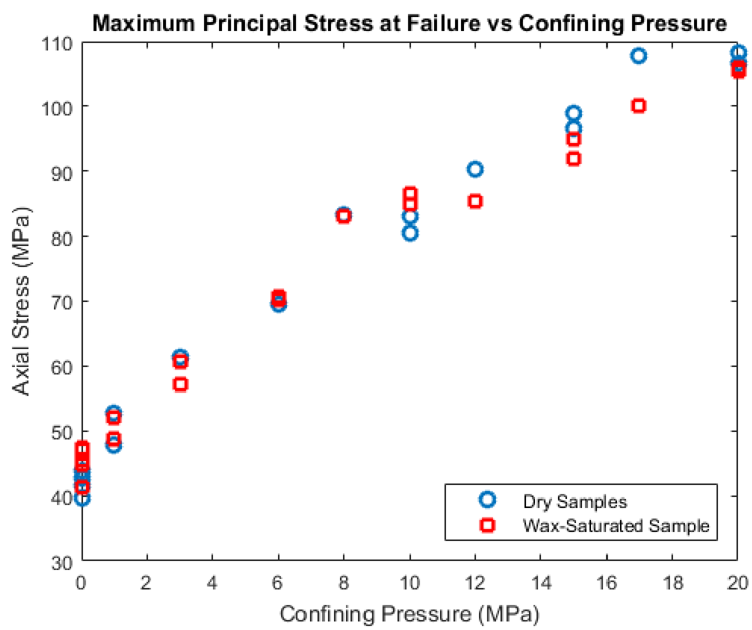

Figure 3: Peak compressive strength of Indiana limestone core samples.

There does not appear to be an obvious difference between the dry and the wax-saturated strengths of Indiana limestone. The wax saturated samples do appear to consistently fail at a lower differential stress but this difference is relatively small and therefore cannot be interpreted as meaningful. Unexpectedly, however, the wax-saturated samples appear slightly more compressible (i.e. lower Young's modulus as determined from the ratio of the applied stress to the axial strain) than the dry samples. The Brazilian tensile testing data from Indiana limestone samples show the wax-saturated Indiana limestone samples having a higher average tensile strength than the dry samples.

Conclusions

An analog to the Grosmont formation was tested for compressive and tensile mechanical properties. Half of the samples were saturated with paraffin wax to simulate bitumen in the reservoir. When comparing the compressive strength results of wax-saturated and dry samples, the peak strength was similar, but the stress-strain relationship appears to differ. The average tensile strength was also higher for the wax-saturated samples. One indication follows that, although static tests are criticized for not replicating reservoir conditions, the peak strength of the sample may not vary greatly in cases where a viscous, almost immobile fluid like bitumen is occupying the pore space.

Brazilian tensile tests will be completed in the near future on prepared Grosmont formation samples. The tensile strength results will be used to upgrade constraints on reservoir stress magnitudes interpreted from the presence of drilling induced tensile fractures in the image logs. Higher confining pressures in triaxial testing of Indiana limestone will also be pursued. Further analysis of the elastic properties and various strength criterion will be applied to the Indiana limestone data.

Acknowledgements

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References

Alberta Energy Regulator (2015), ST98-2015: Alberta's Energy Reserves 2014 and Supply/Demand Outlook 2015-2024, , 299.

ASTM D4543 (2008), Standard Practices for Preparing Rock Core as Cylindrical Test Specimens and verifying Conformance to Dimensional and Shape Tolerances, *Astm*, (D4543-8), 1–9, doi:10.1520/D4543-08.

Ong, O.N., D.R. Schmitt, R. Kofman, J. Nycz, and K. Gray (2017), Experimental study of a heavy oil carbonate under thermal recovery conditions: A case from the Grosmont Formation, *Geoconvention 2017 Abstract (submitted)*

Perras, M. A., and M. S. Diederichs (2014), A Review of the Tensile Strength of Rock: Concepts and Testing, *Geotech. Geol. Eng.*, *32*(2), 525–546, doi:10.1007/s10706-014-9732-0.

Rabbani, A., D.R. Schmitt, J. Nycz, and K. Gray (2017), Pressure and temperature dependance of accoustic wave speeds in bitumen saturated carbonates: Implications for seismic monitoring of the Grosmont Formation: *Geophysics (submitted)*

Yang, D., M. H. Mohebati, S. Brand, and C. Bennett (2014), Thermal recovery of bitumen from the grosmont carbonate formation - Part 1: The Saleski Pilot, *J. Can. Pet. Technol.*, *53*(4), 200–211, doi:10.2118/171561-PA.