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Applications of Rock Scratching Tests in Borehole Instability

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ABSTRACT: The mechanical properties of rocks are essential for analysis of different problems during oil and gas drilling and production and future development. These properties are required for borehole stability, sand production, and select optimum flow rate during the completion stage and many other problems related with the short and long term mechanical stability of the well and the reservoir. The correct predictions may help in saving millions of dollars in drilling and completions costs, and may allow preventing long term and costly consequences. A common problem in oil and gas industry is the unavailability of the real core samples. To overcome this problem the engineers struggle to develop alternative sources of data via correlations, log measurements, etc. In this study, a simple scratching cell was developed and data produced was used to develop a correlation for predicting the unconfined compressive strength (UCS) for Saudi Arabian rocks.

The output of this paper is a great addition to the rock mechanics and petroleum engineering disciplines especially in Borehole instability problems during drilling of oil and gas wells.

INTRODUCTION

Most of the oil and gas reserves are located in sedimentary basins. Rock and fluid properties as well as pressure and temperature must be evaluated for effective exploitation of these valuable hydrocarbon reserves. Fluid properties to be evaluated are density, viscosity, compressibility, composition, etc. Rock properties include petrophysical properties (porosity, permeability, lithology saturation and density etc.) and rock mechanical properties (compressive strength, elastic properties, frictional properties, etc.).

Rock mechanical properties are needed for maintaining borehole stability during oil and gas wells drilling and completion stage. The mechanical properties of rocks are of high importance for oil and gas wells drilling, production, and future development. Additionally, these properties are needed to select the optimum production rate especially in soft formations to avoid sand production problem. Normally, rock mechanical properties are evaluated in a laboratory using an adequate number of preserved cores.

Numerous brands of testing equipment are employed in these estimations including: stiff compression/tension machine, servo-controlled confining pressure pump, triaxial cell, data acquisition system, etc. These expensive and high technology laboratories are not available everywhere worldwide. Real core samples for use in research and development studies are limited by the oil and gas companies either due to difficulties in coring and preserving or due to the limited availability of core samples after some have been reserved for use in future problem solving.

The current study aims to develop an economical and fast test to evaluate rock strength using a limited number of full cores or core fragments. The test is called rock scratching and is mainly dependent on a new locally developed scratching cell.

EVALUATION OF ROCK MECHANICAL PROPERTIES

In addition to evaluating rock mechanical properties through extensive testing using conventional rock mechanics laboratory equipment, there are several methods that can be used to estimate rock strength available nowadays such as correlations, indentation, calibrated logging tools, scratching, etc. The most important techniques are correlations and rock scratching.

The rock scratching test can solve some of the problems related to laboratory measurements on field cores. It is a fast, low cost and accurate test, requires significantly less rock material than ordinary laboratory testing for rock characterization, and represents a direct measurement of rock mechanical parameters. Laboratory scratch measurements on field cores have the potential of increasing the amount of rock mechanical data from cores, since the test technique is continuous.

The University of Minnesota [1] and SINTEF Petroleum Research [2] have worked for several years on the development of a rock strength device (RSD) and a scratch test method to determine the uniaxial compressive strength (UCS) and the Young's elastic modulus (E) of rocks. Because of the robust correlations obtained between the scratch measurements and material strength and stiffness, this test method seems to have a huge potential.

This study is divided into two parts. Firstly developing a new cell for rock scratching testing, and secondly developing a universal correlation between various rock mechanical properties. In this paper rock scratching testing will be presented while the universal rock correlations will be presented in a future publication.

EXPERIMENTAL WORK

A variety of very expensive and sophisticated rock scratching equipment is available in a few rock mechanical laboratories and research centres worldwide. These apparatuses cannot be easily integrated with the available rock mechanical laboratories and additionally are expensive, sensitive, and need well trained technicians to run. The most advanced rock scratching apparatuses (see Figures 1 and 2) were developed at the University of Minnesota [1], SINTEF [2], and Terra Tek Inc. [3]. Figure 3 represents a typical output of a rock scratching test. This study attempts to develop a simple, cheap, and easy to handle scratching cell that can be part of any existing compression machine.

The cell developed in this study is made at College of Engineering workshop, King Saud University Riyadh, Saudi Arabia. The body of the cell is made from a hard stainless steel material which can withstand higher applied loads from the compression machine to the rock sample inside the cell. The inner diameter of the cell is 2 ½ inches. Three adjustable scratchers are fixed at an angle of 120^o to ensure average scratching of the rock sample. Scratch resistance load and scratching linear movement are recorded by the compression machine.

The rock sample and the inner body of the scratching cell are movable parts while the inner cell body supports the rock sample during scratching test. The outer body of the cell remains fixed during the entire test to prevent the rock sample from backward and forward motion due to the applied load. This arrangement allows for smooth scratching without damaging the rock sample, and the scratching test can be repeated many times for the same sample.

The main advantages of the developed cell are its low manufacturing cost and the ability to use it as a part of any rock compression machine without the need of additional accessories. Additionally, it does not require a huge sample and can accommodate even a thin disc of rock. Rock fragments can also be scratched to find unconfined compressive strength by fixing them using resins in a suitable mold. Figure 4 shows (a) a schematic diagram of the new developed rock scratching cell, and (b) the actual setup of the scratching test.

A typical scratching test using the developed cell can be easily performed by applying the following steps:

1) A rock sample (disk, L/D<1) is placed above the three scratchers inside the cell.
2) The upper steel platen is then placed above the rock sample.
3) The assembly is placed in the compression machine.
4) A controlled compression load is applied on the cell as shown in Figure 4-b.
5) The scratching resistance load and scratchers linear movement were recorded continuously using a linear variable differential transducer (LVDT); and the compression machine pressure transducer.

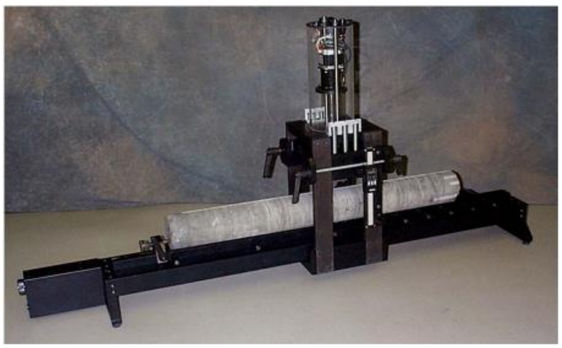

Figure 1: Scratching Cell Developed at the University of Minnesota [1].

Figure 5 shows sample 1 before and after multiple scratching tests. It is clear that this test is a non-destructive one, i.e. the sample can be used in further tests such as porosity and permeability measurements, etc.

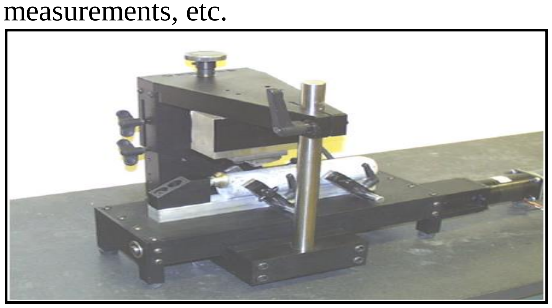

Figure 2: Scratching Cell Developed by Terra Tek Inc. [3].

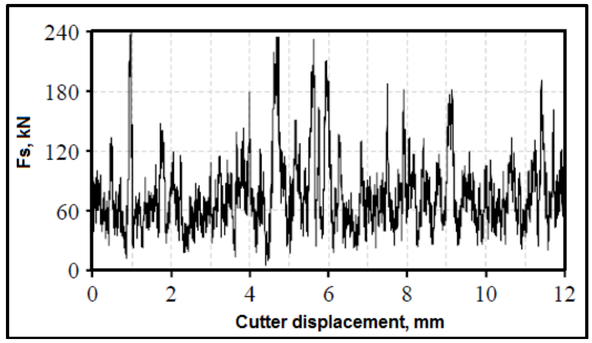

Figure 3: A Typical Scratching Test Output [4].

RESULTS AND DISCUSSIONS

As a start for evaluating the validity of this newly developed scratching cell, scratch measurements on two different rock samples were made. For each sample, at least three scratching runs were made using new unscratched surfaces each time.

The final result was obtained by taking average scratching resistance values throughout the length of the sample. Table 1 represents the petrophysical properties of the tested rock samples as well as the calculated unconfined compressive strength and scratching resistance force.

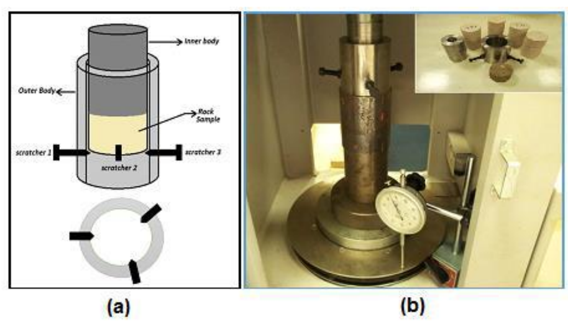

Figure 4: (a) A Schematic Diagram of the Developed Scratching Cell. b) Laboratory Setup of the Scratching Test.

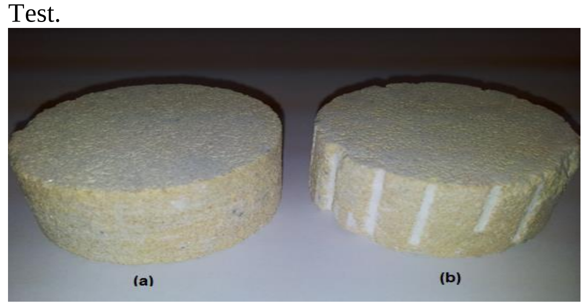

Figure 5: Rock Sample before (a) and after (b) Scratching Tests.

Figures 6 and 7 show the continuous recorded scratching resistance for samples 1 and 2 respectively. By comparing Figures 3, 6 and 7, it is clear that the newly developed rock scratching cell was yielding a technically valid output.

The average scratching resistance for rock samples 2 and 3 as well as the unconfined compressive strength are shown in Table 1. If the two measurements are repeated for several types of rocks worldwide, a universal correlation can be developed as shown in Figure 8. The universal correlation is then used along with the scratching resistance value for any rock fragment to predict the unconfined compressive strength if full and sufficient cores are unavailable.

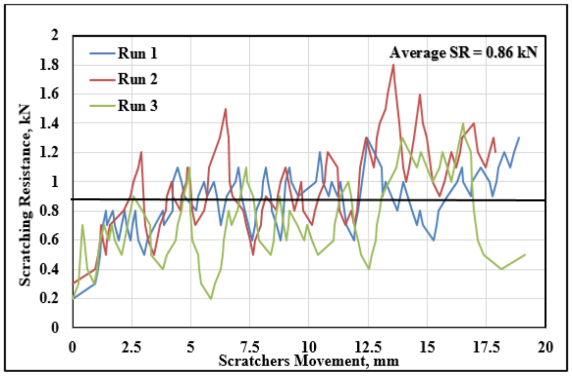

Figure 6: Scratching Tests Results for Rock Type 1

Table 2: Unconfined compressive strength data of sample 1

Rock Type 1			
Load, kN	**Area,mm^2**	**L/D**	**UCS, MPa**
49.50	**2.03x10^{-3}**	**2.25**	**24.40**
66.50	**2.03x10^{-3}**	**2.00**	**32.74**
Average UCS			**28.57**

It is clear from the experimental work performed on the developed scratching cell that the sample can be scratched more than one time to get an average scratching resistance value. As seen in Figures 3.6 and 3.7, in the first 2 millimetres, the scratching area of the core cone is small, therefore the resistance to scratching is also small. After few millimetres, when the cone half surface area starts to scratch the rock, the scratching resistance increases and fluctuate in the same region depending on the homogeneity of the rock.

Table 1: Petrophysical Properties of the Tested Rock Samples

Property	Rock 1	Rock 2
Type of rock	Carbonate	Sandstone
Porosity	18%	22%
Permeability	126md	224md
Scratching Resistance (SR)	Diameter (D)=2.0" Thickness (t)= 2.0”	Diameter (D)=2.0" Thickness (t)= 1.4"
	SR= 0.86 kN	SR= 0.55 kN
Unconfined Compressive Strength (UCS)	Diameter (D)=2.0" Length (L)= 4.5"	Diameter (D)=2.0" Length (L)= 4.2"
	UCS= 28.57 MPa	UCS= 25.86 MPa

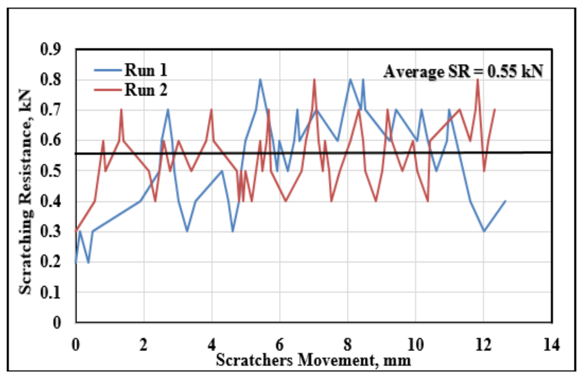

Figure 7: Scratching Tests Results for Rock Type 2.

Additionally, the developed rock scratching cell can be used to evaluate rock unconfined compressive strength for heterogeneous cores as shown in Figure 9. Therefore, this work is considered as a start for validating a promising new rock scratching cell. More core scratching tests using various rock types available worldwide will be done in phase 2 of this study.

Thirteen sedimentary rocks of different types were tested using the developed scratching cell. These rocks are ranging from very weak to moderately strong due to scratchers strength limitation. However, in future, the cell can scratch even extremely hard rocks, if suitable scratchers are available.

Table 3: Unconfined compressive strength data of sample 2

Rock Type 2			
Load, kN	**Area,m^2**	**L/D**	**UCS, MPa**
52.20	**$2.03x10^{-3}$**	**2.10**	**25.74**
51.30	**$2.03x10^{-3}$**	**2.15**	**25.24**
54.00	**$2.03x10^{-3}$**	**2.25**	**26.60**
		Average UCS	**25.86**

From the Figure 8 it is clear that the current study points of unconfined compressive strength, MPa vs SRS, MPa (same as intrinsic energy) giving the same trend line.

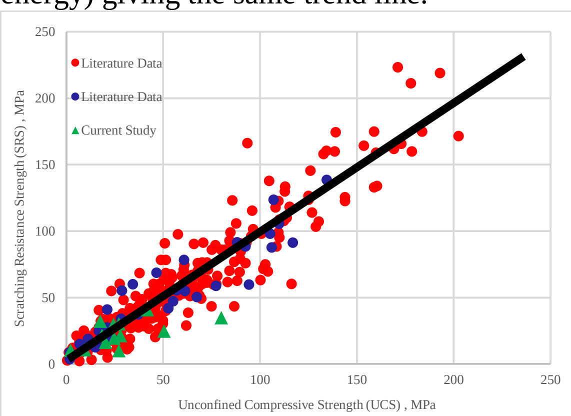

Figure 8: Scratching Resistance vs. UCS Correlation Attempt

CONCLUSIONS

Based on the performed work in this study, the following conclusions can be drawn:

1. Rock scratching test is a powerful tool for predicting rock strength when standard core samples are unavailable.

2. The developed rock scratching cell is cheap, simple, and technically valid.

3. A universal correlation between rock scratching resistance and unconfined compressive strength can be generated given sufficient rock samples of different types. The developed scratching cell can be used to predict strength for both homogeneous and heterogeneous rocks.

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