Development of Simple Rock Scratching Cell for Unconfined Compressive Strength Estimation

Musaed N. J. Al-Awad and Imtiaz Ali

Petroleum and Natural Gas Engineering Department, College of Engineering, King Saud University, Riyadh, Saudi Arabia
malawwad@ksu.edu.sa

Abstract

The mechanical properties of rocks are of high importance for oil and gas wells drilling, production, and future development. Rock mechanical properties are needed for maintaining borehole stability during oil and gas wells drilling and completion stages. Additionally, these properties are needed to select the optimum production rate especially in soft formations to avoid many problems such as sand production. The evaluation of such properties requires a sufficient number of standard core samples and sophisticated testing equipment. When there is a lack for sufficient core samples or testing equipment, rock mechanical properties can be predicted using correlations or simple indirect tests such as scratching or indentation. In this study, a simple and cheap rock scratching cell was developed and manufactured in-house (college workshop). The validity of this cell was tested using strength and scratching data generated from testing of fourteen rock samples covering rocks strength range. The measured unconfined compressive strength (UCS) and scratching resistance strength (SRS) data were located in the same region of similar laboratory data obtained by other researchers using very sophisticated and expensive testing equipment that are not available in the market. Furthermore, using the rock scratching cell developed in this study, it is found possible to perform scratching tests using small rock fragments. A correlation between SRS and UCS was developed based on laboratory measurements performed in this study in conjunction with published similar data. Therefore the developed rock scratching cell provides an excellent mean for predicting rock unconfined compressive strength using scratching test results.

Keywords: Scratching Resistance Strength, UCS, Core Samples, Rock Fragments, Correlation

1. Introduction

Oil and gas reserves are mainly located in sedimentary basins. For efficient exploitation of these valuable hydrocarbon reserves, rock and fluid properties as well as pressure and temperature must be evaluated. 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.).

The mechanical properties of rocks are of high importance for oil and gas wells drilling, production, and future development. Rock mechanical properties are needed for maintaining borehole stability during oil and gas wells drilling and completion stage. 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 laboratory using an adequate number of preserved cores.

Several types of testing equipment are utilized in these evaluations including: stiff compression/tension machine, servo-controlled confining pressure pump, triaxial cell, data acquisition system, etc. These expensive and high technology equipment are not available everywhere worldwide. Real core samples for use in research and development studies are limited either due to difficulties in coring and preserving or due to reserving this limited number of cores for use in future problems solving or development.

Numerous researchers attempted to use correlations or simple indirect tests such as scratching or indentation to estimate rock strength. Rock scratching was found as a promising mean for UCS estimation (Schei G. et al., 2000; Roberto S. R. et al., 2002; Thomas R. et al., 2012) by developed very sophisticated rock scratching testers as shown in Figs. 1, 2 and 3. However, these testers are expensive, complex, unavailable in market, and require special care for test samples preparation.

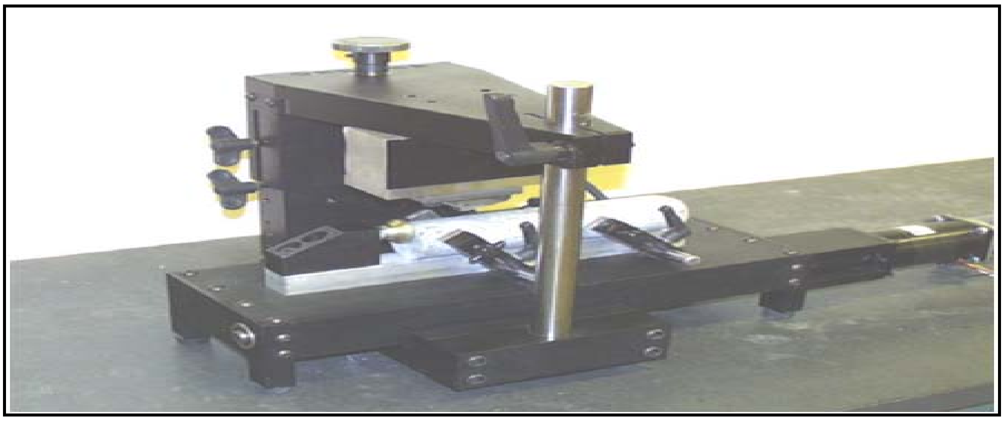

Fig. 1. Rock scratching cell developed by Terra Tek Inc., USA
(After Roberto S. R. et al., 2002)

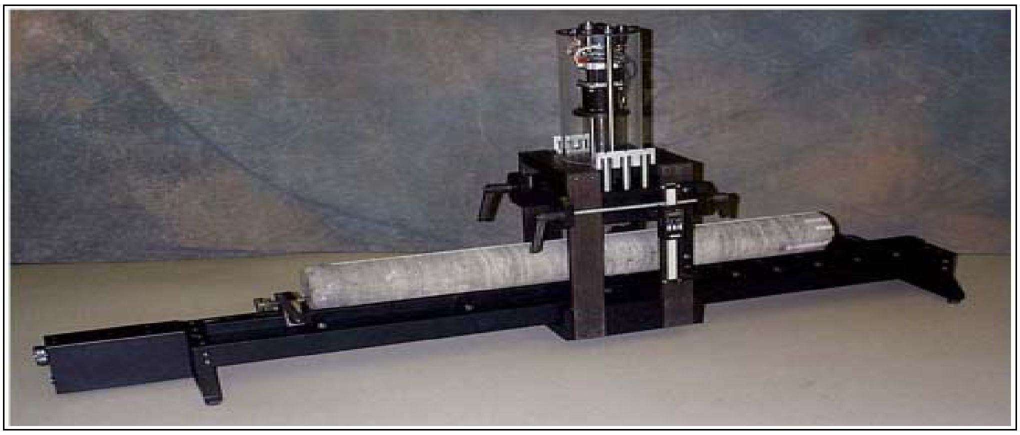

Fig. 2. Rock scratching cell developed by SINTEF, Norway and University of Minnesota, USA
(After Schei G. et al., 2000).

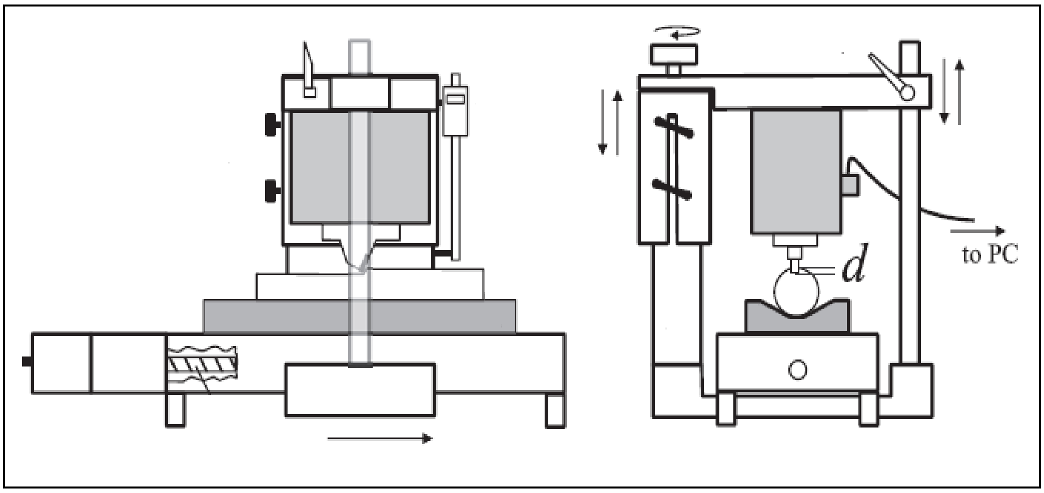

Fig.3. Sophisticated rock scratching cell (Thomas R. et al., 2012).

2. Objective of the Study

The objective of this study is to develop a new rock scratching cell that fulfills the following important requirements:

i. Cheap, fast and accurate,
ii. Simple data acquisition system is required,
iii. Used as an accessory with available compression/tension testers,

iv. Requires small and limited number of test samples (disks) or fragments, and
v. Tests are non-destructive, and repeatable.

3. Experimental Work
3.1 Properties of the Tested Rocks

Fourteen rocks of different types were tested for its UCS and SRS. These rocks are ranging from very weak to moderately strong depending on scratchers strength limitation. However, in future, the cell can scratch even extremely hard rocks, if the existing scratchers are replaced by other suitable durable scratchers. The tested rocks are eleven sandstones, one carbonate, and one granite.

3.2 Measurement of Unconfined Compressive Strength

The unconfined compressive strength (UCS) was evaluated experimentally for the same scratched rocks that were tested using the developed rock scratching cell. Suggested standards for testing and test specimens preparation outlined by the International Society of Rock Mechanics (ISRM) for UCS measurement were applied in this study (Bieniawski Z. T. et al., 1979). Thirty eight specimens from fourteen different rocks were tested and an average UCS was estimated for each tested sample.

3.3 Measurement of Rock Scratching Strength

The rock scratching cell developed in this study is made from a hard stainless steel material. The cell is assembled from three parts as shown in Fig. 4. The first part is a hollow stainless steel cylinder having the inner diameter of 2.01 inches and outer diameter of 2.95 inches so that a 2.0 inch core sample can slide smoothly without friction resistant with the cell inner wall.

The second part is a solid stainless steel platen of diameter equal to 2.0 inches and 3.27 inches in length. The remaining space (2.16 inch) above the scratchers represents the maximum core sample length. The maximum scratching length is 2.0 inch in order to avoid damage of the three scratchers by the steel platen. The platen is further modified to accommodate three rock fragments for scratching test in a uniform cylindrical rock is not available. The third part is a set of three adjustable scratchers made from hard steel to make sure that they will not be damaged easily. These three scratchers are 120 degree apart fixed into the hollow cylinder body by welded nuts. They are placed at 2.16 inch from the top of the cell. Each scratcher has a conical shape with specifications.

The depth of the each scratcher depends on the requirement of the user and sample. In the current study a uniform depth of 1mm is selected to scratch fourteen samples of different strength. For scratching rock fragments, the graves are drilled in the steel platen with 120 degree apart. The axial movement of the scratchers is recorded using linear variable differential transducer (LVDT). The applied load is recorded using a pressure transducer.

4. Results and Discussion

Fig. 5 shows typical scratching results for sample number 9 using rock scratching cell developed in this study. UCS and scratching measurements of the same sample are shown in Table 1. Summary of the properties and testing results of the tested fourteen rocks are presented in Table 2.

The UCS is measured using ISRM standards (Bieniawski Z. T. et al., 1979) and corrected based on length-to-diameter ratio using the following equation (Thuro K. et al., 2001):

$$UCS_{corrected} = \frac{UCS_{measured}}{\left[0.88 + \left(\frac{0.24D}{L}\right)\right]} \qquad (1)$$

Rock resistance strength is calculated using the average measured rock scratching resistance load for three scratchers as follows:

$$SRS = \frac{\text{Average scratching resistance load}}{\text{Scratched area}} \qquad (2)$$

The results of the new rock scratching cell were validated by comparison with previously published similar measured data (Roberto S. R. et al., 2002; Schei G. et al., 2000; Thomas R. et al., 2012) as shown in Fig. 6 with identical coefficient of correlation equal to 0.87.

Fig. 4. Details of rock scratching cell developed in this study.

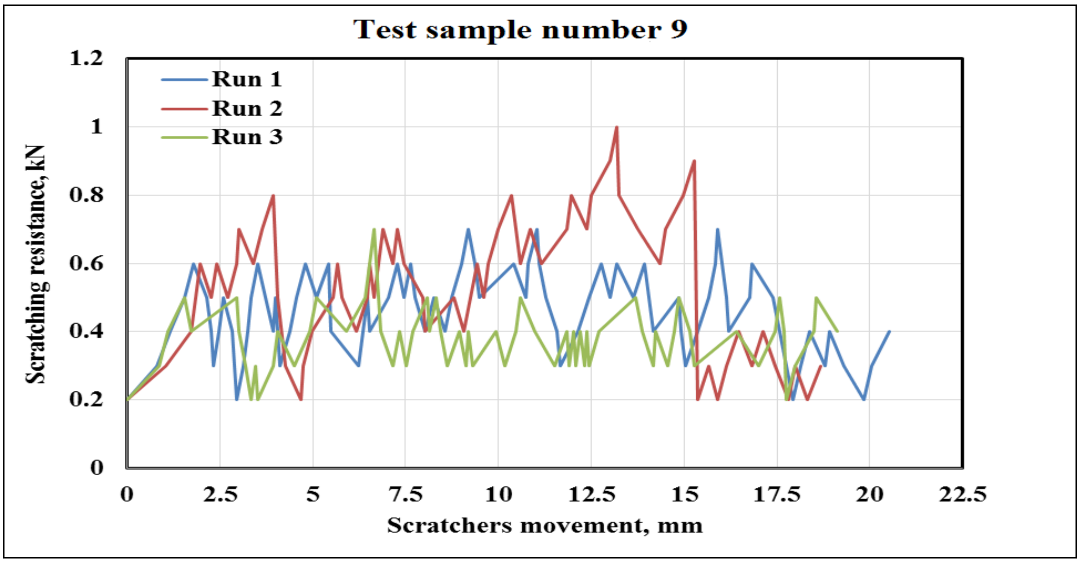

Fig. 5. Scratching test results for rock sample number 9.

Table 1 UCS and scratching measured data of rock sample number 9.

Load, kN	Area, mm^2	L/D	UCS, MPa	
			Measured	Corrected for L/D ratio (Eq. (1))
37.80	$2.03x10^{-3}$	2.90	18.62	19.34
54.20	$2.03x10^{-3}$	3.00	26.70	27.81
37.70	$2.03x10^{-3}$	2.40	18.58	18.96
Average UCS, MPa			21.30	22.04
Average Scratching Resistance, kN			0.46	
Average Scratching Resistance, MPa			16.24	

Table 2 Scratching and UCS data for the tested rock samples.

Sample		Scratching Resistance		UCS, MPa
		Load, kN	Strength, MPa	
1	Sandstone, light grey in color, fine grains	0.61	21.47	19.65
2	Sandstone, yellow in color, fine grains	0.91	32.12	18.81
3	Sandstone, reddish in color, fine grains	0.86	30.30	28.83
4	Sandstone, yellowish in color, fine grains	0.84	29.68	26.37
5	limestone, whitish in color, very fine grains	1.51	53.41	63.52
6	Sandstone, light red in color, fine grains	0.29	10.26	2.29
7	Sandstone, light red in color, fine grains	0.60	21.28	30.28
8	Sandstone, light yellow in color, fine grains	0.55	19.47	26.10
9	Sandstone, light red in color, fine grains	0.46	16.21	22.04
10	Sandstone, light red in color, fine grains	0.27	9.55	9.94
11	Sandstone, light yellow in color, fine grains	0.28	9.90	29.40
12	Sandstone, grey in color, fine grains	1.15	40.68	44.18
13	Sandstone, blackish in color, fine grains	0.70	24.76	54.97
14	Granite, white and black	3.46	122.32	115.24

It can be noticed that results generated in this study are located within the same range of the published data indicating that the developed rock scratching cell and testing methodology are valid. Data in Fig. 6 provided a universal correlation between rock UCS and SRS as follows:

$$SRS = 0.945\, UCS \tag{3}$$

Furthermore, the developed rock scratching cell can be of more value if harder scratchers are available to enable scratching even very hard rocks.

By scratching a disk or even a fragment of any rock, the unconfined compressive strength can be estimated using eq. (3). Therefore a new fast, simple and cheap rock scratching cell is introduced to the rock mechanics field.

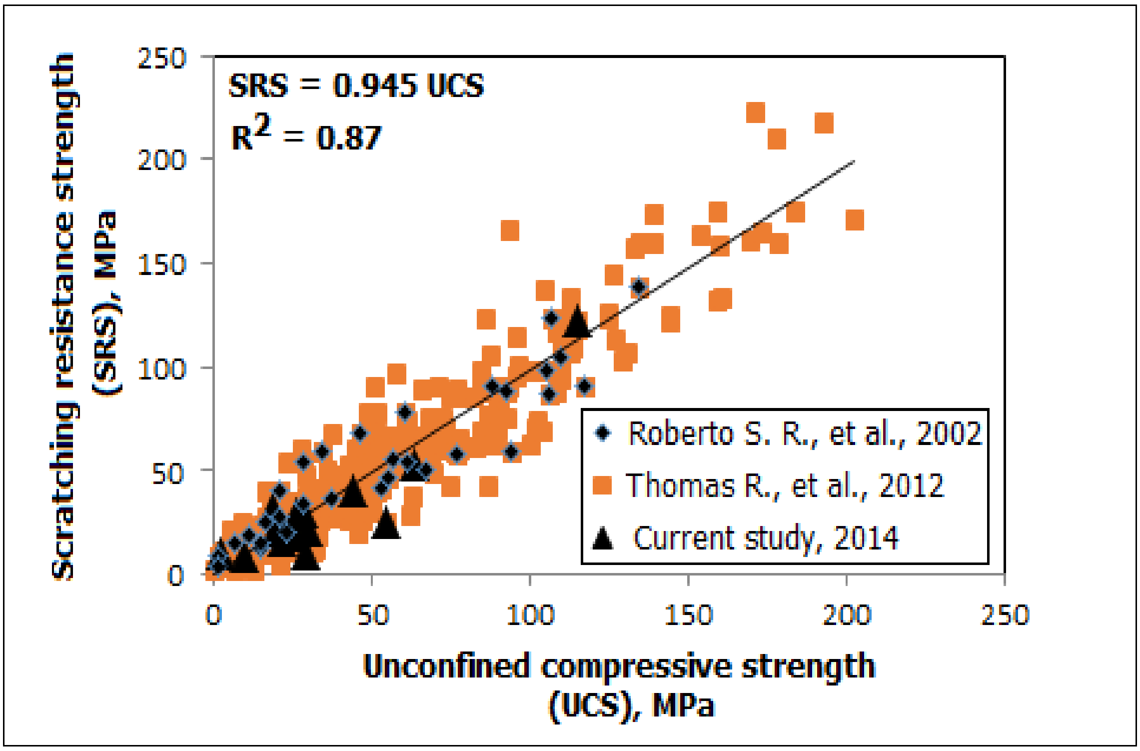

Fig. 6 Universal correlation between SRS and UCS.

5. Conclusions

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

i. Rock scratching test is a promising powerful tool for predicting rock UCS when standard core samples are unavailable.
ii. Cheap, simple, and technically valid rock scratching cell has been developed in this study.
iii. The main advantage of the developed rock scratching cell is that it is used as an accessory for any existing rock tension/compression tester.
iv. A universal correlation between rock scratching resistance strength (SRS) and unconfined compressive strength (UCS) has been developed.
v. By scratching rock disks or fragments, the UCS can be estimated.

Acknowledgements

The authors would like to express their sincere thanks to King Saud University for funding this research project and providing them with the opportunity to present this work in the ARMS8, Sapporo, Japan, 14 - 16 October 2014.

References

Bieniawski Z. T. and Bernede M. J., 1979. Suggested methods for determining the uniaxial compressive strength and deformability of rock materials, *International Journal of Rock Mechanics and Mining Science Publications*, Volume: 16, Issue Number 2, Pergamon Press, Incorporated, ISSN: 0020-7624.

Roberto Suárez-Rivera, SPE, TerraTek Inc., Jørn Stenebråten, TerraTek Inc., Fabrice Dagrain, Faculté Polytechnique de Mons., 2000. Continuous Scratch Testing on Core Allows Effective Calibration of Log-Derived Mechanical Properties for Use in Sanding Prediction Evaluation", SPE/ISRM 78157, presented at *SPE/ISRM Rock Mechanics Conference* held in Irving, Texas, 20-23 October.

Schei G., SINTEF Petroleum Research; E. Fjær, E. Detournay, University of Minnesota; C.J. Kenter, SPE, Shell; G.F. Fuh, SPE, Conoco; F. Zausa, SPE, Eni Agip, 2000. The Scratch Test: An Attractive Technique for Determining Strength and Elastic Properties of Sedimentary Rocks, SPE 63255, presented at *The 2000 SPE Annual Technical conference and Exhibition* held in Dallas, Texas, 1–4 October.

Thomas R., Fabrice D., Edmond P., and Emmanuel D., 2012. Rock Strength Determination from Scratch Tests, *Engineering Geology* 147–148 (2012) 91–100.

Thuro K., Plinninger R.J., Zäh S., Schütz S., 2001. Scale effects in rock strength properties. Part 1: Unconfined compressive test and Brazilian test, presented at *ISRM Regional Symposium EUROCK 2001*, 3-7 June.