Investigating the Mechanical Properties and Drill-ability of Rocks

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Abstract

Drilling is the primitive and common operation in rock excavation industry, starting from exploration to exploitation. Effect of mechanical properties of the formation on drilling operation is a big challenge to mining engineers. The primarily problem is rock drill-ability. The objective of this paper is to correlate the drill-ability of certain rocks with their mechanical properties including Compressive strength, Tensile strength, Schmidt hammer rebound number and Shore Hardness number, in order to establish rate of penetration. This paper contains investigation of both laboratory experiments and Field examination of drilling equipment. Laboratory work includes the determination of various mechanical properties of rock specimen, determined according to ASTM procedure using Universal Testing Machine. Schmidt hammer test conducted on the rock specimen by clamping into the UTM loading platens. Shore hardness test performed on disc specimen carefully prepared for the purpose. The test was conducted as per standard procedure.

Keywords: Drill-ability, Mechanical Properties, Schmidt Hammer Test, Rate of Penetration, Universal Testing Machine.

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INTRODUCTION

Drilling is the prehistoric and common operation in rock excavation industries, starting from exploration to exploitation of mineral, oil and water. Rocks are drilled for several purposes. such as, geological exploration, blast hole for mineral production, for rock bolting, rock cores for determining geotechnical parameters and rock excavation for civil constructions (Akun and Karpuz, 2005; Kahraman et al., 2003).

In addition, energy applied to the rock affects the type of fracture and breakage develops in rock. No single rock property is a measure of drill-ability of the rocks; infact all the geotechnical properties of rock in some way or the other contribute to the drilling performance (American Society of testing and Material 1974; Brady and Brown, 1985) The most influencial parameters for drilling are mechanical property of the rock, cutting tools and their shapes, magnitude of forces influenced at the bit, rock interface and flushing rate. The performance of a drilling system is usually represented by the drill-ability of rocks which is defined as the real or projected rate of penetration in a given rock type. Thus, a study which describes relationship between penetration rate and the various rock properties for drilling parameters is required to perform economical and efficient drilling (Hardy, 1957; Hetenyi, 1966; Olgay and Eren, 2011).

MATERIALS AND METHODS

The behavior of rock mass is governed by the defects existing in the rock mass. Because rock mass in general is non-homogeneous and the properties of the samples are taken from one portion of rock, the rock mass may be different from another portion. Therefore, sample collected must truly represent the rock mass, the properties of which are to be determined. Samples collected for laboratory testing should be in the form of large blocks from the field [11]. In instances where substantial drilling is required to evaluate a deposit, it is usually considered to be good practice to core a certain percentage of holes in the drill program. The actual percentage will vary with the available budget and the degree of complexity of the geology, but usually average about 10% core samples offer the advantage that sample location can be closely defined, and there is little possibility of contamination or loss of values as long as recovery is good. On the negative side, core drilling is expensive and usually the sample obtained is relatively small. In case where the ore boundaries are fairly well known, the cost can sometimes be lowered by rotary drilling to near the ore boundary and then continuing with core. Rebound and rebound of diamond tipped impactor hardness is calculated by Shore Sceleroscope Hardness Test (Figure 1) .Rebound hardness is calculated by Schmidt Hammer Hardness Test (Figure 2) which impacts the piston striking. This test was first used for rapid examination of compressive strength of concrete and later it was used to calculate the hardness of rock. UTM (Universal testing machine) (Figure 3) is used to determine UCS (UNI-AXIAL COMPRESSION TESTING) which is the most basic parameter of rock strength, and the bore ability prediction is performed by using UTM [8]. It is calculated in accordance with instructions given in ASTM (American Society for Testing and Materials).

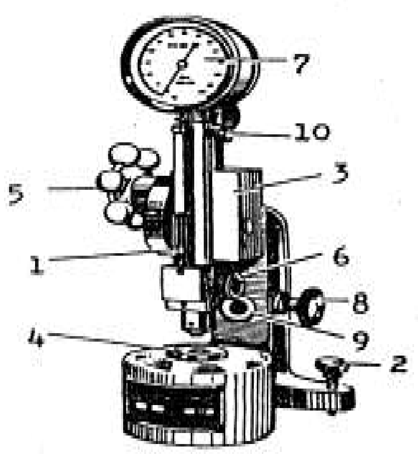

Figure 1 – Shore Sceleroscope

1. Level Rod
2. Level Adjust Screw
3. Main Body
4. Table
5. Control Knob
6. Operation Knob
7. Indication Scale
8. Butt Gage Fixed Handle
9. Hole For Butt Gage
10. Dial Gauge Fixed Screw

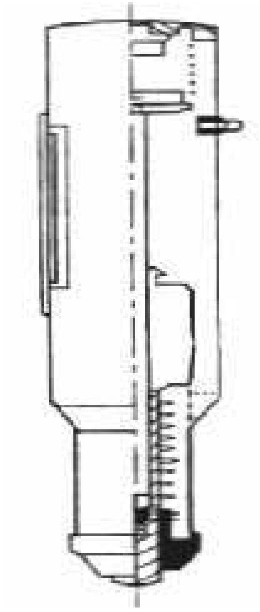

Figure 2 – Schmidt Hammer

Figure 3 - Universal Testing Machine (UTM)

In laboratory, the test specimens are required to be prepared from the rock sample brought from the field. The shape and size of specimen depend upon the type of the test to be conducted. Most of the test specimens to Mechanical Properties are of regular shape (i.e. Cylindrical). Typical diameter range used for Cylinder sample are 25mm to 50mm. As a standard, however, unconfined compressive strength tests require that test specimen be right circular cylinder with a diameter not less than (54mm) core size and the ratio of length and diameter is 2.0 to 2.6 to avoid the stress concentration at the time of testing (Olgay and Eren, 2011)s. The specimen sides should be regular in order to avoid abrupt irregularities. The specimen ends should be cut parallel to each other and of normal to longitudinal axis. The ends should be ground and end lapped. The result obtained from testing a single specimen may not represent the property of rock mass. Therefore, in order to limit the testing work, at least four specimens should be tested to get an absolute value.
The strain, corresponding to each stress level (or equivalent load level), is obtained by multiplying the apparent strain by the calibration constant of the compress meter. The uni-axial compressive strength is calculated by Qu = Pu/A, Pu = the maximum load carried out by the specimen while the testing, and A = the actual cross sectional area calculated in accordance with the specification (Hartman, 1987). Indirect tensile strength of a substance can be obtained by the ratio of multiplication of failure load with 2 and multiplication of constant (π) into diameter and thickness of the specimen. Tensile strength is calculated by σt= 2P/DT, σt= indirect tensile strength, P= failure load, D = diameter of specimen (disc), and T = thickness of specimen disc (Lewis, 1964).

RESULTS AND DISCUSSION

The rate of penetration (ROP) is an essential parameter for the calculation of drillability. Causing the rock to break during drilling is a matter of applying sufficient force with a tool to exceed the strength of the rock. This resistance to penetration of rock is termed as its drilling strength, an empirical property; it is not equivalent to any of the well-known strength parameters.

Experimental work involves three samples from three different sites. The rate of penetration data of sample 1 and Sample 2 are shown in Table 1 and Table 2.

Table 1- Rate of penetration of Sample 1

HOLE ID	STARTING TIME	STOPPING TIME	TIME ELAPSED	METER DRILLED
2 JULY 01	10:25AM	10:40AM	15 MIN	17 METERS
2 JULY 02	10:56AM	11:17AM	26 MIN	19 METERS
7 JULY 03	11:05AM	11:23AM	18 MIN	21 METERS
14 JULY 04	10:26AM	10:42AM	16 MIN	17 METERS
15 JULY 05	11:50AM	12:06PM	20 MIN	12 METERS
TOTAL			95 MIN	80 METERS

Table 2- Rate of penetration of Sample 2

HOLE ID	STARTING TIME	STOPPING TIME	TIME ELAPSED	METER DRILLED
3 NOV 01	11:20AM	11:34AM	14 MIN	11 METERS
3 NOV 02	12:16PM	12:33PM	17 MIN	13 METERS
4 NOV 03	11:05AM	11:20AM	15 MIN	10 METERS
4 NOV 04	11:26AM	11:41AM	15 MIN	12 METERS
4 NOV 05	11:50AM	12:06PM	16 MIN	12 METERS
TOTAL			77 MIN	58 METERS

Table 3- Rate of penetration of Sample 3

HOLE ID	STARTING TIME	STOPPING TIME	TIME ELAPSED	METER DRILLED
10 NOV 01	10:23AM	10:59AM	36 MIN	7 METERS
11 NOV 02	10:35AM	11:18AM	43 MIN	8 METERS
12 NOV 03	10:15AM	10:57AM	42 MIN	7 METERS
13 NOV 04	10:26AM	11:02AM	36 MIN	6 METERS
14 NOV 05	10:30AM	11:10AM	40 MIN	7 METERS
TOTAL			197 MIN	35 METERS

The uni-axial compressive strength tests of the limestone rock specimens are calculated by dividing maximum load carried by the specimen (i.e. failure load) during the test, by the actual cross-sectional area. Three samples were tested to determine UCS of lime stone as shown in Table 3. The tensile strength of limestone rock specimen is calculated as shown in Table 4.

Table-4 Results of UCS Tests of Limestone

Test No.	Length cm / (m)	Diameter cm / (m)	X-sectional Area (m^2)	Failure Load (N)	UCS $_c$ MPa
Sample 1	11.5 (0.115)	4.7 (0.047)	0.001734	112710	65
Sample 2	11.5 (0.115)	4.7 (0.047)	0.001734	100572	58
Sample 3	11.5 (0.115)	4.7 (0.047)	0.001734	147390	85

Table-5Results of Tensile Strength of Limestone

Test No.	Thickness cm / (m)	Diameter Cm / (m)	Failure Load (KN)	Tensile Strength $_t$ MPa
Sample 1	2.5 (0.025)	4.7 (0.047)	22.148	**11.98**
Sample 2	2.5 (0.025)	4.7 (0.047)	23.847	**12.91**
Sample 3	2.5 (0.025)	4.7 (0.047)	38.799	**21.00**

Shore hardness has to be determined by the shore hardness testing instrument. The 2cm thickness sizes of specimens were prepared in the laboratory by means of cutter and grinder from the each sample of the sites. The readings of the shore hardness test of each specimen are shown in the tables 5 and Summary of Mechanical properties is shown in Table 6.

Table-6 Shore hardness test

ITERATIONS	Sample 1		Sample 2		Sample 3	
	Side1	Side	Side1	Side2	Side1	Side2
01	20	28	43	45	54	47
02	31	31	46.5	48	57	49
03	26	08	46	39	47	42
04	35	36.5	53.5	35	49	40
05	38	47	46	37	63	51
06	46	32.5	47	24	46	43
07	33	42.5	38	36	49	57
08	21	14.5	22.7	31	52	58
09	28	23	36.5	35	51	52
10	10	32	39	37	58	54
11	16	39	39	47	48	42
12	34	31	39.5	49	53	40
13	43	32	41	51	52	42
14	45	31	46.4	47	51	49
15	46	39	44.5	52	62	60
AVERAGE	**31.46**	**31.13**	**41.90**	**40.86**	**52.08**	**48.04**

Table-7 Summary of Mechanical properties

Sr. No	Sample ID	UCS (MPa)	Tensile Strength (MPa)	Shore Hardness No.	Rate of Penetration meters/hour
1	Sample 1	65	11.98	31.58	50.5
2	Sample 2	58	12.91	43.77	45
3	Sample 3	85	21.00	50.64	10.8

Drill-ability of rock manifests the various mechanical properties of rock. Assessment of drill-ability or penetrability is the most serious issue among the drilling equipment manufacturers and operators. Unfortunately there is no direct method of drill-ability measurement but it could be measured through empirical correlation of various mechanical properties of rocks [11]. Correlation of UCS (Uni-axial Compressive strength) & ROP (Rate of penetration), Correlation of Tensile Strength & ROP, and Correlation of Shore Hardness & ROP are shown in Figure 4, 5, and 6.

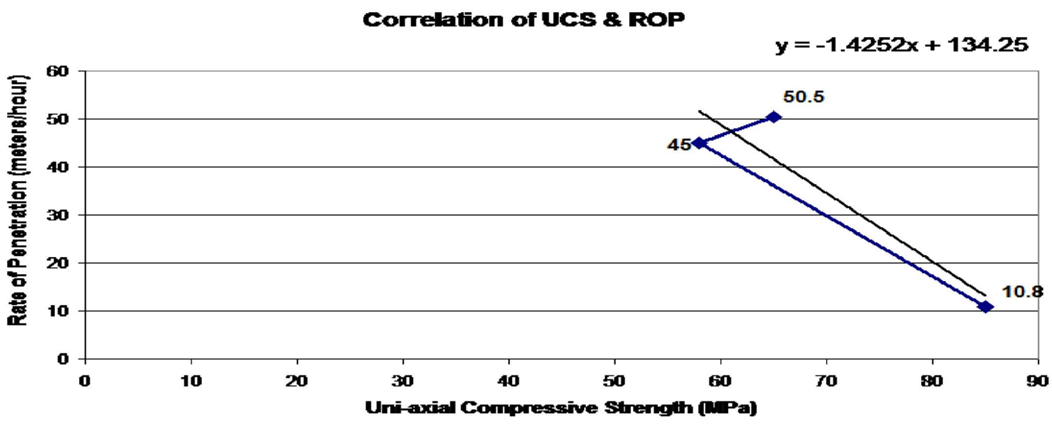

Figure 4 – Correlation of UCS & ROP

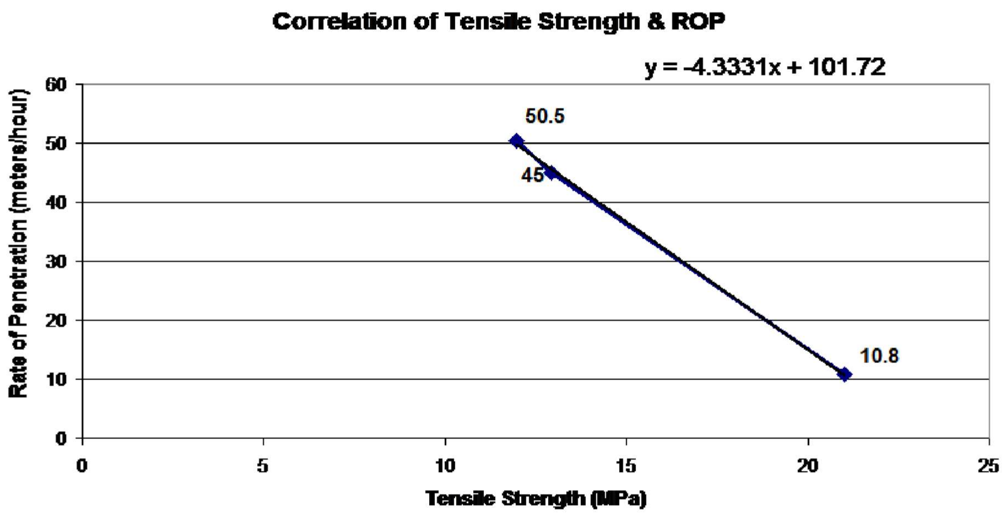

Figure 5 - Correlation of Tensile strength and ROP

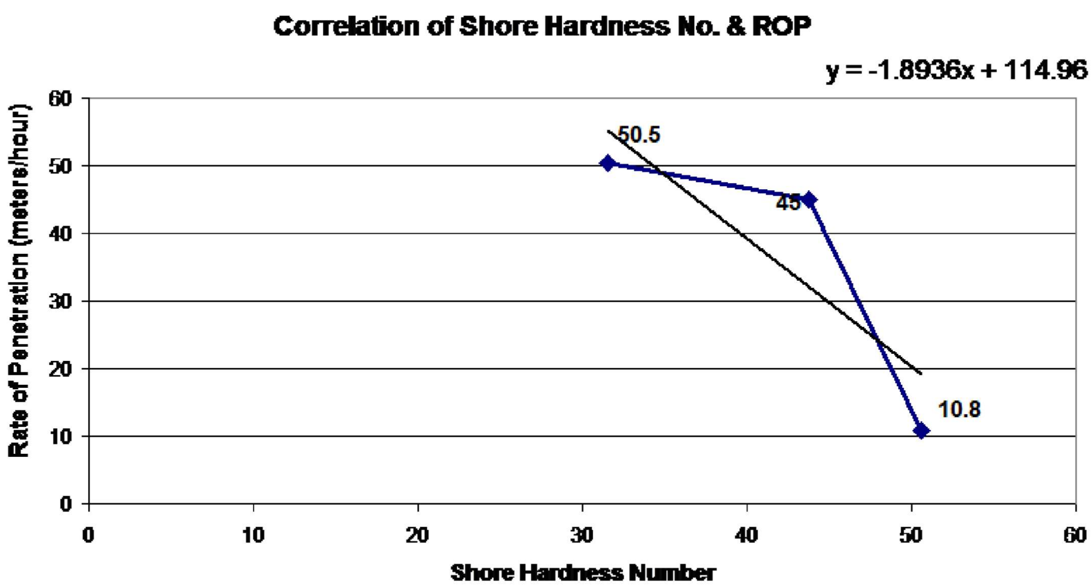

Figure 6 - Correlation of Shore Hardness & ROP

CONCLUSION

In this paper attempts have been made to correlate the rate of penetration in the rocks having different mechanical properties. Following conclusions were drawn from the experimental data. The limestone samples obtained from the three different sites were analyzed for Uni-axial Compressive Strength, Tensile Strength and Shore Hardness Number. Compressive Strength test shows that all three rocks fall under the category of Medium Hard Rock.

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