The International Journal Of Engineering And Science (IJES)
||Volume|| 3 ||Issue|| 2 ||Pages|| 68- 74 || 2014 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Drillability of Migmatite Gneisses in Lokoja Environs

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ABSTRACT

In this study, correlation analysis was applied to investigate the relationship between some strength properties (Uniaxial Compressive Strength, Point Load Strength, Schmidt Hammer Value, Equivalent Quartz Content and Penetration Rate) of Beautiful Rock Quarry along Ajaokuta Road in Kogi State, North Central Nigeria. These properties were determined and the relationships between them were described by Regression Analysis. The coefficient of correlation for all the parameters evaluated is more than 0.7. The result indicated that Uniaxial Compressive Strength (UCS) varies between 239.60MPa and 283.01MPa, Point Load Strength varies between 5.9MPa and 6.01MPa, the Schmidt Hammer Value varies between 42 and 56, Equivalent Quartz Content varies between 55.3% and 70.2%, and the Penetration Rate Varies Between 1.10m/min and 1.60m/min. This result shows that the Uniaxial Compressive Strength of the rock tested was extremely high while the Point Load Strength was high [5]. The Schmidt hammer rebound value is moderate. The study revealed that the Equivalent Quartz Content is one of the major factors controlling penetration rate in rocks.

Keywords*: Drillability, penetration rate, strength properties, correlation and, regression analysis*

Date of Submission: 02 November 2013 ⟺ Date of Acceptance: 20 February 2014

I. INTRODUCTION

Drillability and penetration rate are similar terms. While drillability indicates whether penetration is easy or hard, penetration rate indicates whether it is fast or slow [1].

Migmatite Gneiss rock is economically useful for construction works and ornamental purposes. It is imperative to study and determine its drillability or penetration rate in order to have a long term production plan schedule or to meet up with target production rate. The drillability of the migmatite Gneiss can be studied by determining various strength properties: Its mechanical properties (uniaxial compressive strength, tensile strength, point load index) and physical properties (porosity, density, hardness, permeability among others). The mineralogical compositions and petrography of these rocks have significant effects on their properties and thus greatly influence the drillability. Drillability is a measure of the resistance of mine rock to disintegration during drilling. Rock drillability largely depends on hardness of minerals, grain size, degree of cementation of light minerals and the influence of specific tools that is used which determine the velocity or the speed of rotation.

Rock drilling is performed with a number of techniques depending on operational variables, usage, hardness and strength characteristics of the rock. The operational variables that are controllable are rotation speed, thrust, blow frequency and flushing. However, rock properties and geological conditions are uncontrollable parameters [2] and [3]. Various methods have been used to determine the mechanical properties of migmatite Gneiss using the standards like ISRM, ASTM among others. The most important mechanical properties measured are Uniaxial Compressive Strength (UCS), Point Load Test (PLT), mineralogical compositions and physical properties (hardness).

Factors affecting drillability can be described as changeable and unchangeable. These factors are rock characteristics, mechanical factors and complementary factors. The hardness of the rock, uniaxial compressive strength (UCS), tensile strength and point load test are the vital unchangeable factors. Penetration rate is the progression of the drilling bit into the rock in a certain period of time, which is generally expressed in “m/min”. The main changeable factors are type and design characteristics, the amount of compression applied and drill rotational speed. Fast and economical penetration depends on the mineralogical structure of the rock, drilling machine, geo-mechanic characteristic, and the choice of drilling tools appropriate to the rock [4].

Migmatite gnesis is the commonest rock type in Nigerian Basement Complex. There are two main types of gneisses: the biotite gneiss and the banded gneiss which is very wide spread. The biotite gneisses are normally fine grained with strong foliation caused by the parallel arrangement of alternating dark and light colours.

The banded gneisses show alternating light – coloured and dark bands and exhibit intricate folding of their bands. The migmatite gneiss is the oldest rock and is believed to be sedimentary in origin but was later source altered into metamorphic and granite rouse.

Table 1 shows the coordinates of the study areas and a brief description of the rock samples studied.

Table 1: Location of the Study Areas

Samples No.	Locations	Sizes	Descriptions
A	$N7^0$ 42^1 14.0^{11} $E06^0$ 44^1 37.8^{11} - 55M ASL	350MM	Medium to coarse grains & Dark in colour.
B	$N7^0$ 42^1 15.3^{11} $E06^0$ 44^1 39.3^{11} - 64M ASL	350MM	Coarse grain & Light in colour.
C	$N7^0$ 42^1 12.2^{11} $E06^0$ 44^1 44.2^{11} - 52M ASL	350MM	Medium to Coarse grain & Grey in colour.
D	$N7^0$ 42^1 12.2^{11} $E06^0$ 44^1 44.2^{11}	350MM	Fine – medium grain & pinkish in colour
E	$N7^0$ 42^1 16^{11} $E006^0$ 44^1 30^{11}	350MM	Medium to Coarse grain & grey colour.

II. METHODOLOGY

2.1 Uniaxial Compressive Strength

This method is intended to determine the uniaxial compressive strength of rock samples in the form of specimen of regular geometry and is mainly for strength classification and characterization of fragmented rocks. The test procedure was in accordance with ISRM [5] as highlighted below:

(i) The test specimen was prepared in cubic shape with dimension 60mm x 60mm.
(ii) The test specimens were cut to shape with the aid of mansonry saw.
(iii) Micrometer screw gauge was used to measure the dimensions
(iv) Fifteen prepared specimens (three per location) were compressed under a uniaxial compression machine with a constant stress rate of 0.5-1.0 MPa such that failure occurred within 5-10 minutes of loading.

The uniaxial compressive strength is then calculated using Equation 1.

$$C_O = \frac{F}{A} = \frac{4F}{\pi D^2} \quad \text{.......... ....}(1)$$

where Co is the compressive strength in MPa, F is the load at failure kN, and A is the cross- sectional area of the cylindrical core samples in m^2 and D is the sample diameter in m.

2.2 Point Load Strength

The test is intended to measure point load strength of the rock specimen. The rock samples were prepared for each location to the standard suggested by the international Society of Rock Mechanics [5] and the American Society for Testing and Materials International (ASTM) [6].

Basic diametrical tests were performed on the specimens. The sample is placed between the conical platen points in a way to allow at least 0.5D as a free end after the longest axis has been measured. The loading diameter is read from the scale pointer and recorded. Load is then applied steadily through the platens until failure occurs and the failure load is taken as recorded by the dial gauge. The tensile strength is measured as the point load strength index (Is) as shown in Equation (2).

$$I_s = \frac{P}{D^2} \quad \text{.......... ....}(2)$$

Since the samples tested do not have a diameter of 50mm, the point load index has to be corrected to standard strength indices as shown in Equation (4).

The uncorrected point – load strength index is corrected to the point –load strength as equivalent core diameter of 50mm, for $D_e \neq 50$mm

The corrected point load strength index, $I_{s(50)}$ is calculated as in Equation 3.

$$I_{s(50)} = FI_s \text{ ------------------------------------ } (3)$$

$$F = \left(\frac{D_e}{50}\right)^{0.45} \text{ .... } (4)$$

where F is the size correction factor, P is the failure load(kN), and De is the equivalent core diameter (m).

2.3 Petrographic Analysis

Modal analysis is the method of determining the detailed petrography of rocks by counting different minerals, thereby determining the mineralogical composition and the percentage of the minerals crystal formation of various minerals present in the samples of the different rock types.

The polarizing microscope was used in the determination of these properties in each of the slide by placing the slide on the stage of polarizing microscope taking records of the first, second and the third counts respectively. The total number of each mineral were estimated against the ground total and multiplied by 100 to give the percentage composition of the minerals using Equation (5).

Mathematical formular for percentage composition is

$$C_m = \frac{Tm}{Ttm} X \ 100 \text{ ---------------------------------- } (5)$$

where C_m is the Percentage composition of minerals, Tm is Total number of counts for a mineral and Ttm is Total number of counts for all minerals.

The point count method as given by Hutchinson [7] was used to determine modal composition.

2.4 Penetration Rate

A drilling rig (SECROC 3") was used to determined rocks penetration rates. The penetration rates tests were carried out on five different locations numbered 1 to 5. New drilling bits were used in the penetration tests. The rotational speed of the bit is between 30 to 40rpm and diameters of the holes varies from 80 to 90mm.The highest penetration rate was observed in location (1).

III. RESULTS

The results of uniaxial compressive strength, point load test, Schmidt hardness, Equivalent Quartz contents and penetration rate of migmatite gneiss rock samples in different locations of Beautiful Rock Quarry were shown in Table 2.

Figures 1, 2, 3 and 4 depict the regression analysis of penetration rate against uniaxial compressive strength, point load strength, Schmidt hammer value and equivalent quartz content respectively.

Plates A to E are the photomicrographs of the studied samples.

Table 2: Results of Penetration Rate, Equivalent Quartz Content, Schmidt Hammer Value, Compressive Strength and Point Load Strength Values.

Samples	**Penetration rate (m/min)**	**Equivalent quartz content (%)**	**SHV**	**C_O MPa**	**$I_{S(50)}$MPa**
A	1.60	57.8	55	283.07	6.02
B	1.33	59.2	46	251.70	5.25
C	1.43	61.8	48	256.60	5.45
D	1.10	70.2	42	239.60	5.09
E	1.50	55.3	56	281.33	5.98

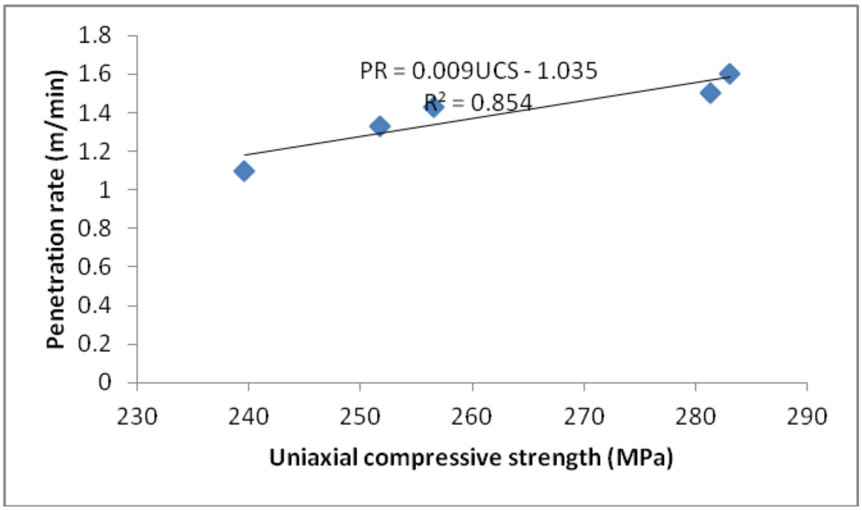


Figure 1: Penetration rate versus Uniaxial compressive strength

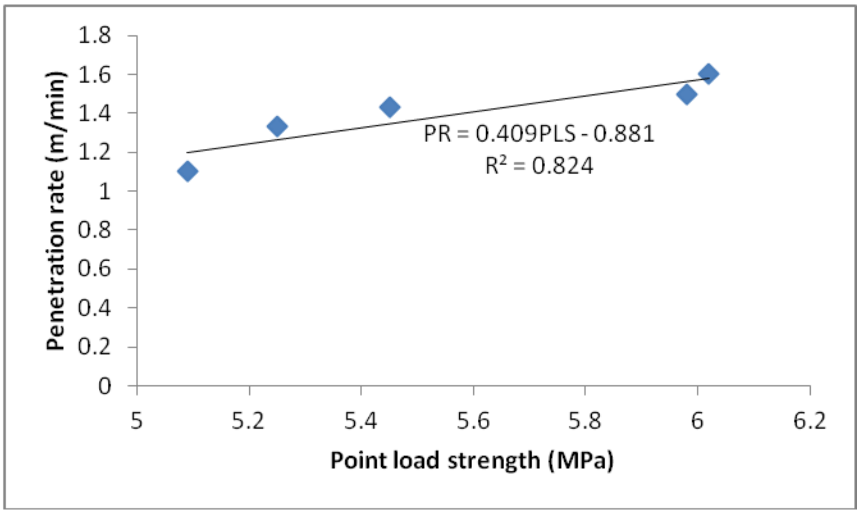


Figure 2: Penetration rate versus Point load strength

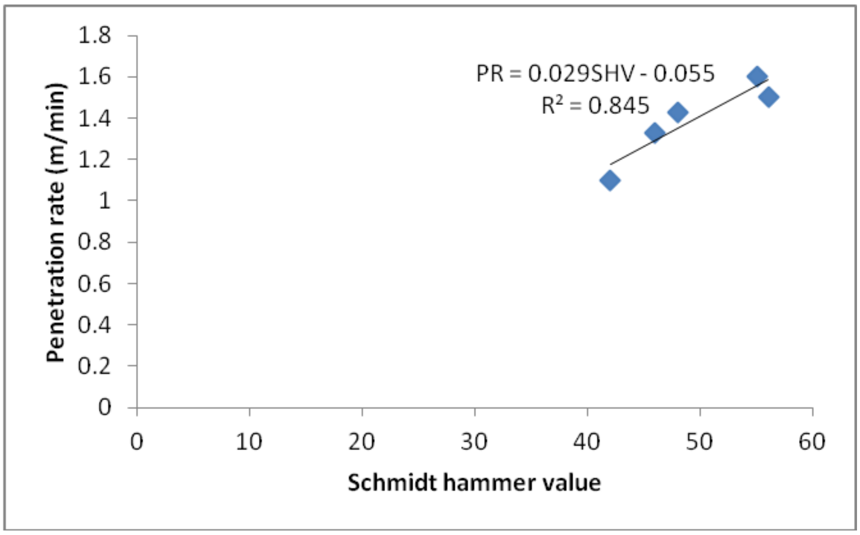


Figure 3: Penetration rate versus Schmidt hammer value

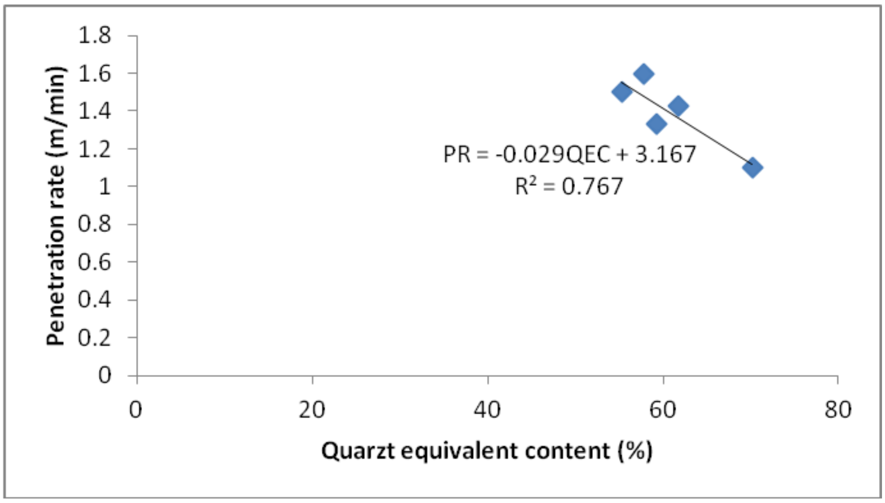
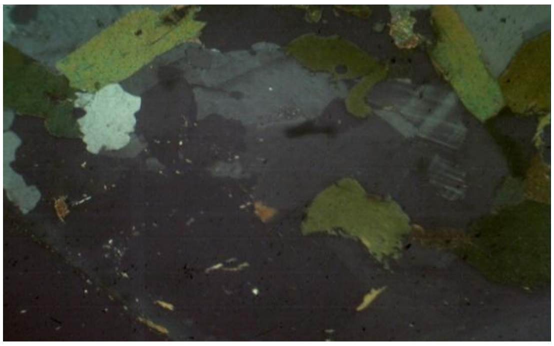
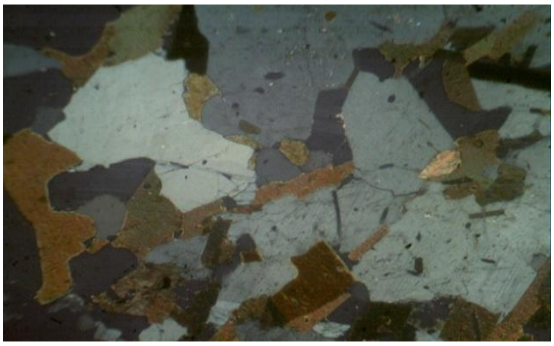


Figure 4: Penetration rate versus Equivalent quartz content



A



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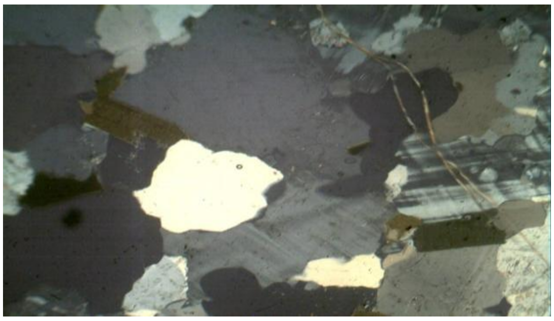

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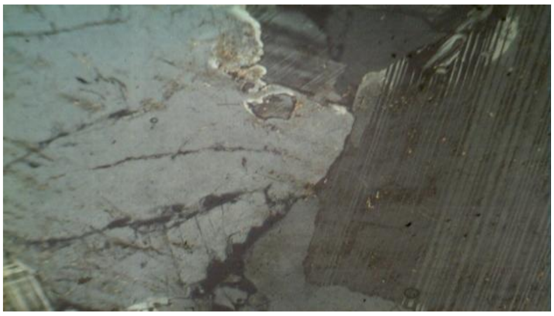
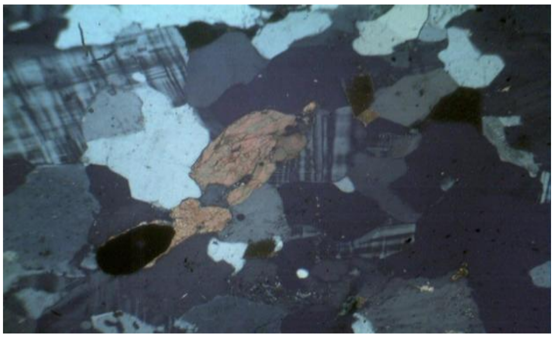


D



E

Plates A,B,C,D and E: Photomicrograph of Migmatite Gneisses (with crossed Nicols. X 40)

IV. DISCUSSION

4.1 Appraisal of Strength Characteristics

Table 2 shows that locations A to E possess extremely high uniaxial compressive strength with A having the highest value when compared to other locations. The Table also indicates that the point load strength from location A to E has high strength values according to ISRM [8] while location A still have the highest strength value. All the locations have moderate Schmidt hammer rebound values. From all the locations, the percentage composition of Quartz belongs to the "highest" class. It can thus be concluded generally that the rock type is of high strength.

The highest equivalent quartz content and highest penetration rate were recorded at location D. Location A has the lowest penetration rate. The different penetration rates were largely due to the heametite variation in each of the locations.

4.2 Correlation Analysis between Strength Characteristics to Drillability Efficiency of Migmatite Gneiss

From Figure, it was observed that penetration rate exhibits a direct relation with the uniaxial compressive strength value. This indicates that when penetration rate increases, the uniaxial compressive strength increases as reflected in Equation 6.

$$PR = 0.009\ UCS - 1.035,\ R^2 = 0.854 \quad \text{.......... ....}(6)$$

where PR = Penetration rate (m/min), UCS = Uniaxial Compressive Strength (MPa)

In Figure 2, the relationship between Penetration Rate and Point Load Strength follows a linear function as shown in Equation 7.

$$PR = 0.409\ PLS - 0.881,\ R^2 = 0.824 \quad \text{.......... ....}(7)$$

where PR = Penetration rate (m/min), PLS = Point Load Strength (MPa)

Figure 3 shows that the penetration rate is directly proportional to Schmidt hammer value as shown in Equation (8).

$$PR = 0.0295\ SHV - 0.055,\ R^2 = 0.845 \quad \text{.......... ....}(8)$$

where PR = Penetration rate (m/min), SHV = Schmidt Hammer Valve (%)

In contrary, [4] and [9] got a negatively correlated values of PR against UCS, PLS and SHV while in this study, it is positively correlated.

Figure 4 shows that the penetration rate is inversely proportional to Quartz equivalent content as shown in Equation (9)

$$PR = 0.029\ EQC + 3.167,\ R^2 = 0.767 \quad \text{.......... ....}(9)$$

where PR = Penetration rate (m/min), EQC = Equivalent Quartz Content (%)
From the study, it is evident that the higher the Equivalent Quartz Content (EQC), the higher the uniaxial strength and point load strength. This implies that the mineralogical composition of migmatite gneiss samples from Beautiful rock Quarry has a great influence on its mechanical properties, and more so, it is evident that increase in EQC will lead to decrease in Penetration Rate.

From the thin section analysis, the mineral composition of the rock, shape, size and textural composition were determined. Texturally, it was observed that locations A,C,D,E are medium to coarse grained while location B is coarse grained.

IV. CONCLUSION

The relationship between the data obtained from the rock mechanics and drillability tests were evaluated by using regression and correlation analysis with the aid of EXCEL Program. The equation of the best-fit line and the correlation coefficient were determined for each regression.

Predicting the penetration rate is very important in rock drilling. The penetration rate is a necessary value for cost estimation and planning of any drilling programme. One of the most important factors affecting drillability is rock properties. Among these properties are uniaxial compressive strength, point load strength, Schmidt hammer rebound value (Hardness) and quartz equivalent content. As a pre planning measure for drilling programme, an ideal of the likely penetration rate can thus be estimated from the relationships generated.

V. RECOMMENDATIONS

The strength properties of the samples tested from beautiful rock quarry have a very high strength, therefore, it is recommended for various constructional purposes.
Further study is required to check the validity of the derived equation for the other rock types.

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