Effect of Physico-Mechanical Characteristics of Some Basement Complex Rocks on their Drillability in North Central Nigeria

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Abstract: ***The work examined the effect of physical and mechanical characteristics of some basement complex rock types on their drillability in north central Nigeria. The work was carried out using the field data and rock samples collected from the four locations of four different rock types, namely; City Gate (Porphyritic Granodiorite); Garaku (Granite); Gawaraka (Biotite Granite); and Madalla (Hornblende Granite). The physical properties(hardness, density and Water Absorption), mechanical properties (Uniaxial Compressive Strength (UCS), Point Load and Brittleness) and the drilling rate index (DRI) were determined in the laboratory using the appropriate standards. The results of the investigation showed that physico-mechanical characteristics of rocks have influence on the drillability. City Gate (Porphyritic Granodiorite) that has the lowest hardness of 45, lowest density of 2.661kg/m^3 and highest water absorption value of 0.4%; was found to have the highest DRI value of 61. However, Madalla with the highest hardness of 52, has the highest density of 2.831kg/m^3 and lowest water absorption value of 0.25%; has the lowest DRI value of 32. City gate and Madalla are classified as having high and low DRI respectively. This same trend was observed in the mechanical properties. City Gate (Porphyritic Granodiorite) with the highest DRI value was found to have the UCS value of 88.6MPa, point load value of 4.68MPA, with brittleness value of 78.23 while Madalla with lowest DRI value has UCS, point load and brittleness values of 126.6MPA, 6.97MPA and 49.78% respectively.***

Keywords: DRI, Drillability, Mechanical, Physical, Rock

1. Introduction

The basement complex is one of the three major litho-petrological components that make up the geology of Nigeria (Obaje, 2009). The basement complex of Nigeria occur east of the West African Craton, northwest of the Congo Craton, and south of the Tuareg shield (Ibrahim, 2008). According to Ajibade (1982), the basement complex rocks are subdivided into migmatite-gneiss complexes, the older metasediments, the younger metasediments, the older granites and younger granites alkaline ring complexes and volcanic. He added that older granites are widespread throughout the basement complex, the granitoids have been emplaced into both the migmatite-gneiss complex and the schist belts and they occur in all parts of Nigeria.The Precambrian crystalline basement complex covers nearly 60% of land surface of Nigeria and extends to neighboring countries (Agbor, 2014). The study areas namely Niger, Nassarawa and Abuja (FCT) are typical examples of the precambrian basement Complex of Nigeria. The precambrian basement complex of North Central Nigeria consist of migmatite/migmatitic gneiss, including banded varieties; the schist belt constituted by mica schist and tremolite-schist. Graphite schist with occasional marbles and dolomite (Obiora and Ukeagbu, 2009).

Drillability is a term used in construction to describe the influence of a number of parameters on the drilling rate (drilling velocity) and the tool wear of the drilling tool (Thuro and Spaun, 1996). The drillability of a rock mass is determined by various geological and physical /mechanical parameters. Drillability of rock is one of the important parameter to decide the progress and economics of excavation.

Physical and mechanical properties influencing fragmentation of rocks include Young's modulus, compressive and tensile strength (Kahraman*et al*., 2003a). In the work of Kahraman *et al* (2003a), it was stated that drillability of the rocks mainly depends on operational variables and rock characteristics. They went further to add that operational variables known as the controllable parameters are rotational speed, thrust, blow frequency and flushing while rock properties and geological conditions are the uncontrollable parameters. They concluded that the effect of geological discontinuities on the efficiency of mechanical rock destruction is an important point, which is partly neglected by research.

According to Yarali and Soyer (2011), the physical/ mechanical properties that influences the drilliability of rock includes: compressive strength, Brazilian tensile strength (BTS), Shore scleroscope hardness (SSH), porosity, density as well as rock brittleness.

For many researchers, compressive strength of rock is the most widely used parameter for rock drillability (Paone and Madson, 1966; Paone*et al*., 1969a,; Fowell and McFeat-Smith, 1976; Poole and Farmer, 1978; Aleman, 1981; Karpuz*et al*., 1990; Akcin*et al*., 1994; Bilgin*et al*., 1996; Huang and Wang, 1997; Kahraman, 1999; Kahraman*et al*., 2003a,b; Tanaino, 2005; Akun and Karpuz, 2005. Yarali and Soyer (2011) investigated the effect of uniaxial compressive strength on the drilliability of rock, it was observed that the drilliability of the rock decreases with increase in the uniaxial compressive strength

Kahraman*et al*., (2000) showed that for the rocks tested, the drillability index is closely related to rock compressive strength. Kahraman*et al.*, (2003a) found that uniaxial compressive strength is one of the dominant rock properties affecting the penetration rate of percussive drills. Pathinkar and Misra (1980) concluded that conventional rock properties such as uniaxial compressive strength, tensile strength, specific energy, shore hardness and mohr hardness do not individually give good correlation with the penetration rate of percussive drilling. That means for this research work, uniaxial compressive strength will not be used in isolation for accurate prediction of the drilliability of the rock types under consideration.

Various method have been adopted for determination of compressive strength of rocks (ISRM 1981). Among these are Uniaxial compressive strength test method, point load test method and Schmidt hammer rebound value method. According to ISRM (1981), uniaxial compressive test method is the accurate method of determine the compressive strength for detail design. It is more accurate, but more expensive because it requires more precision.

Point load and Schmidt hammer equivalent methods are always refer to as indirect method ISRM (1981).They are faster, easier, cheaper but less accurate than the uniaxial compressive strength. In this work, the three methods were adopted

Yenice*et al*. (2009) studied the relation between drillability index of marbles (DRI) and their physical, mechanical and textural characteristics. As a result, they determined significant relations between marbles density, hardness, uniaxial compressive strength, tensile strength and DRI. Kahraman*et al.* (2000) showed that for the rocks tested, the drillability index is closely related to rock compressive strength, tensile strength, N type Schmidt hammer rebound number and impact strength. Kahraman*et al*. (2003a) found that uniaxial compressive strength, tensile strength, the point load strength and the Schmidt hammer value are the dominant rock properties affecting the penetration rate of percussive drills. As earlier stated by Pathinkar and Misra (1980), tensile strength cannot be used in isolation of others to determine the drilliability of rock.

Brittleness is one of the most important mechanical properties of rocks. Some researchers have investigated the relation between brittleness and drilling rates. However, there are no available studies on the relation between the brittleness and the DRI (Yarali, 2007; Altindag, 2010).

Brittleness is defined by a few researchers for different purposes. Hetenyi (1966) defined brittleness as the lack of ductility. Ramsey (1967) defined a rock to be brittle when its internal cohesion of is broken. Obert and Duvall (1967) defined brittleness as when materials such as cast iron and many rocks terminate by fracture at or slightly beyond the yield stress''. Generally, brittleness is defined as a property of materials that rupture or fracture with little or no plastic flow.

Drilling plays a vital role in mining and it affect the overall operational cost (Busuyi, 2009). Therefore, the prediction of the penetration is a necessary value for the cost estimation and the planning of the project (Okewale and Olaleye, 2013). They observed that the performances of a drilling operation are dependent on technical characteristics of the drilling, drillability of rock and work organisation.

The work therefore determined the physical and mechanical properties of Rock types; asses the Drilling rate index; and developed the regression model of the drilling rate and determined the index properties for drillability prediction.

2. Materials and Methods

a) Materials

Porphyritic Granodiorite, Granite, Biotite Granite and Hornblende Grante rock types were used for the determination of the physical and mechanical properties required for the drillability prediction.

Location of Study Areas

The study areas are located in Abuja FCT, Nassarawa and Niger states, in the North Central Nigeria. The locations are as shown in Fig. 2.1 while the locations and the respective coordinates are as shown in Table 2.1.

Table 2.1: Location and Coordinates of Studied **Areas**

S/N	Location	State	Coordinates
1	City Gate (CG)	Abuja FCT	N 9° 2′ 11.7″ ; E 7° 26′ 55.8″
2	Garaku (GA)	Nassarawa	N 8° 49′ 60″; E 8° 7′ 0″
3	Gawaraka (GR)	Niger	N 9° 11′ 60″; E 7° 18′ 0″
4	Madalla (MD)	Niger	N 9° 6′ 16″; E 7° 12′ 48″

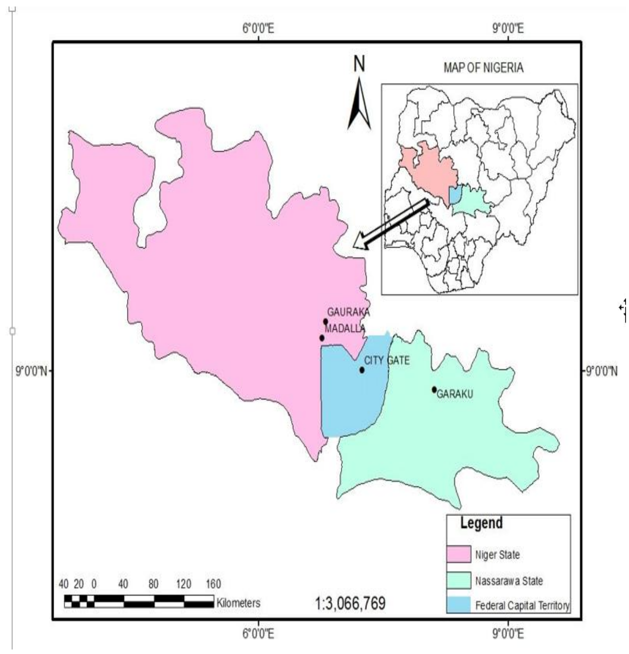

Figure 2.1: Map showing the study area (Researcher's Field work)

b) Methods

1) Determination of Schmidt Rebound Hardness

This method involves the use of Schmidt Impact hammer for the hardness determination of rocks in accordance to ISRM (1989). The test surface of test specimen were ensured to be smooth and flat over the area covered by the plunger. Twenty individual tests were conducted on each samples. Tests that caused cracking or any other visible failure were rejected.

2) Determination of Density
The specimen volume V was calculated from an average of several calliper readings for each dimension. The specimen was dried to constant mass at a temperature of 105°C and allowed to cool for 30 minutes in a desiccator and the mass M was determined. ISRM (1989) Standard was used to determine the density.

3) Determination of water Absorption
All the steps for the determination of Water Absorption were followed in accordance to ISRM (1989).

4) Determination of Uniaxial Compressive Strength
A Riedligen testing machine capable of loading up to 3000 kN at rate conforming to the ISRM (1989) requirement was used.

5) Determination of Point Load Strength
The Point Load strength test is intended as an index test for the strength classification of rock materials. The test procedure was in accordance with ISRM (1989).
The size-correction Point Load Strength Index I_s (50) was unnecessary because the diametral tests were all conducted at D = 50 mm

6) Determination of Brittleness Value
The brittleness test is basically an aggregate impact test and this was conducted in accordance with the Norwegian Soil and Rock Engineering Association (Borg, 1988).

The aim of this test is to determine impact value of coarse aggregates. The rock was broken into smaller aggregate all passing 12.5 mm. Not less than 500 gm of the coarse aggregate was introduced into the cup of the rammer. Twenty blows of 20 kg load was released on the sample inside the cup. The sample was thereafter packed from the cup and sieve with 11.2 mm sieve. Weight of undersize and oversize fractions were recorded.

3. Results and Discussion

a) Physical Properties
The results of the physical properties tests are as shown in Table 3.1. The Hardness, Density and Water Absorptions are 45, 2.661 kg/m3 and 0.40% for City Gate; 50, 2.734 kg/m3 and 0.30% for Garaku; 49, 2.694 kg/m3 and 0.33% for Gawaraka; and 52, 2.831 kg/m3 and 0.25% for Madalla.

Table 3.1: Physical Properties of the selected rock samples

Location	Rock Type	Hardness	Density	Water Absorption
City Gate	Porphyritic Granodiorite	45	2.661	0.40
Garaku	Granite	50	2.734	0.30
Gawaraka	Biotite Granite	49	2.694	0.33
Madal la	Hornblende Granite	52	2.831	0.25

b) Mechanical Properties
Table 3.2 shows the results of the mechanical properties of the selected rocks. The Uniaxial Compressive Strength (UCS), Point Load (PL) and Brittleness (Br) are 88.6 MPa, 4.68 MPa and 78.23% for City Gate; 112.7 MPa, 6.56 MPa and 61.37 % for Garaku; 96.1 %, 5.60MPa, and 64.12% for Gawaraka; and 126.6MPa, 6.97MPa and 49.78% for Madalla.

Table 3.2: Mechanical Properties of the selected rock samples

Location	Rock Type	UCS (MPa)	Point Load (MPa)	Brittleness (%)
City Gate	Porphyritic Grano diorite	88.6	4.68	78.23
Garaku	Granite	112.7	6.56	61.37
Gawaraka	Biotite Granite	96.1	5.60	64.12
Madalla	Horn blende Granite	126.6	6.97	49.78

c) Drilling Rate Index
Table 3.3 shows the DRI of the selected rock samples. The DRI values are 61, 43, 50 and 32 for City Gate, Garaku, Gawaraka and Madalla respectively.

Table 3.3: Drilling Rate Index (DRI) of the selected rock samples

Location	Rock Type	UCS	Classification
City Gate	Porphyritic Granodiorite	61	High
Garaku	Granite	43	Medium
Gawaraka	Biotite Granite	50	High
Madalla	Hornblende Granite	32	Low

d) Relationship between physico-mechanical characteristics of rocks and the Drilling rate Index.

1) Physical properties and DRI
The relationship between the physical properties and DRI are as shown in Fig. 3.1-3.3. It was observed that the equations connecting hardness, density and water absorption with DRI are linear. The equations are expressed in (6), (7) and (8)

$$DRI = -4.038SH + 244.38 \quad (6)$$
$$DRI = -160.07\rho + 483.49 \quad (7)$$
$$DRI = 193.22W_A - 15.331 \quad (8)$$

2) Mechanical properties and DRI
The relationship between mechanical properties and DRI are as shown in Fig. 3.4-3.6. A linear relationship was observed in the equations connecting UCS, PL and Br with DRI. These equations are expressed in (9), (10) and (11).

$$DRI = -0.7001\sigma_c + 120.71 \quad (9)$$
$$DRI = -11.616PL - 115.64 \quad (10)$$
$$DRI = 1.0295Br - 18.742 \quad (11)$$

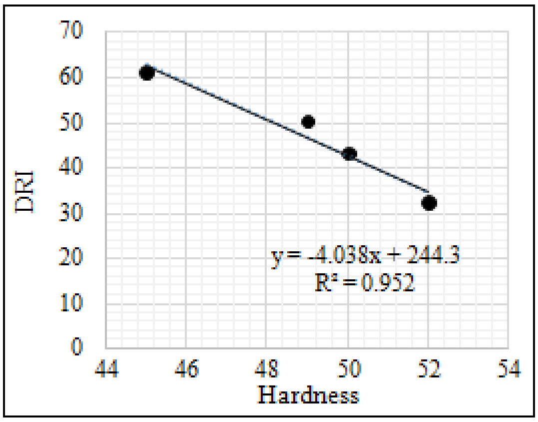

Figure 3.1: Plot of DRI against Hardness

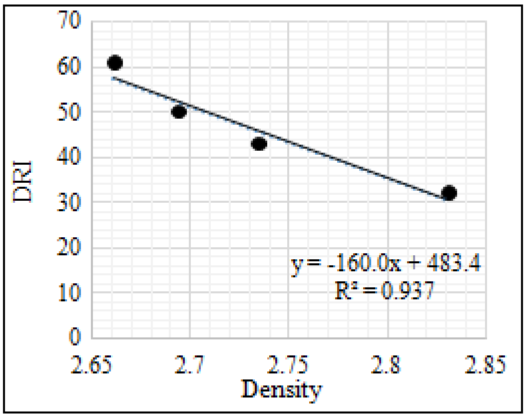

Figure 3.2: Plot of DRI against Density

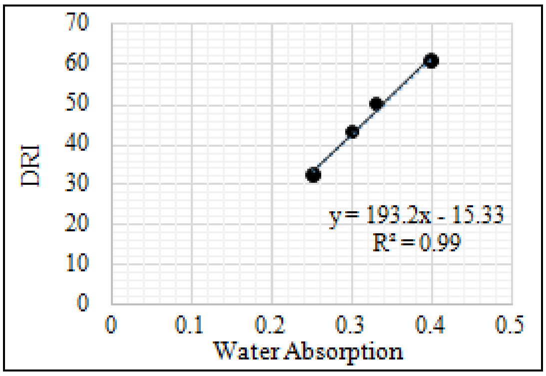

Figure 3.3: Plot of DRI against Water Absorption

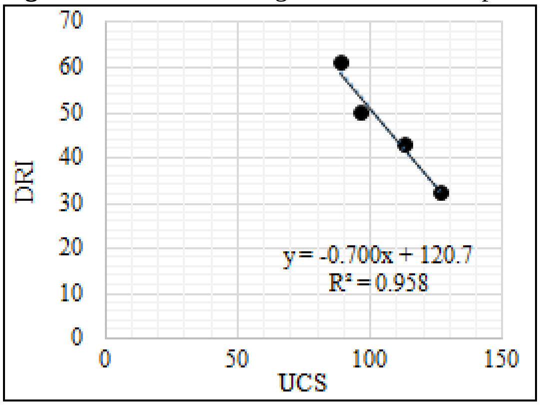

Figure 3.4: Plot of DRI against UCS

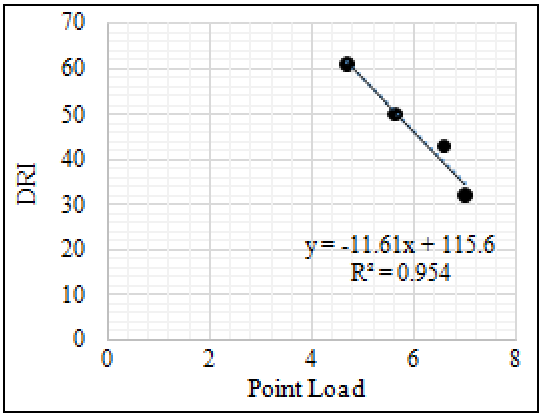

Figure 3.5: Plot of DRI against Point Load

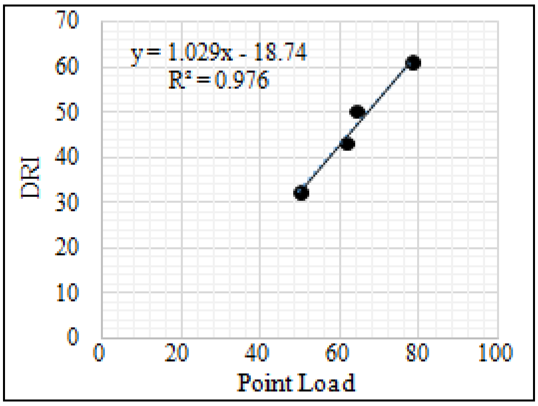

Figure 3.6: Plot of DRI against Hardness

4. Conclusion

The study of the effect of physico-mechanical characteristics of rock on their drillability is essential in the selection of drilling equipment and tool needed for drilling operations in the quarry or mine. Moreover, the knowledge of drillability prediction using physico-mechanical properties of rocks is important in proper production planning and effective drilling cost analysis. The various physico-mechanical properties were found to exhibit strong relationship with DRI. It can therefore be concluded that the various physical and mechanical characteristics of rock have great influence on the drillability.

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