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Rock Brittleness Index of Gneiss Rock Selected From Quarries in Kwara State, Nigeria

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ROCK BRITTLENESS INDEX OF GNEISS ROCK SELECTED FROM QUARRIES IN KWARA STATE, NIGERIA

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Abstract: *This research examines the brittleness index in some gneiss rock samples collected from four different quarries in Kwara State, Nigeria. The gneiss samples were tested in the laboratory to determine chemical and mineral compositions using X-ray fluorescence (XRF) spectrometer and atomic absorption spectrophotometer (AAS). Schmidt rebound hammer (L type) was used to estimate compressive strength of the rock samples. The average gneiss silica contentis72.1 %.The average uniaxial compressive strength and tensile strength are 138.5 MPa and 5.81 MPa respectively, classified as extremely high and very high strength. The average density of the rock is 2.6 g/cm^3. The result of statistical correlation indicates the dominant factors (uniaxial compressive strength and density) affecting the brittle nature of the rock samples having high coefficient of correlation. The relationship between the strength parameter, area under the line $\sigma_C - \sigma_T$ of the graph falls within the range of 285.78 – 462. 65MPa. The rock brittleness concept value obtained from the graph was within 96.62 – 136.68MPa. The brittleness index of the selected quarries serves as a reference for the selection of drill bits and drilling equipment in accordance to the nature of the rock within the basement complex.*

Keywords: *Brittleness, Rock, Correlation, Chemical and Mineral Composition, Density, and Strength.*

1. Introduction

The scope of the project is limited to gneiss rock samples. The samples were free from joints, fissures and other discontinuities. To determine the brittle nature of rocks these test are carried out, compressive strength, rock characteristics e.t.c. These tests were carried out on samples of gneiss rock located at four different locations within Ilorin, Kwara State, Nigeria. 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 Drill Rate Index [1, 2]. It was emphasized that in actual drilling, some relatively low strength rocks are more difficult to drill than the rocks with higher strength and brittle rocks although very hard can be easily drilled when compared to less hard but tougher rocks [3]. In other words, there is very little plastic deformation before failure occurs. However, stated that with higher brittleness the following facts are observed [4]: low values of elongation; fracture failure; formation of fines; higher ratio of compressive to tensile strength; higher resilience; higher angle of internal friction; and formation of cracks in indentation.

2. Location of study Area

The study area covers Ilorin, Kwara state, Nigeria. These states fall within the precambrian of north-central Nigeria, which is a part of Nigeria basement complex. Sixteen groups of rocks could be identified in the basement complex [5]. The location of the study areas are presented in Table1 and Figure 1**:**

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Table 1 Description of the study areas

Location Code	Quarry	Town	Co-ordinates of Locations
KLD	Chinese Quarry	Kulende	08^0 81' 50" N004^0 54' 39" E
OKY	Kamwire Quarry	Oke-Oyi	08^0 33' 18" N004^0 45' 31" E
BDSD	Ibrosalam Quarry	Bode-Sadu	07^0 16' 58" N005^0 14' 55" E
ADW	Wemmy Station	Adewole	08^0 28' 28" N004^0 30' 22" E

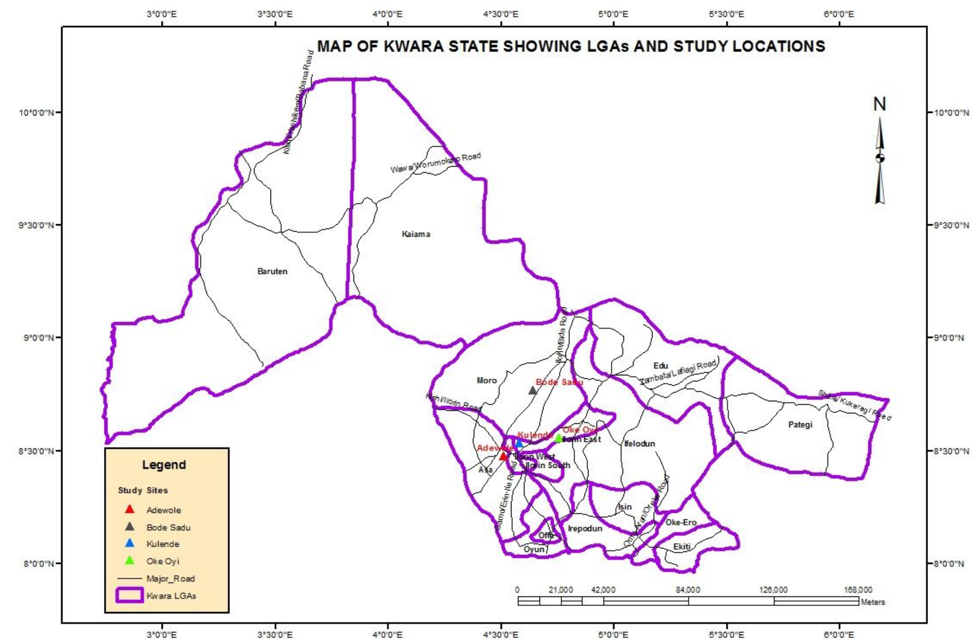

Figure 1 : Map of Nigeria showing the location of the study areas

3. Materials and Methods

3.1 Rock Samples

The rock samples used for the various test was*Gneiss*lumps.

3.1.1 Mineral Composition

The study of the thin section was carried out on the slides prepared in accordance with procedure suggested by [6]. The prepared slides were viewed with the aid of polarizing microscope. The mineral composition of the rocks were estimated using modal analysis, the percentage of each mineral and their forms were also determined as presented in Table 2:

Table 2 Estimation modal

Mineral	KLD	OKY	BDSD	ADW
Quartz, %	28	29	35	33
Feldspar, %	44	42	48	45
Garnet, %	9	8	-	-
Opaque, %	7	5	4	6
Biotite, %	12	16	13	16
Total (%)	100	100	100	100
Rock Type	Gneiss			

3.2 Chemical CompositionDetermination

A Laboratory Atomic Absorption Spectrophotometer (AAS) would be used to determine percentage oxides of elements present in the sample as suggested by [7]. Standard solution, each of the elements was prepared in flask for the determination of the element. Each standard solution was aspirated which the aspiratory tube of the AAS and a range of values were obtained. Appropriate wavelength setting, range setting, slit setting, and adjustment were done before analyzing for each element. Table 3 present the chemical composition of the gneiss and granite gneiss samples.

Table 3 Chemical composition of the gneiss samples

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	Total (%)
A(KLD)	72.15	12.13	0.60	0.09	2.11	1.91	3.64	5.38	98.01
B(OKY)	70.35	13.31	1.46	0.01	2.21	1.95	3.65	5.75	98.69
C(BDSD)	73.05	12.27	0.83	0.01	1.88	1.92	3.65	5.38	98.99
D(ADW)	72.88	12.23	0.73	0.06	1.19	1.94	3.63	5.36	98.02

3.3 Rock Density Determination

Density is a measure of mass per unit of volume. It is sometimes defined by unit weight and specific gravity. Density is common physical properties. The dry density of rock samples of irregular form from the locations. The Saturation and Buoyancy technique for irregular rock sample was adopted and the procedures follow the standard suggested by [8] and conform to [9]. The saturated volume of the sample was calculated using Equations 1 and 2:

$$\text{Saturated volume of samples} = V_2 - V_1 \quad (1)$$

Where: V_1 (ml) is the initial water level; and V_2 (ml) is the final water level in the cylinder after the immersion of the irregular rock sample.

The dry density of the rock samples was calculated using Equation 2:

$$\text{Dry density} = \frac{M}{V_2 - V_1} \quad (2)$$

Where: M (g) is the oven dried mass at a temperature of 105^0C;
V_1 (ml) is the initial water level; and
V_2 (ml) is the final water level in the cylinder after the immersion of the irregular rock sample.

3.4 Strength Determination

Various strength tests were carried out and they include; compressive test, Schmidt rebound hardness test and tensile test.

3.4.1 Uniaxial Compressive Strength Test

The uniaxial compressive strength of the rocks was determined using 1100kN compression machine. The rock specimen to be tested was placed on the machine platen. The machine is jacked manually, the release valve was closed, sealing off the exhaust system thereby allowing the pump to build up pressure and activate the ram. As the load was applied, it was shown on the gauge after failure and the failure load was recorded. The test procedure was in accordance with [6, 10]. The uniaxial compressive strength was determined using Equation 3:

$$Co = P/A \quad (3)$$

Where:Co is the uniaxial compressive strength (MPa); P is the applied peak load (kN); and A is the area (m^2).

3.4.2 Schmidt Rebound Hardness Test

The Uniaxial Compressive Strength of the rock samples were estimated from the values of the equivalent Type L Schmidt Hammer Hardness and the density of the rock. The UCS was used for the strength classification and characterization of the intact rock for the generalized Hoek – Brown criterion for obtaining the friction angle and the cohesion.

3.4.3 Determination of Tensile Strength

Tensile strength was calculated on the block samples prepared using point load tester.This test was carried out in accordance with [6, 10]. The units of the point load index are MPa and whereas the test is considered to cause tensile failure it can be converted to compressive strength (Co) by Equation 4:

$$Co = 30\, Is_{(50)} \quad (4)$$

The general relationship between tensile strength (To), the point load strength (Is) and compressive strength (Co) was expressed in Equation 5:

$$Co = 20To = 30Is \quad (5)$$

3.4.4 Determination of Brittle Fracture

The determination of brittle fracture is largely empirical. Usually, brittle fracture measures the relative susceptibility of a material to two competing mechanical responses, deformation and fracture; ductile–brittle transition. The used brittle fracture concepts in this study are given below:

(a) The determination of brittle fracture from the ratio of uniaxial compressive strength to the tensile strength for the rock was calculated using in Equation 6:[4]

$$B_1 = \frac{\sigma_c}{\sigma_t} \quad (6)$$

(b) The determination of brittle fracture from tensile strength and uniaxial compressive strength was calculated usingEquation 7: [4]

$$B_2 = \frac{\sigma_c - \sigma_t}{\sigma_c + \sigma_t} \quad (7)$$

(c) The determination of brittle fracture from the area under the line of $\sigma_c - \sigma_t$ graph, was calculated using Equation 8: [11]

$$B_3 = \frac{\sigma_c \times \sigma_t}{2} \quad (8)$$

(d) The determination of brittleness concept, B_4 is given by using Equation 9: [2]

$$B_4 = (\sigma_c x \sigma_t)^{0.72} \quad (9)$$

Where: B_1, B_2 and B_3 and B_4 denote are brittle fracture, σ_c is Compressive Strength (Mpa) and σ_t is Tensile Strength (MPa)

Determination of brittle fracture in rock is very important; gneiss samples are selected in such a way that its average strength will represent the strength of the entire rock in-situ. The act of properly selecting such a sample is called sampling.

4. Results and Discussions

4.1 Physical Properties Results

4.1.1 Density

Table 4 present the results of average density of the rock samples.

Table 4 Summary of density results

Code	Quarry	Average Density (g/cm^3)	Average Unit Weight (kN/m^3)
KLD	Chinese	2.65	25.98
OKY	Kamwire	2.56	25.09
BDSD	Ibrosalam	2.64	25.88
ADW	Wemmy	2.57	25.19

4.2 Strength Results

4.2.1 Schmidt Rebound Hardness

Table 5present the results of the schmidt rebound hardness value and equivalent compressive strength. The results were arranged in descending of values. The lower 50% of the values were discarded and the average obtained of the upper 50% values for each of the rock samples as Suggested by [8]. The average of the upper half is taken to represent the average rebound values of their respective hardness.

Table 5 Results of schmidtrebound value and equivalent uniaxial compressive strength

Location Code	Average Schmidt Rebound Value	Equivalent Uniaxial Compressive Strength, (MPa)
KLD	51.6	149
OKY	48.4	115
BDSD	52.4	149
ADW	47.2	141

4.2.2 Uniaxial Compressive and Tensile Strength

The strength parameter of the rock samplesaccording to their respective location codes and classification are presented in Table 6:

Table 6 Summary of strength characterisation

Location Code	UCS (MPa)	T_o (MPa)	Rock Classification
KLD	149	6.21	Very High Strength
OKY	115	4.97	Very High Strength
BDSD	149	6.21	Very High Strength
ADW	141	5.87	Very High Strength

4.2.3 Rock Brittleness Index Results

The result obtained from the computation of rock brittleness index is presented in Table 7

Table 7 Summary of rock brittleness index result

Code	KLD	OKY	BDSD	ADW
B_1	23.9	23.1	23.9	24.0
B_2	0.92	0.92	0.92	0.92
B_3	462.65	285.78	462.65	413.84
B_4	136.68	96.62	136.68	126.14
BI	23.9	23.1	23.9	24.0

4.2.4 The Relationship between Uniaxial Compressive and Tensile Strength

The graphs of the relationship between compressive and tensile strength for all the study area are presented in Figure 2:

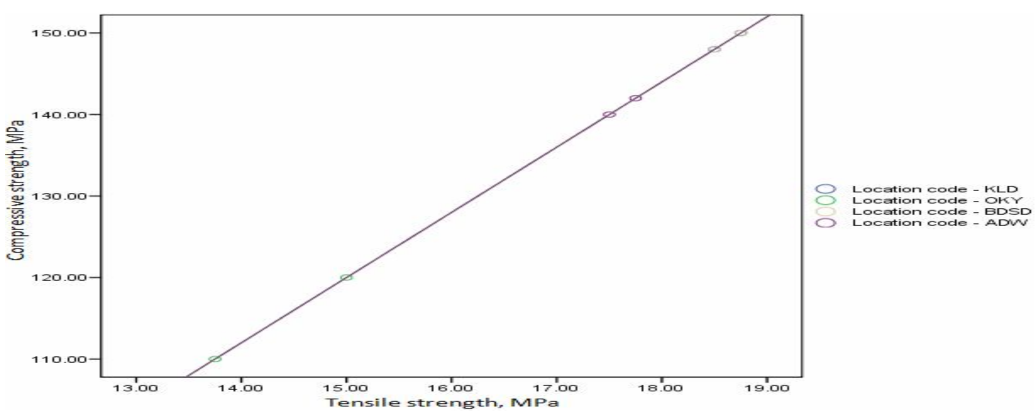

Figure 2 : A graph of UCS against tensile strength (location A -D)

4.3 Regression

4.3.1 The Relationship between Uniaxial Compressive Strength, Schmidt Rebound Value and Density

The graphs of the relationship between compressive strength, schmidt rebound value and density is presented in Figure 3. The regression model equation for determining the relationship between compressive strength, schmidt rebound value and density is expressed in Equation 10:

$$UCS = -1199.024 - 7.744RBV + 67.513DEN \quad (10)$$

Where;

UCS is the Compressive Strength (MPa);RBV is the Schmidt Rebound Value; and

DEN is the Unit Weight (kN/m^3).

4.3.2 The Relationship between Brittleness Index, Uniaxial Compressive Strength, and Density

The graphs of the relationship between brittleness index, compressive strength, and density is presented in Figure 4. The regression model equation for determining the relationship between brittleness index, uniaxial compressive strength and density is expressed in Equation 11:

$$BI = 32.043 - 5.126DE + 0.036UC \quad (11)$$

Where;BI is the Brittleness Index; DE is the Density (g/m^3); andUC is the Uniaxial Compressive Strength (MPa).

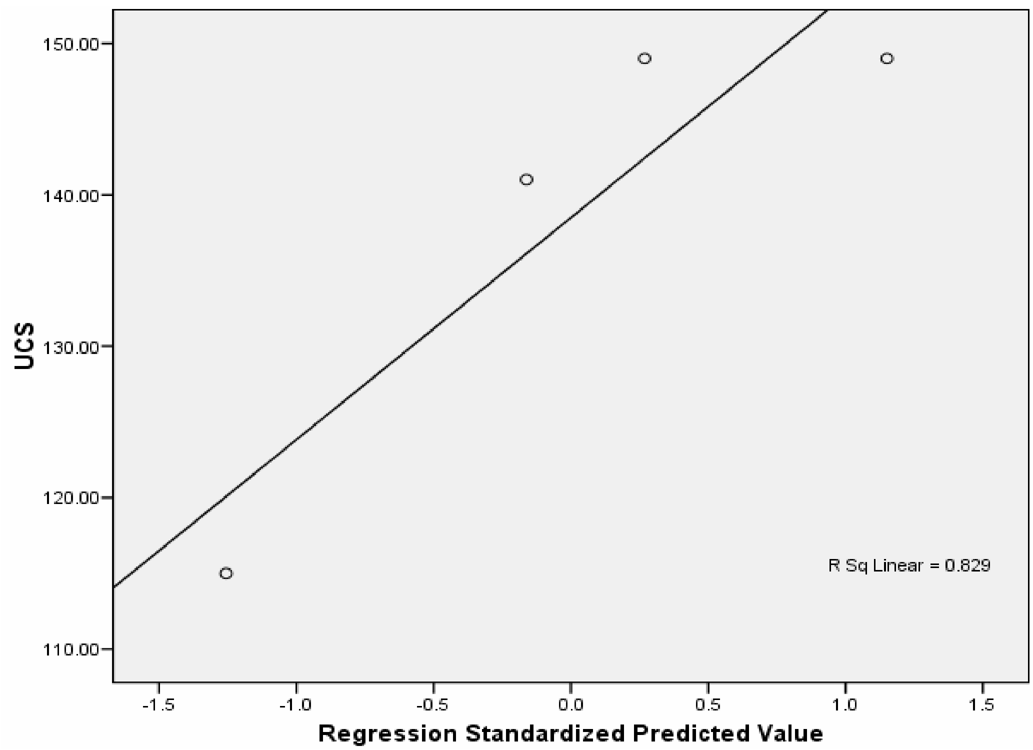

Figure 3 : A graph of UCS against regression standardized predicted value

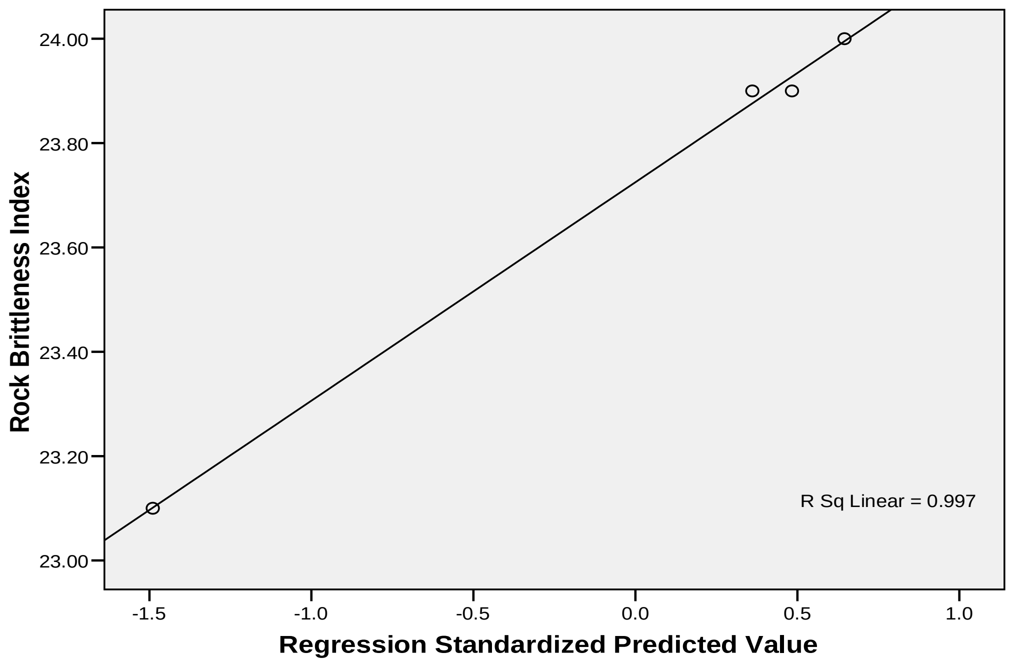

Figure 4 : A graph of rock brittleness index against regression standardized predicted value

4.4 Discussions

4.4.1 Chemical Composition Analysis

The major element chemical compositions of the gneiss rock samples were presented in Table 3. SiO_2 content ranges between 70.35% and 73.05% with an average of approximately 72%. Also, there are variations in other content, Al_2O_3 content ranges from 12.13% to 13.31%. K_2O while Na_2O varies from 3.63% to 3.65% content range from 5.36% – 5.75%. The gneiss sample classification was based on the variation in chemical composition of the samples.

4.4.2 Density Analysis

The density is present in Table 4. All the rock samples tested possess a density of between 2.5g/cm^3 – 2.7g/cm^3 while their unit weight ranged between 25.09 – 25.98 kN/m^3. Table 4 shows that Chinese Quarry (KLD) has the highest density values whileKemwire (OKY) has the least.

4.4.3 Uniaxial Compressive Strength Analysis

The compressive strength values obtained from all the study areas is presented in Table 5 with their mean value. The strength characterization of the gneiss rocks shows that uniaxial compressive strength ranges from 115 - 149 MPa, classified to have an extremely high uniaxial compressive strength. The tensile strength values obtained from all the study areas is presented in Table 5 with their mean value. The strength characterization of the gneiss rocks shows that tensile strength ranges from 4.97 – 6.21 MPa, classified to have very high tensile strength.

4.4.4 Rock Brittleness Analysis

The brittleness values obtained as presented in Table 7 shows a varied rock brittleness values ranged from 23.1 to 24.

4.4.5 Analysis on the Relationship between UCS and Tensile Strength

The graphs of the relationship between uniaxial compressive strength and Tensile strength are presented in Figure 2. The ratio of compressive strength to tensile strength which is the rock brittleness index varied between 23.1 and 24. Considering the area under the line $\sigma_C - \sigma_T$ of the graph falls within the range 285.78MPa to 462.65MPa. The rock brittleness concept value obtained from the graph was within 96.62 – 136.68MPa.

4.4.6 Analysis on the Relationship between UCS, Schmidt Rebound Value and Density

The plot of UCS and regression standardized predicted value for schmidt rebound value and unit weight shows that the model is valid having multiple coefficient of R^2 = 0.829 (82.9%) as presented in Figure 6. Also, the summary of the models confirms the validity of the model equation having multiple correlation coefficient of R^2 = 0.829 this show that 82.9% of the variation in UCS could be attributed (schmidt rebound value and Unit Weight) of the gneiss rocks.

4.4.7 Analysis on the Relationship between Brittleness Index, UCS and Density

The plot of brittleness index and regression standardized predicted value for UCS and density shows that the model is valid having multiple coefficient of R^2 = 0.997 (99.7%) as presented in Figure 7. Also, the summary of the models confirms the validity of the model equation having multiple correlation coefficient of R^2 = 0.999 this show that 99.9% of the variation in brittleness index could be attributed (UCS and Density) of the gneiss rocks.

5. Conclusions

The results of the various analyses such as laboratory analyses and field measurements carried out on the 16 samples from the four locations show that the strength characterization of the gneiss rock sample has uniaxial compressive strength ranging from 245-320 MPa, classified to have high uniaxial compressive strength. The result of tensile strength shows that gneiss rock value ranged from 18.59 – 26.98 MPa which is classified to have high tensile strength. The highest values of the silica content was 73.05% (for location C) and lowest values silica content was 70.35% which was obtained from the chemical composition of the gneiss rock samples; these indicate the gneiss rock is of high percentage of quartz mineral content. The brittleness of B_3 concept can be seen as an indicator to define the drill cutting efficiency.

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