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DETERMINATION OF PHYSICO-MECHANICAL PROPERTIES OF PETRA QUARRY GRANITE ROCK TYPE IHIEVBE, EDO STATE

Jethro Michael Adebola, Agbalajobi Sunday Ayodele and Ogbodo David Ajayi

[1]Department of Mineral and Petroleum Resources Engineering, School of Engineering, Itakpe Campus, Kogi State Polytechnic, Lokoja. E-mail: adebolajethro@yahoo.com

[2]Department of Minerals and Petroleum Resources Engineering Technology, Institute of Technology, Kwara State Polytechnic, Ilorin. Nigeria.

[3]Department of Mineral and Petroleum Resources Engineering, School of Engineering, Itakpe Campus, Kogi State Polytechnic, Lokoja.

ABSTRACT: *This research work determined the physico-mechanical properties of Petra quarry granite rock type, Ihievbe, Edo State, Nigeria. Five (5) samples were obtained from the quarry and subjected to various laboratory analyses to determine their Uniaxial Compressive Strength, Point load index, Hardness, porosity and density. Five (5) cubic samples were analyzed for Uniaxial Compressive Strength (UCS) with result ranging from 25.75MN/m^2 to 101.08MN/m^2. Five core samples were collected from five bore holes with three core samples each from each bore hole for point load test (PLT) with result ranging from 0.36MN/m^2 to 3.69MN/m^2. Average Hardness test ranges from 47 to 56. Effective porosity result ranges from 0.1% to 0.9%. Bulk Density results ranges from 1.5Mg/m^3 to 3.8Mg/m3. Based on the results, the UCS values confirmed that the rock is extremely strong, and on the basis of International Rock Index Correlation indicates that Point load index ranging from 0.36MN/m^2, to 3.69MN/m^2 is of high strength and hence requires high explosives to obtain proper fragmentation. The results also show that the rock has a low porosity which will enhance the efficiency of blasting operation and the rock has a low density which will facilitate the displacement of rock mass fragmented by blasting. The result showed there is a great relationship between the uniaxial compressive strength and point load index as indicated in the correlation equation as UCS=23.276IS + 15.655 with R^2 = 0.9827 as conformed with the internationally accepted value as UCS=24Is.*

KEYWORDS: Analysis, Blasting, Bulk Density, Correlation, Fragmentation, UCS, Porosity

INTRODUCTION

Physico-Mechanical properties of rocks are important characteristics of rock that determined the variability usage of rock and rock masses including the equipment to be used. The concept cannot be left out in rock engineering aspect. Atici and Comakli (2019) reported that very weak correlations were found between textural coefficient and density and porosity. It is an established fact that an experimental analysis as indicated in tensile strength and compressive strength of a rock can dictate energy that can be absorbed before failure of the rock mass. The texture of the rocks can be fine grained, medium grained or porphyritic in texture with compact interlocking crystals. The charnockites are dark grey in colour and the texture varies from medium grained to coarse grained. They occur along the edges of the older granites (Rahaman, 1976; Talabi, 2013). Afolagboye *et al*., (2016) reported the petrographic characteristics of the rocks). However, Ojo and Olaleye (2002) observed that the strength of rocks does not only vary from rock to rock but also vary within the same rock and various geological conditions. It also varies with season because of moisture effect on the mineral grains. They concluded that the strength of rock decreases with increase in water content due to the reduction in the coefficient of internal friction of the rock particles. Presence of water in rock also increases the deformability of the rock mass. A variety of rocks are when crushed suitable for use as aggregates. Their technical suitability for different aggregate applications depends on their physical characteristics, such as crushing strength, porosity and resistance to impact, abrasion and polishing. Lower quality aggregates may be acceptable for other applications such as constructional fill. Higher quality aggregates are required for demanding applications such as road pavements and in concrete. Among the index tests, the Point Load Test (PLT) is an inexpensive method for rock strength estimation. The testing method and specimen preparation are simple in addition to its possible field and laboratory applications (Basu and Kamran, 2010; Bieniawski, 1975; Broch and Franklin, 1972). Different authors have reported the use of the point load strength index ($I_{S(50)}$) as an indirect method of estimating the compressive or tensile strength of rocks (Basu and Kamran, 2010; Çobanogˇlu and Çelik, 2008; Heidari *et al*., 2012; Li and Wong, 2013) and several studies on the empirical relations between $I_{S(50)}$ and UCS have been reported (Bieniawski, 1975; Broch and Franklin, 1972; Kahraman, 2001; Mishra and Basu, 2013; Salah *et al*., 2014).

Compressive Strength

Compressive strength is the capacity of a material to withstand axially directed compressive forces. The most common measure of compressive strength is the Uniaxial Compressive Strength or unconfined compressive strength. Usually compressive strength of rock is defined by the ultimate stress. It is one of the most important mechanical properties of rock material used in design, analysis and modeling according to Bell (1999) as shown in Table 1.

Table 1: A Rock Classification According to Uniaxial Compressive Strength (UCS) Values (Bell, 1999).

Geological Society (Anon, 1986)		**IAEG (Anon, 1990)**		**ISRM (Anon, 1981)**	
Term	**Strength (MN/m^2)**	**Term**	**Strength (MN/m^2)**	**Term**	**Strength (MN/m^2)**
Very weak	Less than 1.25	Weak	Under 15	Very low	Under 6
Weak	1.25 – 5.00	Moderately Strong	15 – 20	Low	6 – 10
Moderately Weak	5.00 – 12.50	Strong	50 – 120	Moderate	20 – 60
Moderately Strong	12.50 – 50	Very Strong	120 – 230	High	60 – 200
Strong	50 – 100	Extremely Strong	Over 230	Very high	Over 200
Very Strong	100 – 200				
Extremely Strong	Over 200				

(Source: Bell 1999)

Point Load Strength

Point load is the load applied to a single, specific point on a structural member. It is also known as a concentrated load, and example of it would be a hammer hitting a single on a beam according to Brock and Franklin (1998) as shown in Table 2.

Table 2: Point Load Strength Classification (Brock and Franklin, 1998)

Classification	Point Load Strength Index (MN/m^2)	Equivalent Uniaxial Compressive Strength (UCS) (MN/m^2)
Extremely High Strength	Over 10	Over 160
Very High Strength	3 – 10	50 – 160
High strength	1 – 3	15 – 60
Medium Strength	0.3 – 1	5 – 16
Low Strength	0.1 – 0.3	1.6 – 5
Very Low Strength	0.03 – 0.1	0.5 – 1.6

Porosity

Porosity is a measure of relative volume of void space in rock to the total volume.

Table 3: International Association for Engineering Geology (IAEG) 1990a for the Classification of Porosity (Brock and Franklin, 1999)

Class	Porosity (%)	Description
1	Over 30	Very high
2	30 -15	High
3	15 -5	Medium
4	5 -1	Low
5	Less than 1	Very low

Dry Density

Dry or bulk density is defined as the dry weight of soil per unit volume of soil. Bulk density considers both the soils and the pores; whereas, particle density considers only the mineral solid.

Table 4: International Associations for Engineering Geology (IAEG) Anon 1997 for the Classification of Dry Density (Brock and Franklin, 1999)

Class	Dry Density (Mg/m^3)	Description
1	Less than 1.8	Very low
2	1.8 – 2.2	Low
3	2.2 – 2.55	Moderate
4	2.55 – 2.75	High
5	Over 2.75	Very high

METHODOLOGY

Sample Collection

Five samples of blasted boulders were collected at three different faces of the quarry. The coordinates of each location were recorded as shown in Table 4 and Figure 1 depicts the geological map of the study area. The cubed sample was obtained from a boulder which was cubed using cutting machine to prepare a specimen for the laboratory tests.

Table 5: Coordinates of Samples Locations

SAMPLE	LATITUDE	LONGITUDE
1	N07^{0}9’9.30.1’’	E06^{0}8’27.22.6’’
2	N07^{0}9’9.34.5’’	E06^{0}8’27.20.3’’
3	N07^{0}9’9.35.7’’	E06^{0}8’27.23.4’’
4	N07^{0}9’9.32.3’’	E06^{0}8’27.21.9’’
5	N07^{0}9’9.33,4’’	E06^{0}8’27.19.1’’

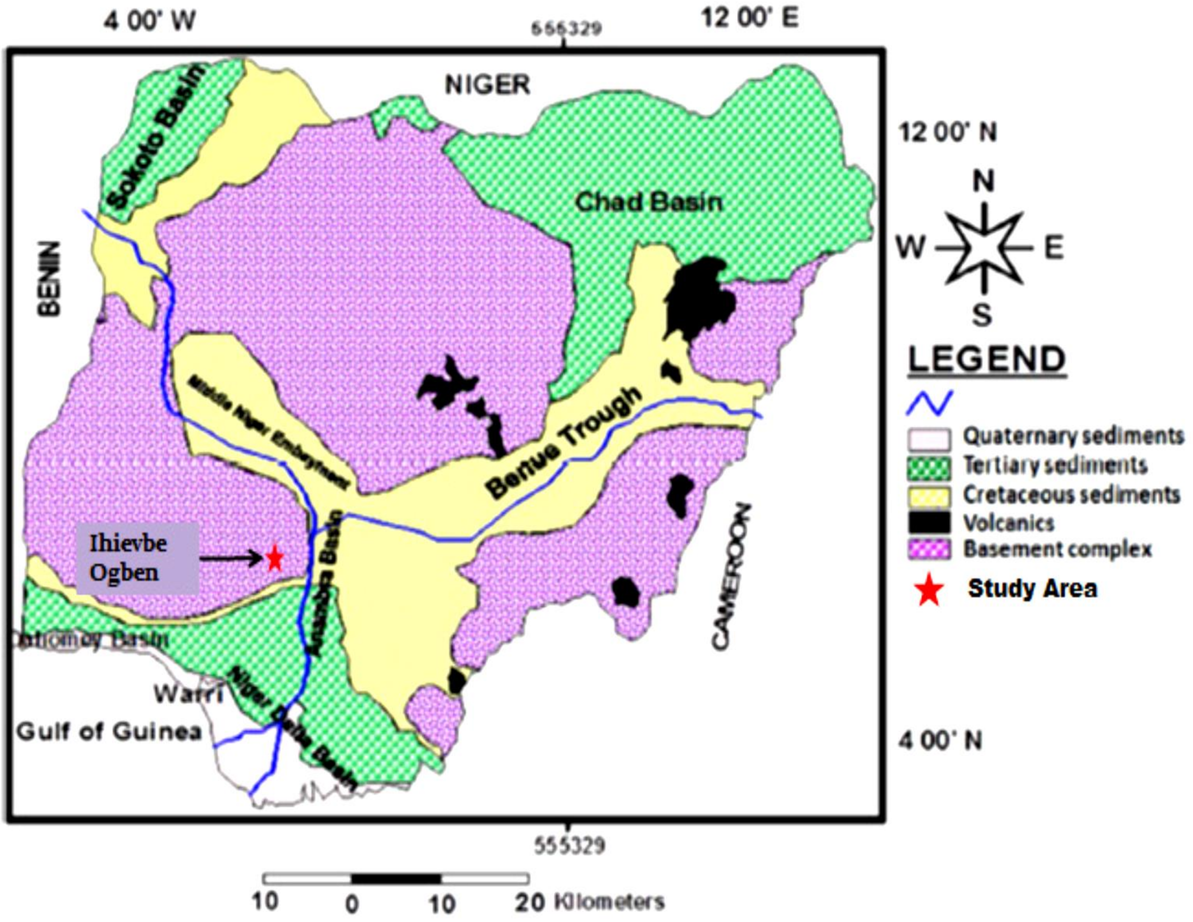


Fig. 1: Geological Map Showing the Study Area

Sample Preparation

A circular saw with a diamond blade was used to cut the specimens to their final lengths. The surfaces were then grounded after cutting in a grinding machine in order to achieve a high-quality surface for the axial loading. The measurement of the specimen dimensions was made with a sliding caliper. Furthermore, the tolerances were checked by means of a dial indicator and a stone face plate. The specimen preparation was carried out in accordance with ASTM test procedure (ASTM, 39-71). The sample was cut using cutting machine to a dimension suitable for UCS (Uniaxial Compressive Stress) test. The specimen was placed in horizontal direction but perpendicular to the direction of cutting edge of the blade. Then the vice was used to hold the specimen firmly to obtain a smooth surface as accurately as possible. The machine was switched on and the necessary shield applied. Water was allowed to lubricate the blade during the cutting process.

Uniaxial Compressive Strength Test (UCS)

The ASTM test procedure (39-71) was adopted. The specimen was placed in the ELE ADR 2000 compression machine. The load is continuously applied on the specimen until it failed. The failure mode was noted as well as the pressure or load at failure. The type of failure and the maximum load carried by the specimen were recorded. The unconfined (uniaxial) compressive strength of the rock sample was obtained by dividing the maximum load carried by the cross-sectional area.

Test Specimens

Cubed sample were used for this test. The four sides of each sample were ground flat, smooth and perpendicular to axis, that is they were parallel to each other 10cm x 10cm cube specimen were cut from block samples supplied (in the absence of core which are commonly used). The platens on the compression machine were altered to suit this configuration. The edges were cut to shape and smoothened by polishing them with carborundum powder.

Calculation

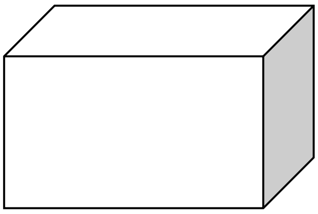
The unconfined uniaxial compressive strength of the rock samples was obtained by dividing the maximum load at pressure by the cross-sectional area of the specimen as shown in Equation 1.

$$UCS = \frac{P}{A} \qquad 1$$

Where:

P is Load at Failure (KN); and

A is Cross-Sectional Area (cm^2)



$L \times B$ is Area (cm^2);

Where: L is Length (cm); and

B is Breath (cm)

Fig. 2: Cubed Sample for Uniaxial Compression

Point Load Test

The point load test was developed as a small hand-portable test apparatus to provide an index for the strength classification of hard rocks in the field; it allows a quick and non-expensive on-site evaluation of stone strength of hard rocks. It is also helpful in predicting other strength parameters with which it is correlated. This test is easy to perform as it requires little or no sample preparation. Basically, the test method relies on the principle of inducing tensile stress into the rock by the application of a compressive force. The maximum tensile stress at the center of the specimen may be related to the applied load and to the distance between the Point loads according to the Equation 2:

$$T = \frac{KP}{h^2} \qquad 2$$

Where:

K is Constant;

P is Applied Load, (kN);

h is Distance between Loading Points (cm); and

T is Maximum Tensile Strength (MPa)

This testing equipment consists of the systems for measuring the load required to break the specimen and for measuring the distance between the two platen contact points. Rock specimens in the form of core (diametral and axial test) cut blocks (block test) or irregular lumps (irregular lump test) are broken by application of concentrated load through a pair of spherically truncated, conical platens. The irregular lump test in accordance with ISRM, RTH POINT LOAD STRENGHT (325-89) was adopted for this study (Franklin and Broch, 1999). Set of three oven dried rock lumps were prepared from each representative rock sample and broken by the application of concentrated load through a pair of truncated conical platens. The widths of the specimen and distance between the platens contact points were measured and the load at failure recorded. From the 70' it is a generalized and standardized test of the International Society for Rock Mechanics (ISRM, 1992) for obtaining rock strength data in a field environment. For irregular lumps uncorrected Point Load Strength index (l_s) is equal to P/De^2 (MN/m^2) according to Equation 3 - 7.

$$De^2 = \frac{4A}{\pi} \qquad 3$$

$$And;\ A = WD \qquad 4$$

Where: P is Load at Failure (kN);

De is Equivalent Diameter, (mm);

A is Minimum Cross-Sectional Area (mm^2);

W is Average width of Specimen (mm); and

D is Diameter of Sample (mm);

$$ls = \frac{P}{De^2} \qquad 5$$

Corrected point load strength can be given as:

$$Is_{(50)} = (\frac{De}{50})^{0.45} \qquad 6$$

$$Is_{(50)} = \frac{p}{D^2} \qquad 7$$

$I_{S(50)}$ is the corrected point load strength index.

Test Procedure for Point Load

A set of specimens were prepared from each representative rock sample each specimen was measured and placed between the loading point of the test machine pressure was slowly applied to grip the specimen which was then gradually loaded to failure. The failure load was then gradually loaded to failure. The failure load was recorded and the process repeated for the remaining samples.

Hardness Test

The hardness test otherwise known as the Schmidt hammer test is a non-destructive apparatus developed for the building industry. It was used for the determination of strength of concrete in finished structure but has been found useful for rocks both in-situ and in the laboratory, in this test, it is necessary that the flatness and regularity of the rebound surface for all the specimens tested should be about the same. A number of studies have indicated the usefulness of the Schmidt hammer test on different rocks and have established its strong correlation with UCS through numerous empirical equations.

Procedure for Hardness Test

Hardness test was achieved by cutting out rough surfaces with a chisel and grinding the resultant surface with carbonrundum wheel. These type of N Schmidt hammer was use to evaluate the hardness of the rock specimen by placing it vertically on the specimen and a slight pressure applied against it. The release of the impact plunger was then pressed against the rock face. As the pressure on the plunger increases gradually, the impact mass of the hammer was released and rebounded by the rock. The recovery distance of the hammer was measured on the scale. 15 points were taken, spread through all faces on the specimen that could be tested and the Schmidt Hammer Hardness (Rebound Number) was recorded. The values were presented as 'highest (R_1), lowest (R_2) and average (R)'. The limitations of the Schmidt hammer test were obvious during the test. The anisotropism of some of the specimen resulted in exceptionally low rebound number whenever the impact plunger rested on such a segregation limited by pore space close to the rock surface, as well as recording high values when the hammer impacts on maybe quartz crystal in massive shale. It is considered that the average rebound number is more realistic than the highest rebound number of any material is as strong as well as its weakest point.

Bulk Density

Bulk density is defined as the mass per unit volume of a specimen in its natural state and differs from the mass of the same volume of rock containing only its solid phase.

Procedure for Bulk Density

The determination of the bulk density was carried out in accordance with procedures suggested by ISRM (1992) using the equation

Where:

ρ is the Bulk Density, (kg/m^3);

M is Mass of Specimen (g); and

V is Volume of the Specimen, (m^3)

Density of Rock

$$P = \frac{M}{V} \qquad 8$$

The mass of was determined using the laboratory weighing balance while the volume was determined by linear measurements using a vernier caliper.

Effective Porosity

The effective porosity was determined using saturation and caliper techniques in accordance with ISRM (1992). This is intended to measure the porosity of specimens of regular geometry (a cube in this particular study). Due to the limited samples a cube (10 x 10 x 10) was used. The specimen bulk volume V_b was calculated from caliper readings for each dimension and was all accurate to 0.1mm. The specimen was saturated by water immersion in a vacuum of less than 800 Pa for a period of 1 hour, with periodic agitation to release air traps. The specimen was then removed and air dried using a moist napkin, care being taken to remove surface water only without losing rock fragments, after which the mass of saturated specimen was recorded as M_{sat}. The oven dried mass of the specimen was also recorded as M_s, after which it was allowed to cool in a desiccators' according to (ISRM, 1992).

Calculation

Pore Volume,

$$Vp = \frac{Msat - Ms}{Density\ of\ Water\ (pw)} \tag{9}$$

Porosity

$$n = \frac{Vp}{Vb} \times 100\% \tag{10}$$

ρ_w is Density of Water (kg/m^3);

M_{sat} is Mass of Saturated, (kg);

M_s, is Oven Dried Mass of the Specimen (kg);

V_p is Pore Volume (cm^3);

V_b is Specimen Bulk Volume (cm^3); and n is Porosity (%)

RESULTS AND DISCUSSION

Results of the Mineral Composition

The Petra quarry granite rock type contains the following minerals;

Table 6: Minerals Contained in Petra Quarry Granite Rock Mineral Percentage %

Mineral/ Sample ID	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Quartz	21%	19%	24%	23%	29%
Potassium Feldspar	42%	45%	39%	48%	38%
Sodium Feldspar	27%	20%	23%	18%	20%
Muscovite	6%	7%	9%	4%	4%
Biotite	3%	8.3%	3.4%	6%	7%
Opaque	1%	0.7%	1.6%	1%	2%

Fig. 3 and Table 6 shows the mineral composition of Petra quarry granite rock with quartz ranging from 21% to 29%, and potassium feldspar ranging from 38% to 48%, sodium feldspar ranging from 18% to 27%, and other accessories ranging from 0.7% to 9%.

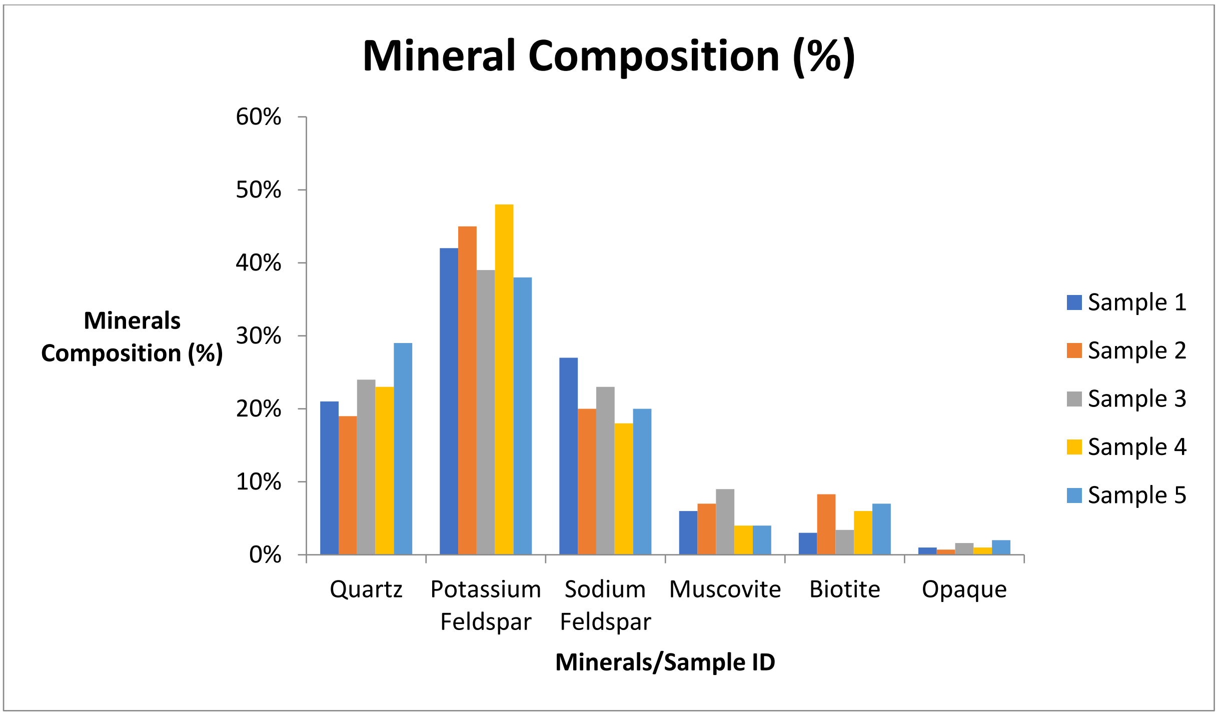


Fig. 3: Minerals Contained in Petra Quarry Granite Rock (%)

Summary Results of the Petra Granite Quarry

Table 7: Unconfined Uniaxial Compressive Strength of Petra Quarry granite

Sample ID	Average Rebound Number (R)	Uniaxial Compressive Strength (MN/m^2)	Bulk Density Mg/m^3 (10^6)	Effective Porosity (%)	Average Corrected Point Load Index I^s $_{(50)}$ MN/m^2
1	52	25.75	2.3	0.8	0.36
2.	53	51.33	2.7	0.6	1.35
3	47	43.42	3.8	0.1	1.51
4	53	101.08	2.5	0.5	3.69
5	56	98.07	1.5	0.9	3.46
Average	**52.2**	**63.93**	**0.6**	**0.6**	**2.07**

Results of Schmidt Hammer Rebound Number Hardness Test

Table 7 shows the hardness from the analysis and the average values were found to be 52, 53, 47, 53, and 56. The average hardness test from the analysis were found to be 52.2 and according to Brock and Franklin, (1999) it is considered that the average rebound number is more realistic than the highest rebound number and any material is as strong as it weakest point.

The Results of Uniaxial Compressive Strength of the Samples

The Average of the Uniaxial Compressive Strength of Petra Quarry is 63.93 MN/m^2. And Table 7 shows the results of uniaxial compressive strength of five (5) samples, with results at 25.75MN/m^2, 51.33MN/m^2, 43.43MN/m^2, 101.08MN/m^2, 98.07MN/m^2, respectively with an average of 63.93MN/m^2. Which indicated that (Fig. 4) sample 1 and sample 3 resulted to be Very Strong, and sample 2, sample 4, and sample 5 resulted to Extremely Strong as obtained and shown in Table 1 of the Geological Society (Anon 1986).

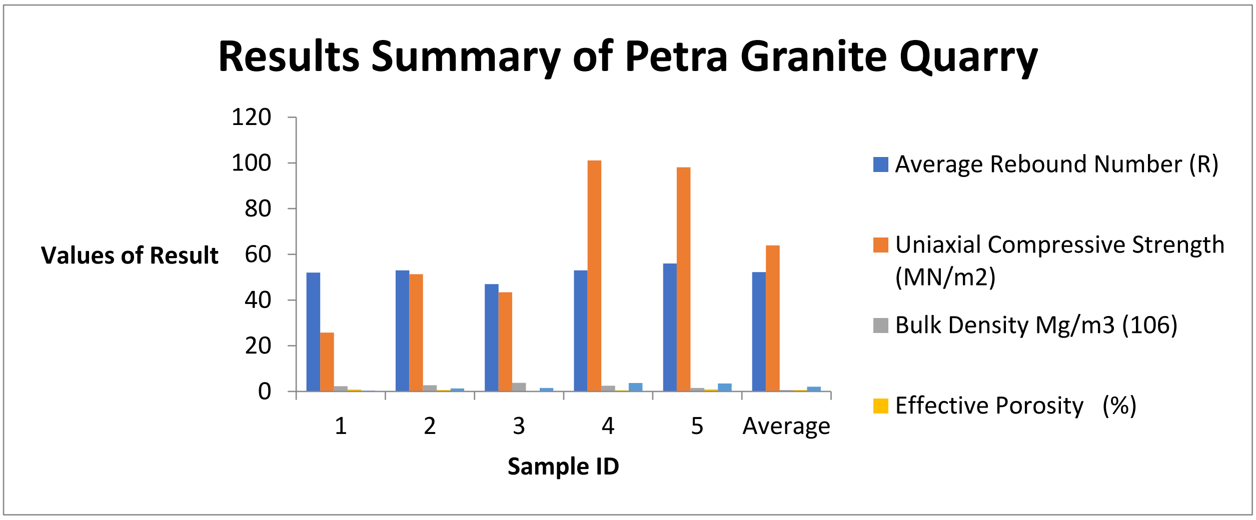


Fig. 4: Summary Results of Petra Granite Quarry

The Average Result of the Bulk Density of Petra Quarry

Table 7 shows the result of bulk density of granite determined from laboratory test, of five (5) samples with results as 2.3Mg/m^3, 2.7Mg/m^3, 3.8Mg/m^3, 2.5Mg/m^3, 1.5Mg/m^3 respectively with an average of 2.6Mg/m^3, (Fig. 4) and which resulted to be of Low density as obtained from Table 4 of the International Associations for Engineering Geology (IAEG) Anon 1997.

The Result of the Average Effective Porosity of the of Petra Quarry

Table 7 shows the result of effective porosity determined from the laboratory, of five samples with results at 0.8%, 0.6%, 0.1%, 0.5%, and 0.9% respectively with the average of 0.6% (Fig. 4) and which resulted to be of low porosity as obtained from Table 3 International Association for Engineering Geology (IAEG) 1979 as the rock falls within the classification of low porosity.

The Results of the Average Point Load of the of Petra Quarry

Table 7 shows the results for the point load test values which are: 0.36MN/m², 1.35MN/m², 1.51MN/m², 3.69MN/m², and 3.46MN/m² respectively with an average of 2.07MN/m^3 (Fig. 4) and which sample 1 had Medium Strength, sample 2, and 5 had High strength and sample 4 and sample 5 had very High Strength according to Brock and Franklin, (1998), the rock falls within the classification of extremely high strength as shown in Table 2.

Relationship between Uniaxial Compressive Strength (UCS) and Point Load Index

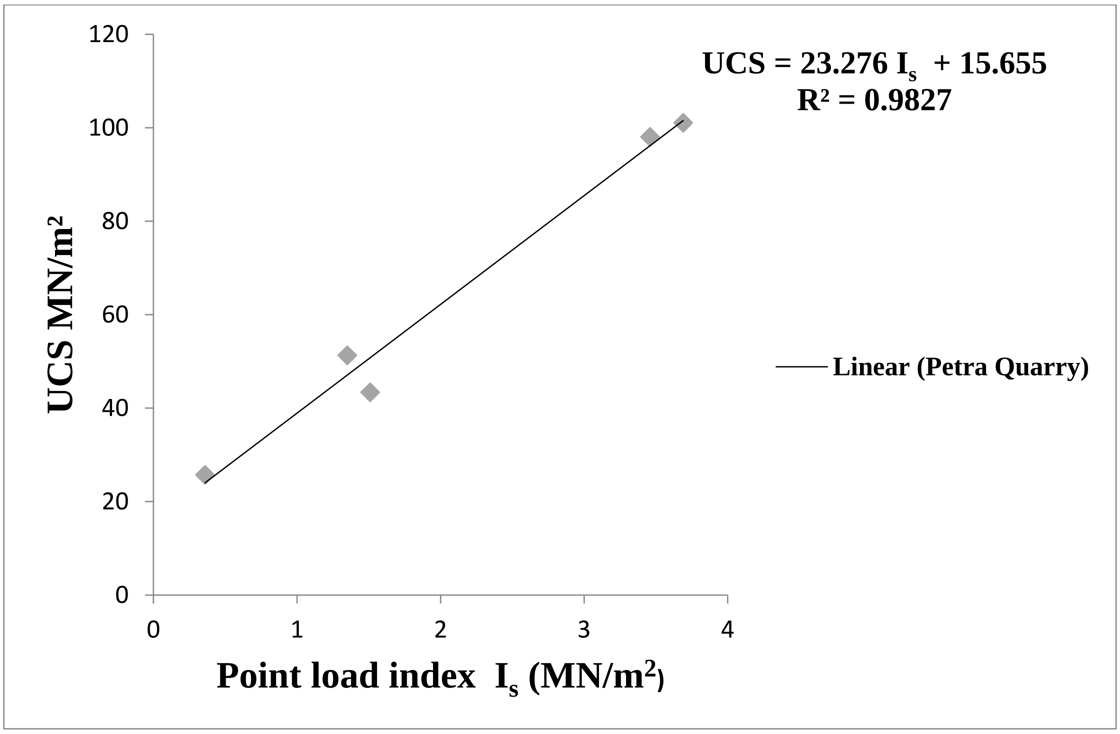


Fig. 5: Relationship between Uniaxial Compressive Strength (UCS) and Point Load Index (I_s)

Also, the result obtained from Fig. 5 shows that there is a great correlation between uniaxial compressive strength and point load index and it shows that as the uniaxial compressive strength increases, the point load index also increases and if the uniaxial compressive strength decreases, the point load index also increases with the correlation result as UCS = 23.276I_s +15.655; $R^2 = 0.9827$, with R^2 as the correlation value between uniaxial compressive strength and point load index. The result also shows that the rock has both a very high uniaxial compressive strength and a very high point load index as confirmed with the internationally accepted value as UCS= 24I_s. Where UCS is Uniaxial Compressive Strength (MN/m²), I_s is Point Load Index (MN/m^2) and R^2 is regression value.

Relationship between Bulk Density and Effective Porosity (%)

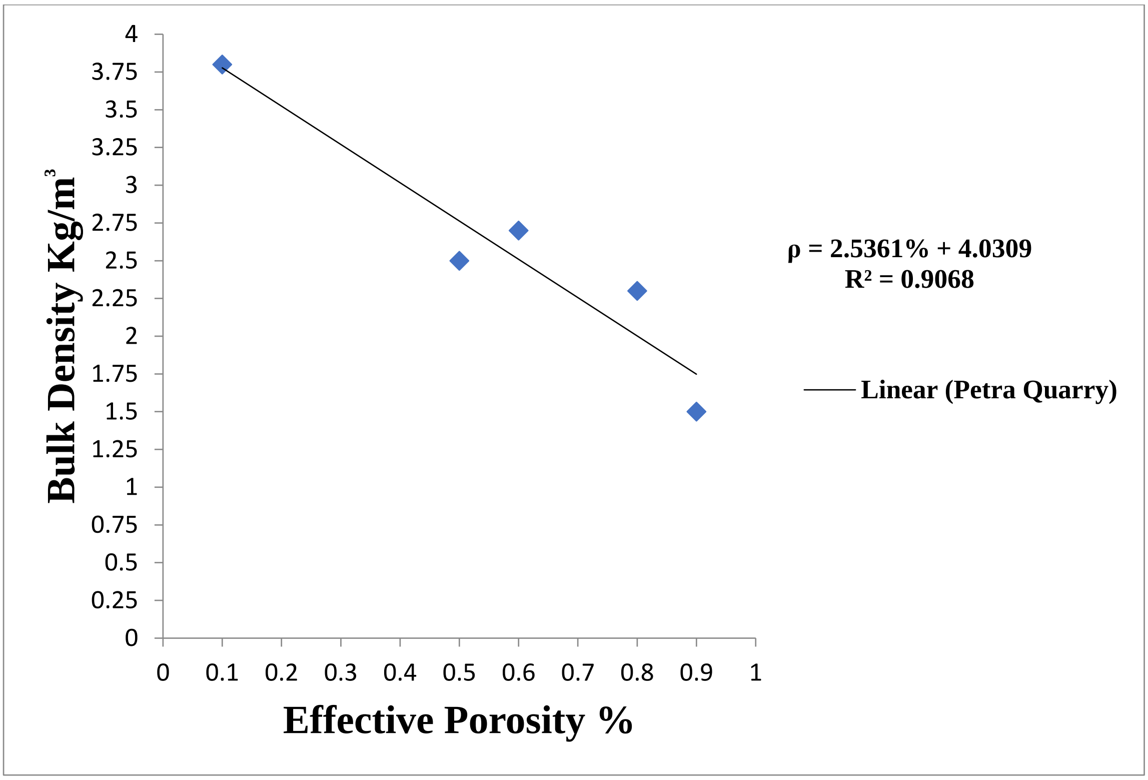


Fig. 6: Relationship between Bulk Density and Effective Porosity

Fig. 6 shows the relationship between Bulk density and Effective porosity which shows that there is a great relationship between Bulk density and effective porosity with the correlation result as $\rho = 2.5361\% + 4.0309$; $R^2 = 0.9068$ with R^2 as the correlation value between bulk density and effective porosity. Where, ρ is the Bulk Density (Kg/m^3) and Effective Porosity (%)

CONCLUSIONS

In order to determine the physic-mechanical properties of the outcrop such as the uniaxial compressive strength, point load, bulk density, porosity and hardness and also, to predict the impact of explosives requirement on blasting from the objective reveal that the uniaxial compressive strength (UCS) and the point load strength index indicates that the rock is strong and satisfactory for road construction according to ANON’s classification.

RECOMMENDATIONS

Based on the results from the analysis carried out in this project, the results revealed that the aggregate material of Petra Quarry ihievbe, is extremely strong. Therefore, it is recommended that there is need for the company to use high explosives in order to minimize the cost of explosives from secondary blasting and also, there is need of powerful machine (crusher) for crushing the blasted rock fragment.

Acknowledgement

The test was carried out on these samples at the Geology laboratory of the Faculty of Physical Science, Department of Geology, University of Benin, Benin City, Edo State, Nigeria.

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