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EVALUATION OF SOME MECHANICAL PROPERTIES OF GRANITES IN PARTS OF SOUTH-WEST NIGERIA

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Abstract

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This work provides an estimation of some engineering properties and behaviours of some rocks in parts of South-West Nigeria for use under various applications, planning and design of construction projects. In mining operations especially drilling and blasting, the brittle fracture of rock in-situ is a very good indicator for rock fragmentation and rock strength characterization. This work determined some strength characteristics and fracture behaviour of granite rocks in four different locations in Ondo and Ekiti States, Nigeria. Granite rocks were sampled, prepared and tested in the laboratory for the Uniaxial Compressive Strength (UCS) using 1100kN compression machine, Tensile Strength (TS) using Brazilian test and Point Load Strength Index (PLSI) using point load tester. Analysis on the strength characteristics of the selected rocks show that the UCS range from 110.65-173.76MPa, TS from 11.94 to 15.46 MPa and PLSI from 5.76 to 7.03MPa. From the result of the analysis, the rocks are classified as very high and high based on their UCS and PLSI respectively. The degree and nature of deformation of the rocks indicated brittle and intergranular fracture. It was found out that the plane of fracture is simple and its nature and description is axial splitting failure in uniaxial compression. The results also show that the strength parameters are positively correlated. The rock strength and behaviour database generated will serve as useful information to granite quarry operators and investors in quarry planning, equipment selection and organization.

***Keywords**:*
Rock, compression, tension, fracture, brittleness

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1.0 Introduction

Rocks are aggregates of crystals and amorphous particles joined together by varying amounts of cementing materials. Rocks are made up of a more or less invariable composition bounded together by forces of molecular attraction (cohesion) that arise either at the sites of direct contact of mineral with one another or at sites of their contact with mineral particles or extraneous cementing substances [1]. Rocks exhibit a vast range of properties which reflect vast varieties of structures fabric and compound, some basic properties measurements which are essential for describing rocks are physical and mechanical properties.

Mechanical properties of rock are characterized by the reaction of rocks to the effect of a force of its environment and it depends on the nature of rock substance, the stratigraphy of rock, rock defects and testing methodology. Such mechanical properties of rocks include compressive strength, tensile strength and point load strength index which were estimated in this work. Rock properties are essential for the prediction of the engineering behaviour of rocks under various applications and planning of mining project. The strength characteristics of rocks are usually considered to be necessary for design of rock structures, stability of rock excavations as well as influence rock fragmentation in quarry and working of mine rocks. This work provided an improved estimation of engineering properties of rock which will guide managers of construction industry and aid quarries and mines operators to select appropriate tools for their operations.

2.0 Strength and deformability

Strength and deformability of rocks and joints has been the subject of numerous experimental investigations, [8]. Certain empirical indices characterizing the behaviour of rocks under the action of specimen, equipment or processes are more often used in mining than parameters dependent on some physical fields. The most widely used mining parameters are the strength of the rock; an index that characterizes the relative resistance to breaking, independently of machines and mechanism adopted. It has been observed that the inherent heterogeneity of the rock mass does significantly affect the pattern of failure since the internal deformation of a heterogeneous rock sample is governed by the local presence of the weak elements, [12].

Compressive strength is the capacity of a material to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. The uniaxial compressive strength (UCS), δc, can be determined using equation (1).

$$\delta c = P/A \quad (1)$$

where δc is the UCS (MPa), P is the applied peak load (kN) and A is the cross-sectional area of the sample (m^2).

The UCS allows comparisons to be made between rocks and affords some indications of rock behaviour under more complex stress systems. According to Bell (1992), classification of intact rocks based on the UCS as suggested by International Society for Rock Mechanics (ISRM) is shown in Table 1.

Rocks have a lower tensile strength than compressive strength, **[1]**. In brittle fracture, the nature and description of fracture surface is very important. Brittle failure theory predicts a ratio of compressive strength to tensile strength of about 8:1 but in practice it is generally between 15:1 and 25:1. The direct tensile strength of rock has been obtained by attaching metal and caps with epoxy resins to specimens, which are then pulled into tension by wires. In direct tensile test, the slenderness ratio of cylindrical specimens should be 2.5-3.0 and diameter preferably should be less than NX core size (54mm). The direct tensile strength has proved difficult since a satisfactory method has not been devised to grip the specimen without introducing bending stresses [6]. Accordingly, most tensile tests have been carried out by indirect method (Brazilian test). A less complex rock failure mechanism is achieved by the Brazilian disc test which records the indirect tensile strength of disc-shaped samples and involves purely tensile stresses across the failure surface. The use of the Brazilian test as an indirect method of assessing the tensile strength of rocks is based on the fact that most rocks in biaxial stress field fail in tension when one principal stress is compressive. The tensile strength, δt, of the rock sample is obtained from the empirical formula given in equation (2) as:

$$\delta t = 0.636\ P/Dt \text{ or } 2P/\pi Dt \quad (2)$$

where P is the load at failure (kN), D is the diameter of test specimen (mm) and t is the thickness of the test sample measured at the centre, (mm). [4] observed a close association between tensile strength and point load strength and the mode of failure involves crack development oriented parallel to axis of loading and obviously very similar for both techniques, although the point test is complicated by irregularly shaped samples.

According to ***[1]***, classification of intact rocks based on point load strength as suggested by ISRM is shown in Table 1. Diametrical testis usually performed on irregular sample using Point Load Tester. The determination of point load strength index is then carried out using equations (3) and (4) as proposed by *[2]* .

$$F = \left(\frac{D}{50}\right) \quad (3)$$

where F is the size correction factor and D_e is the equivalent core diameter (m^2).

$$I_{s(50)} = FI_s \quad (4)$$

where$I_{s(50)}$isthe corrected point load strength index (MPa), F is the size correction factor and I_s is the uncorrected point load strength index (MPa).

Table 1: Strength Classification of Rock

Uniaxial Compressive Strength, MPa (ISRM, 1989)		Point Load strength Index, MPa (Bell, 1992)	
Strength Classification	Value (MPa)	Strength Classification	Value (MPa)
Low	Under 6	Extremely low	Under 0.1
Moderate	6 – 20	Very low	0.1 - 0.3
High	20 – 60	Low	0.3 – 1
Very high	60 – 200	Medium	1 – 3
Extremely high	Over 200	High	3 – 10
		Very high	Over 10

The determination of brittle fracture index 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 brittle fracture concepts in rock materials based on the different natures of rocks are given in equations 5 and 6. The determination of brittle fracture index from the ratio of uniaxial compressive strength to the tensile strength for the rock is expressed in equation (5).

(a) The determination of brittle fracture index from tensile strength and uniaxial compressive strength is expressed in equation (6).

where B_1 and B_2 are brittle fracture indices, δc is the uniaxial compressive strength of the rock (MPa) and δt is the tensile strength of the rock (MPa).

The brittle fracture index of B_1 concept is widely used according to Walsh and Brace (1964). Niwa and Kobayashi (1974) stated that the brittle fracture index of B_2 is suitable for friable rock materials like coal.

3.0 Materials and methods

3.1 Location of Study Areas

The study areas covered Ondo and Ekiti states in Nigeria. The states fall within the Precambrian of South Western Nigeria, which is a part of Nigeria basement complex. Sixteen groups of rocks could be identified in the basement complex **[10]**. The rocks from the study locations are granitic rock types. The study locations are four granite quarries along Iyin Road, Ado-Ekiti and Ise Road, Ikere-Ekiti in Ekiti State; Owo Road, Akure and Ifon Road, Owo in Ondo State. The study locations are coded AD, IK, AK and OW respectively. Figure 1 depicts the geological map of Nigeria showing source rock terrains and study locations

3.1 Sample Collection, Preparation and Testing

The sample locations are granite quarries where granite aggregates are produced for construction works and other various engineering applications. Three (3) lumps each of granite rocks were sampled from the unweathered portion of the rock in-situ using sledge hammer. Five (5) replica cylindrical core samples of about 54.00 mm in diameter having a length-to-diameter ratio that averaged 2.64 were prepared for compressive strength test using laboratory core drilling and rock cutting machines; and tested using 1100 kN Compression Machine. The basic principle of laboratory testing of rock to obtain data for use in design analysis is that the boundary conditions applied to the test specimen should simulate those imposed on the rock element in situ, (Stagg and Zienkiewicz, 1976). Consequently, all the sample preparations and testing procedures were done in accordance with the standard methods suggested by ISRM (1989) for the uniaxial compressive strength, tensile strength and point load strength tests.

For all the tests conducted on the rock samples, the corresponding values of the failure loads and the sample geometries were recorded. The uniaxial compressive strength and tensile strength were then determined using equations (1) and (2) respectively. The brittle fracture index of B_1 concept in equation (5) was used to determine the brittleness index.

The samples used for the point load strength index were of irregular geometry; consequently, basic diametrical test was performed on the samples using Point Load Tester. Since the samples tested do not have a diameter of 50mm, the point load index was corrected to standard strength index using equations (3) and (4).

4.0 Results and discussions

4.1 Results

The results of the uniaxial compressive strength, tensile strength, point load strength tests and brittleness of the rocks from the locations are presented in Table2 and depicted in Figure 2 while Table 3 shows the rock strength classification based on standards.

$$B1 = \frac{\text{Compressive strength}, \delta c}{\text{Tensile strength}, \delta t} \quad (5)$$

$$B_2 = \frac{\text{Compressive Strength} - \text{Tensile strength}}{\text{Compressive strength} + \text{Tensile strength}} = \frac{\delta c - \delta t}{\delta c + \delta t} \quad (6)$$

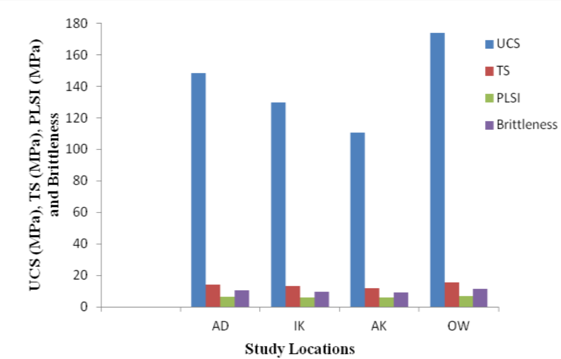

Figure 2: Comparison Between the Strength Properties of the Rocks in Selected Locations

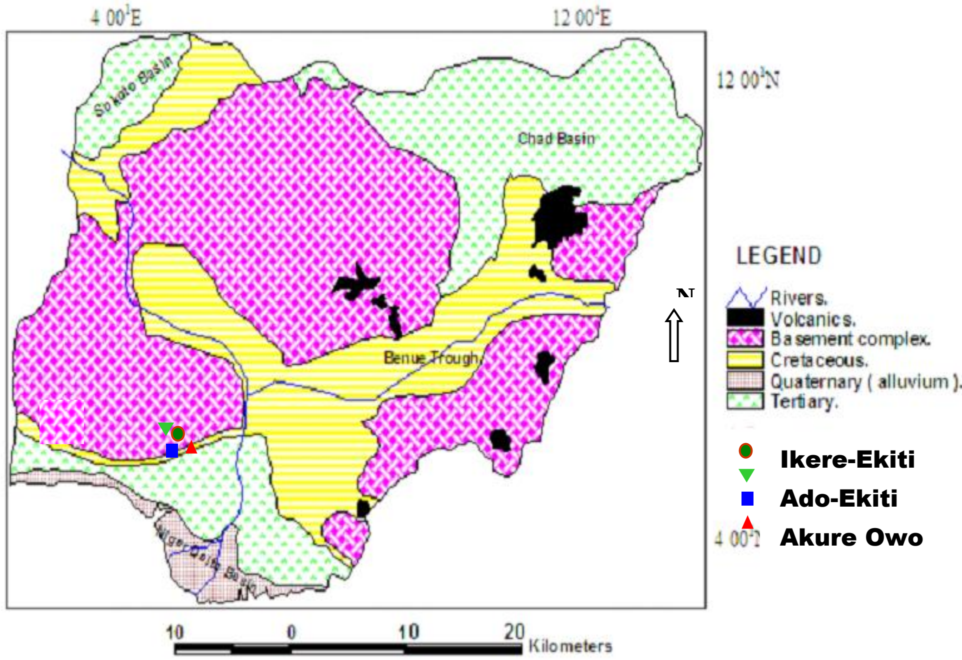

Figure 1: Geological map of Nigeria showing source rock terrains and study locations

Table 2: Average values of the compressive strength, tensile strength, Point Load strength Index *and brittleness of rocks for locations in South West Nigeria*

Location Code	Average Uniaxial Compressive Strength,δc(MPa)	Average Tensile Strength, δt(MPa)	Average Point Load strength Index(MPa)	Brittleness
AD	148.44	14.02	6.22	10.59
IK	129.82	13.23	5.88	9.81
AK	110.65	11.94	5.76	9.27
OW	173.76	15.46	7.03	11.24

Table 3: Classification of the Rocks Based on Standards

Classification of UCS of the Rocks (Based on ISRM, 1989)			Classification of Point Load Strength Index of the Rocks (Based on Bell, 1992)		
Location Code	Value (MPa)	Classification	Location Code	Value (MPa)	Classification
AD	148.44	Very high	AD	6.22	High
IK	129.82	Very high	IK	5.88	High
AK	110.65	Very high	AK	5.76	High
OW	173.76	Very high	OW	7.03	High

4.2 Discussion

The uniaxial compressive strength values of rocks samples obtained from all the locations ranged from 110.65-173.76MPa, classified to have very high strength based on ISRM (1989) classification. The tensile strength values also range from11.94 to 15.46MPa, classified to have high strength based on Bell (1992) classification while the point load strength index and brittleness of the rocks vary from 5.76-7.03 MPa and 9.27 to 11.24 respectively. From Figure 2, it could be seen that there is positive correlation between the parameters. It was observed that the fractures of most of the rock samples occurred at a fairly well-defined angle between 21° and 25°to the direction of the greatest compressive principal stress. Axial splitting failure was also noticed in the uniaxial testing of most of the rock samples, which probably originated from microcracks that constituted the line of least resistance in the rock, according to Walsh and Brace (1964).

From the tests results in Table 2, correlations between the point load strength index [$I_{s(50)}$] and uniaxial compressive strength (δc) and between the point load strength index and Brazilian tensile strength (δt) are deduced as:

$\delta c = 22.6 I_{s(50)}$ (7)

$\delta t = 2.2 I_{s(50)}$ (8)

The determined correlation factor of 22.6 between δc and $I_{s(50)}$in equation (7) is within the range of 10-30 experimented by Paterson and Wong (2005). It is important to note that the uniaxial compressive strength is significantly greater than tensile strength for the rocks which makes rocks to fail easily under tension. Therefore, in design, rock should be subjected to minimum tensile stress.

5.0 Conclusion

The results of the field observation and laboratory tests carried out on the rock samples from the study locations show that the strength characteristics of the rocks range consistently and classified from high to very high strength. The results also show that the strength parameters are positively correlated. The ratio of the point load index [$I_{s(50)}$] to uniaxial compressive strength (δc) and the point load index to tensile strength (δt) of the rocks fall within standard. The degree and nature of deformation of the rocks indicated brittle and intergranular fracture. It was found out that the plane of fracture is simple and its nature and description is axial splitting in uniaxial compression. The rock strength and behaviour database generated will serve as useful information and guide for managers of construction industry and aid quarries and mines operators to select appropriate tools for their operations.

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