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Estimation of Strength Properties of Shale from Some of Its Physical Properties Using Developed Mathematical Models

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Abstract

Estimation of strength properties (uniaxial compressive and point load) from physical properties (density, porosity and rebound hardness) of shale rock type from Kogi State, Nigeria was investigated. The shale rock types were sampled and tested for their properties through in-situ and laboratory tests conducted. Schmidt hammer was used to carry out the in-situ testing of the rock on the field while rock samples were collected for laboratory test. Four samples of each rock type were prepared for the determination of density and porosity. The results obtained from the Schmidt hammer test and those of density determined from laboratory test were used to estimate the uniaxial compressive strength of the rock. The average density and porosity of the shale are 2.39 g/cm^3 and 38.4%. The average uniaxial compressive strength and point load index values are 34.20 MPa and 1.60 MPa respectively. From the results, the strength parameters indicated high strength classification. The determined physical and strength parameters were analyzed statistically. Mathematical models were derived from the relationships between the parameters for the estimation of strength properties of the rock and the coefficient of their correlation (R^2) indicated strong relationship. The results obtained would be useful tools for the prediction of the strength properties of rocks having similar physical properties as the investigated rock type.

Keywords: *Physical properties, strength properties, correlation, relationship, modeling.*

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I. INTRODUCTION

Shale is well known for its anisotropy and heterogeneity, which leads to complexity in the rock mass behaviour. The diverse physical and chemical characteristics of this shale rock mass and reasons of the variation in the properties were investigated in a previous study, (Nandi and Whitelaw, 2009). Certainly physical and mechanical properties of shale have direct impact on its permanence as building materials. Shale which consist mostly of clay minerals, are generally further classified on the basis of composition and bedding, (Spears 1990). All rocks disintegrate slowly as a result of mechanical and chemical weathering, (Chigira 1990). Mechanical weathering is the breakdown of rock into particles without producing changes in the chemical composition of the minerals in the rock. According to Bozdag (1988), ice is the most important agent of mechanical weathering. Water percolates into cracks and fissures within the rock, freezes, and expands. The force exerted by the expansion is sufficient to widen cracks and break off pieces of rock, (Chigira 1990). Heating and cooling of the rock, and the resulting expansion and contraction, also aids the process. Mechanical weathering contributes further to the breakdown of rock by increasing the surface area exposed to chemical agents. Chemical weathering is the breakdown of rock by chemical reaction. In this process the minerals within the rock are changed into particles that can be easily carried away, (Chigira and Sone 1991). Air and water are both involved in many complex chemical reactions. Rock particles in the form of clay, silt, sand, and gravel, are transported by the agents of erosion (usually water, and less frequently by ice and wind) to new locations and re-deposited in layers, generally at a lower elevation.

Rock material like shale rock is economically important in that they can be used as construction material, (Komoo 1995). Shale rocks also often form porous and permeable reservoirs in sedimentary basins in which petroleum and other hydrocarbons can be found. Physical properties are properties exhibited by rocks as a result of inherent characteristics formed at the time of formation of the rock. It also depends on the characteristics of bonding between the mineral particles. Strength testing relates to those characteristics of the rock material which can be sampled and tested in the laboratory otherwise known as intact rock, which implies rock free of large scale structural features, such as joints, bedding planes, partings and shear zones, (Robertson 1995).

The strength properties of rocks are usually considered to be necessary for design of rock structures, stability of rock excavations and also influence rock fragmentation in quarrying and working of mine rocks (Ojo and Olaleye 2002). Strength of rocks has been the subject of numerous experimental investigations because it serves as a useful guide in mine planning and rock excavation. Such strength testing includes uniaxial compressive strength and tensile strength. The procedure of the unconfined compressive strength has been standardized by the American Society for Testing and Materials (ASTM 2004) and the International Society for Rock Mechanics (ISRM 1989). Although the method is relatively simple, it is time consuming and expensive; also it requires well prepared rock cores, which is often difficult for weak rocks and especially for shale. Therefore, indirect tests are often conducted to estimate the unconfined compressive strength by using empirical correlations, such as point load, Schmidt hammer, cone indenter and sound velocity tests. Estimation of the strength properties of the rocks from their inherent physical properties will be an alternative means of solving the difficult and expensive ways of conventional strength determination.

II. MATERIALS AND METHODS.

2.1 Description of the Study Areas

The study area is Odele in Kogi State, Nigeria, (Figure 1). The town is located at $007^0 42^{'}$E longitude and $07^0 41^{'}$N latitude with altitude between 300m and 350m above sea level. The geological setting of State is unique for having the three major Nigerian geological formations; the basement complex, sedimentary basins and the younger granite. Half of the state (western flank) is covered by crystalline basement complex formation and older/younger granite province while the remaining half (eastern flank) is of sedimentary formation with cretaceous to recent sediments. Part of the state is majorly underlain by crystalline basement and ancient hard rocks. This formation is made up of gneiss, migmatite, schist, quartzite's, marble and calc-silicate as well as the Pan African granite/older granites. This basement rocks contained some economic minerals such as iron ore, gemstone, quartz, feldspar and other associated minerals of economic resource such as cassiterite, tantalite, columbite and gemstones. The eastern part of the state is on alluvium and is made up of the younger and most recent sedimentary formation. The geological setting of this flank is similar to that of lower Benue trough in the south of Benue river. It is principally made up of different formations: Mamu, Ajali and Nsukka. These formations are normally inter-bedded with siltstones, carboniferous shale's, coal, sandstones (of fluvial marine nature with distinct cross beddings) and laterite. The formations control the localization of economic minerals such as coal, kaolin, clay, sandstones, limestone, slate, gemstones, phosphate and other associated sedimentary minerals (Ayodele, 2010).

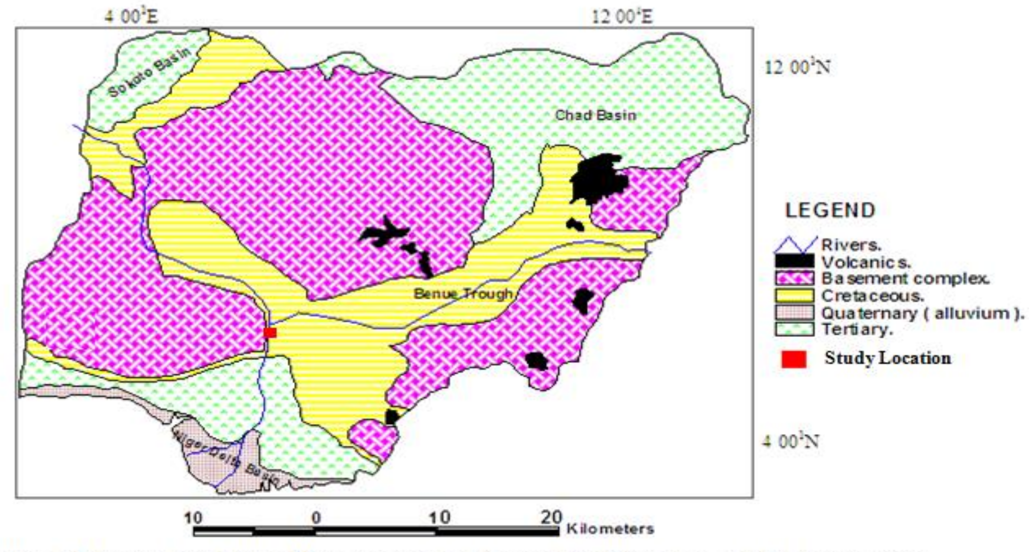

Figure 1: Geological Map of Nigeria showing Source Rock Terrains and Study Location

2.2 Sample Description and Preparation

Five shale samples were collected from different locations of the deposit to ensure the representation of the rock. The samples were labeled SH1 - SH5. Global Positioning System (GPS) was used to record the coordinates of the locations where samples were taken. The samples for the density, porosity and point load tests were prepared in an irregular form and the preparation was carried out in accordance with the standard suggested by ISRM (1989) and conforms to ASTM (1994).

2.3 Physical Properties Determination

2.3 Density

The determination of the density (ρ) was carried out according to the procedures suggested by ISRM (1989) using equation 1.

$$\rho = {}^{M}/_{\Delta V}\,(g/cm^3) \qquad (1)$$

where M is the mass (g) and V is the volume (cm^3)

2.4 Porosity

The sample was saturated by water immersion in a bath with periodic agitation to remove trapped air. Its saturated-submerged mass M_{sub} was determined to accuracy of 0.1g. The saturation and buoyancy technique for determination of porosity (Φ) of rock samples was adopted using equations 2 and 3.

$$\text{Pore Volume } V_v = \frac{M_{Sat} - M_s}{\rho^w}, \qquad (2)$$

$$\text{Porosity, } \Phi = \frac{100 V_v}{V}\,\% \qquad (3)$$

where M_{sat} is the saturated mass of sample (g), M_a is the mass of air dried sample (g), ρw is the density of water used for the saturation, V_V is the volume of void (cm^3) and V is the total volume (cm^3)

2.5 Hardness

The hardness test involved the use of Schmidt Impact Hammer type L for the hardness determination of in situ rock. The standard method for the Schmidt Hammer test as described by ISRM (1989) and ASTM (1994) was followed. The measured test values were ordered in descending order. The lower 50% of the values were discarded and the upper 50% values were averaged to obtain the Schmidt Rebound Hardness (ISRM, 1981).

2.6 Uniaxial Compressive Strength (UCS)

The uniaxial compressive strength of the rock was estimated from the values of the type L Schmidt Hammer Hardness and the density of the rock. The UCS values were estimated by using the chart named after Deere and Miller (1966) shown in the Figure 2.

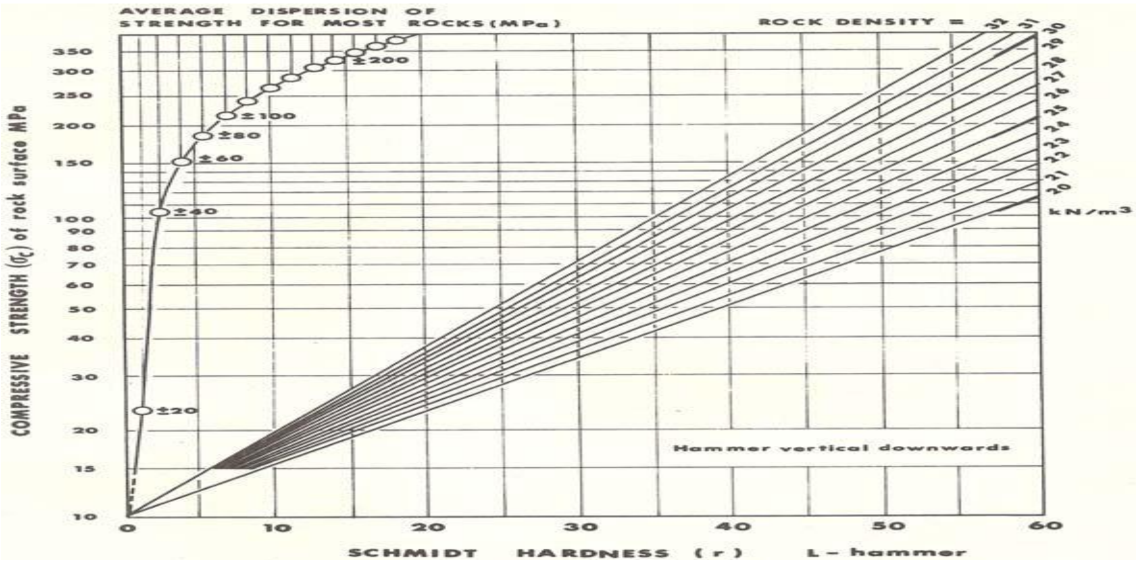

Figure 2: Correlation chart for Schmidt (L) hammer, relating rock density, compressive strength and rebound number (After Deere and Miller, 1966).

2.7 Point Load Strength

The point load strength values were determined in accordance the procedures suggested by ISRM (1989) using equations 3-6.

$$I_s = {}^{P}/_{D_e{}^2} \qquad (3)$$

where I_s is the point load strength index (MPa), P is the failure load (KN) and D_e is the equivalent diameter (mm).

$$D_e{}^2 = \frac{4A}{\pi} = \frac{4DW}{\pi} \qquad (4)$$

where D is the distance between load contact points (mm), W is the width of the sample (mm) and A is the minimum cross-sectional area of the loading points.

$$F = \left(\frac{D_e}{50}\right)^{0.45} \tag{5}$$

where F is the correction factor.

$$I_{S(50)} = FI_S \tag{6}$$

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

III. RESULTS AND DISCUSSION

3.1 Results

The results of the average values of the physical and strength properties of the shale samples are presented in Table 1 while Figures 3 - 6 depict the graphical representations of the relationship between the parameters.

Table 1: Average Values of the Physical and Strength Properties of the Shale

Sample Location	Density (g/cm^3)	Porosity (%)	Schmidt Hardness Value For Shale	Point Load strength Index, $I_{S(50)}$ (MPa)	UCS (MPa)
SH1	2.25	40.0	22.2	1.06	30.7
SH2	2.25	40.0	21.3	1.30	31.2
SH3	2.40	34.0	20.5	1.53	34.7
SH4	2.40	34.0	23.0	1.53	36.7
SH5	2.67	26.0	22.8	2.15	37.6

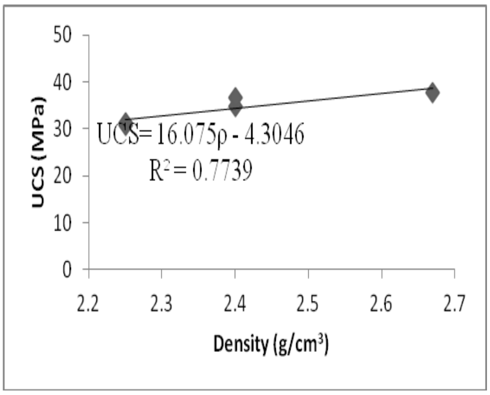

Figure 3: Plot of UCS against Density

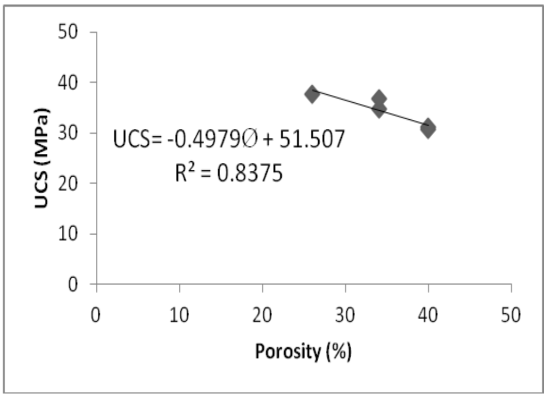

Figure 4: Plot of UCS against Porosity of the Shale

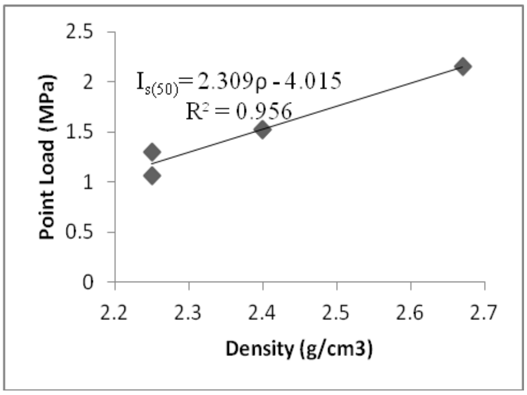

Figure 5: Plot of Point Load against Density

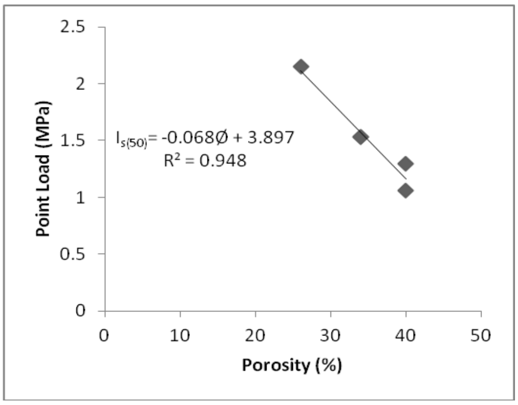

Figure 6: Plot of Point Load against Porosity

3.2 Discussion

From Table 1, the values of the density and porosity of shale samples determined from laboratory test range from 2.25 g/cm^3 to 2.67 g/cm^3 and 26% to 40% respectively. The result of the uniaxial compressive strength values of the shale ranges from 30.7 MPa to 37.6 MPa making the UCS of the rock to fall within the range of high strength according to Broch and Franklin (1972) classification. The result of the point load test value ranges from 1.06 MPa and 2.15 MPa which also fall in the range of high strength.

Statistical models were generated to relate the strength properties with the physical properties. The results of models revealed that as the uniaxial compressive strength of the shale increases, density and porosity decreases while rebound hardness value decreases (Equation 7), as the point load index increases, density and rebound hardness values increase while porosity decreases (Equation 8).

$$\mathrm{UCS} = 285.85 - 73\rho - 2.617\emptyset - 0.0958\mathrm{RH} \quad (7)$$

$$\mathrm{I}_{s(50)} = -4.432 + 2.649\rho - 0.008\emptyset - 0.031\mathrm{RH} \quad (8)$$

where UCS is the uniaxial compressive strength (MPa), I_s is the point load (MPa), ρ is the density (g/cm^3), $\emptyset$ is the porosity (%) and RH is the rebound hardness value.

IV. CONCLUSION

The work analyzed the relationship between the physical and strength properties of shale using Developed Models. The strength parameters of the rock fall in the range of high strength. It was found out that the shale has good engineering properties. The mathematical models developed are useful tools for the determination of uniaxial compressive strength and point load index of rocks of similar characteristics.

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