



AN EVALUATION OF THE SUITABILITY OF SOME BASEMENT ROCKS FROM OBAN MASSIF, SOUTHEASTERN NIGERIA, FOR ENGINEERING CONSTRUCTION PURPOSES

NYONG, V. E., ADEBAYO, I. K., NYONG, M. V., ORLANDO, G. E AND MOGABA, J. N
Email: Victornyong1234@gmail.com,

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ABSTRACT

The physical and engineering properties of some basement rocks from parts of Oban Massif, Southeastern Nigeria were investigated to ascertain their suitability for civil engineering construction purposes. A total of 19 representative rock samples comprising of granites and granodiorites, were obtained from three quarries in Akamkpa Local Government Area of Cross River State, southeastern part of Nigeria. The rock samples were crushed into aggregates and their physical and mechanical properties were assessed. The results obtained showed that the specific gravity ranged from 2.60-2.72, water absorption 0.30-0.96%, aggregate impact value 12-30%, aggregate crushing value, 12-33%, flakiness and elongation Indices both ranged from 14-29%, the uniaxial compressive strength fell between 190 and 209NM/m,² and the Los Angeles abrasion gave 14-41%. Petrographic studies suggested the rocks are granites and granodiorites. Results obtained from the research were compared with known engineering specifications. Such comparisons showed empirical relationships between the physical and the mechanical characteristics of the materials tested. These empirical relationships can, thus, be employed to save cost in future site investigations. Petrographic studies and engineering properties indicate that aggregates derived from the fresh basement rocks in the study areas are capable of withstanding heavy traffic, foundation loads and are generally suitable for most civil engineering construction purposes. It is also expected that the interpretation and ranking of the test results will provide a suitable guide to prospective clients of quarry operators as they can now have some scientific basis for selecting materials needed for different construction works. To achieve this, quarry operators must test and advertise/publicize the properties of their products for public consumption.

KEYWORDS: Construction, basement, Oban Massif, engineering, specifications.

INTRODUCTION

Increase in population and rapid economic development have led to high demand for social amenities in many countries of the world. These amenities come in form of infrastructures which require rocks in most cases as foundation or construction materials. The safety and durability of these structures can be addressed with careful engineering design as well as selection of suitable construction and foundation materials (Bell, 1993).

Civil engineering constructions such as dams, pavements and foundations sometimes do not live through their expected engineering lifespan. This may be due to poor designs, wrong implementation of designs, structural imperfections associated with geo-materials used for civil constructions or the uncertainties in the properties of materials used for construction.

Construction materials such as fills (materials for compaction), cement, steel rods and even water may have their associated challenges.

Nyong, V. E., Department of Geology, Faculty of Physical Sciences, University of Calabar, Calabar, Nigeria
Adebayo, I. K., Department of Geology, Faculty of Physical Sciences, University of Calabar, Calabar, Nigeria
Nyong, M. V., Department of Geology, Faculty of Physical Sciences, University of Calabar, Calabar, Nigeria
Orlando, G. E., Department of Geology, Faculty of Physical Sciences, University of Calabar, Calabar, Nigeria
Mogaba, J. N., Department of Geology, Faculty of Physical Sciences, University of Calabar, Calabar, Nigeria

Typical examples of construction materials with challenges are soils which may contain swelling and shrinking clays. These challenges have led to rigorous studies of these materials (Punmia et al., 2005). Cement and steel rods pose fewer problems as they are artificially made, hence their behavior under certain structural load can easily be modeled in the laboratory and the results applied in the field.

Less attention has been paid to rock materials used for construction purposes especially in developing nation like Nigeria. This may originate from the fact that as basement rocks which "appear strong" in the hand specimen, laymen generally believe that they should withstand any load placed on them. This unwholesome belief has over time crept into the engineering practice. Civil engineers tend to treat rocks as any other construction material like cement and steel which are purely artificial or engineered in nature with homogenous and isotropic properties rather than geologic materials which are heterogeneous, anisotropic and embedded with other structural imperfections all of which affect their overall performances (Deere and Miller, 1966). The suitability of rocks for civil engineering construction depends on its physical properties (Amuda et al, 2014) and is one of the basic goals of rock mechanics needed for predicting failure strength of geomaterials (Falowo, 2019).

This paper focuses on rock aggregates used in civil construction, their physical and engineering attribute, their petrography and how these properties affect the rock behavior.

Several workers such as Kolapo, 2021, Oyediran and Foghi, 2018, Adeyemo et al., (2017), Amah et al., (2012), Waltham, (1998) have worked on the mechanical and engineering properties of basement rocks. Ndukauba and Akaha, (2012) also noted that

more than 90% of asphalt and 80% of concretes consist of aggregate, the remainder being binders such as cement, asphalt and laterite. None of these works have characterized rock aggregates from the Southeastern basement complex based on their mechanical attributes.

This work is thus aimed at ensuring the safety of infrastructures by characterizing rock aggregates based on their physical and mechanical attributes and presenting the results in the form of a working guide for civil engineers and other aggregate users. The work will also evaluate the suitability of basement rocks from Oban Massif for different construction work with a view of improving the lifespan of structures constructed with the aggregates.

STUDY AREA

The study area, Njahasang and Okom-ita forms part of Oban Massif and are situated in the Southeastern Nigeria. They lie between latitudes 05°13'N and 05°22'N and longitudes 008°16'E and 008°24'E. It is covered by the thick equatorial rainforest and is characterized by heavy rainfall which is evenly distributed (Adeleke and Leong, 1980). The temperature of the area ranges from 24°C to 28°C and rarely exceeds 35°C.

Geologically, the Oban Massif, is an integral part is of the Nigerian Basement Complex (Ekwueme and Onyeaokocha, 1985). It consist of banded gneiss, granite gneiss, biotite gneiss, intruded by pegmatite, granites and granodiorite in some places (Rahman et al.; 1981, Ekwueme, 1990, 1995). Typical minerals are quartz, feldspars, microcline, biotite, muscovite and some ferromagnesian minerals.

The drainage in the area is structurally controlled. Rocks are moderately weathered especially at the surface with the overburden profile reaching up to 40-50m in places (Okereke et al., 1998).

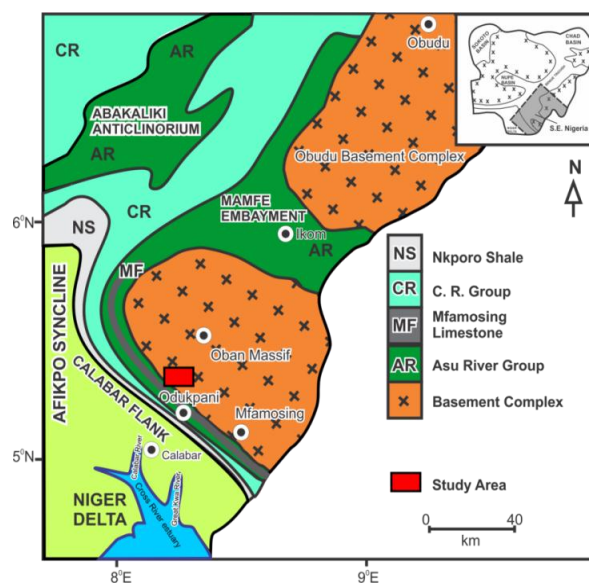


Fig.1 The Geologic map of south eastern Nigeria showing the study area (Ekwueme, 1995).

MATERIALS AND METHODS

Samples for this work come from three quarry sites (Quarries 1 to 3). 5 samples were collected from Quarry 1 while 7 samples each were collected from Quarries 2 and 3. Sample collation was from the quarry floor, quarry face and from surface exposures at the proposed quarry site. The sites were accurately surveyed using Garmin 76 Global Positioning System (GPS) device to obtain coordinates (latitudes and

longitudes) and the relative elevation of the site. Samples were collected with hammer, properly labeled (with masking tape and a permanent marker) and stored in a polyethylene bags. Petrographic studies of thin sections prepared from the representative aggregates from the three sites indicate that Quarry 1 and 2 have granites, while Quarry 3 is made up of granodiorites. The physical and engineering properties tests which were performed on rock aggregates from the three quarry sites are reported below;



Fig.2 GPS reading at Quarry 1



Fig.3. Rock fragment at Quarry2

To determine the Los Angeles abrasion value, (LAAV) of the aggregates, the ASTM C131 (1998) grade B procedure was used. This grade utilizes 11 steel balls of approximately 48mm in diameter as an abrasive charge, 5kg crushed aggregates, 2.5kg passing sieve 20mm and retained on sieve 12.5mm while the other 2.5kg passes sieve 12.5mm and retained on sieve 10mm. Other apparatus includes a balance of 5 kg capacity, drying oven, a steel rotating drum and trays. The procedure involved oven drying the sample at 105°C, then placing the aggregates and the abrasive charge on the cylindrical drum and the cover fixed. The machine was then rotated at a speed of 30 revolutions per minute for 500 revolutions. The machine was then stopped and the materials discharged into tray. The entire stone dust was placed on 1.70mm BS sieve and the coarser fraction (retained) on the 1.7mm sieve weighed. Los Angeles abrasion value (LAAV) was determined using the relationship;

$$LAAV = \frac{W_1 - W_2}{W_1} \times 100$$

Where LAAV= Los Angeles abrasion value

W_1 = Original mass of aggregate

W_2 = Mass of aggregate retained

LAAV is expressed in percentage

Aggregate impact value

This was carried out with 5kg of aggregates passing BS sieve 12.5mm and retained on sieve 10mm in accordance with BSI, (1983). Apparatus used for the determination of aggregate impact value include a

Los Angeles Abrasion Test

balance of capacity 5kg, cylindrical steel cup of internal diameter 10.2mm and length of 5mm attached to a metal base of the impact testing machine and a hammer of 14kg by weight. The steel cup was filled in three layers with each layer tamped for 25 numbers of blows. The metal hammer was arranged to drop with a free fall through a vertical height of 38.0cm on the test material and the specimen was subjected to 15 numbers of blows. The crushed aggregates were sieved through a BS sieve of size 2.36mm and the material passing weighed and recorded. Aggregate impact value was determined from the relationship;

$$AIV = \frac{W_1 \times 100}{W_2}$$

Where; W_1 = weight of sample passing 2.36 sieve

W_2 = Total weight of sample.

Aggregate impact value is expressed in percentage

Aggregate Crushing Value

This was carried out with aggregate 3kg of crushed aggregates passing BS sieve 14mm and retained on sieve 10mm in accordance with BSI (1983). Apparatus used involved, a steel cylinder with open ends and internal diameter of 152mm, square base plate, a plunger hanging on the piston of diameter 150mm with a hole provided across the stem of the plunger so that a rod can be inserted for lifting or placing the plunger in the cylinder. A cylindrical measure with internal diameter of 115mm and height of 180mm, a tamping rod with one rounded end, having a diameter of 16mm and length of 450mm, a balance of capacity 3kg and a compression testing machine were used.

The procedure involved filling the cylindrical measure (mould) with the test samples in 3 layers of approximately equal height with each layer tamped using the rod for 25 numbers of blows. The weight of the aggregate was measured and recorded as 'A'. The surface of the aggregate was leveled in the mould and the leveled samples were inserted in a compression testing machine. The machine was loaded at a uniform rate of 4tonnes per minute for approximately 10 minutes to achieve 40tonnes (400KN) in 10 minutes. After 10 minutes, the mould was released and the material emptied into a dry pan. The crushed sample was then sieved mechanically through a sieved size of 2.36mm and the fraction passing recorded as 'B'.

Aggregate crushing value was determined from the relationship;

$$ACV = \frac{B \times 100}{A}$$

Where; B = Weight passing sieve size 2.36mm

A = Total weight of sample

Aggregate crushing value is expressed in percentage.

Uniaxial Compressive Strength

The apparatus used to carry out the uniaxial compressive strength includes the compressive machine, shaping tools, weighing balance, calipers. To run test, the rock samples were first shaped into standard cubes with dimension of 40mm x 40mm. The test area was relatively flat to give a uniform loading. The cube was placed in a compressive machine and loaded axially to failure. The pressure at failure was read on the dial gauge of the compression machine, (ASTM D- 71a).

Uniaxial compressive strength of the sample was obtained from the relationship

$$\sigma = \frac{P}{A}$$

Where; σ = Uniaxial compressive strength in MN/m²

P = Maximum load in MN

A = Area of cube in m².

Flakiness and Elongation index

Samples for the elongation test weighed 5kg. It was mechanically shaken in a set of BS sieve ranging from 63mm to 6.3mm (BS, 1983). Samples passing sieve 6.3mm were rejected. The apparatus used include; BS set of sieves, a balance of capacity 5kg and a gauge. The procedure includes mechanically shaking the samples in a set of BS sieve and the mass passing or retained at each sieve was recorded. A maximum of about 200 pieces of each fraction of the samples was weighed in a gauge for thickness and samples passing each slot were weighed.

$$\text{Flakiness} = \frac{\text{Total mass passing} \times 100}{\text{Total mass of aggregate}}$$

Flakiness is expressed in percentage.

Water Absorption

This was determined using aggregates passing BS sieve 65mm and retained on sieve 6.3mm (BS 882, 1983). The following apparatus were used; wire mesh basket, oven, and balance of capacity 1kg, trays and dry absorbent clothes. The steps used include;

1. The aggregates weighed approximately 1kg and was thoroughly washed and dried to free them of clay particles.

2. The aggregates were soaked in wire mesh basket and submerged in water for 24hours

3. After 24hours, the samples were dried with dry absorbent cloth and weighed and recorded as m_1 (saturated surface dry)

4. The dry samples were then placed in a well-ventilated oven at a constant temperature of 105°C for about 1hour

5. After 1hour, the samples were removed, weighed and recorded as m_2 (oven dried sample)

Water absorption was determined from the relationship;

$$\text{Water absorption} = \frac{m_1 - m_2 \times 100}{m_1}$$

It is express as a percentage.

Where; m_1 = weight of saturated surface dried sample

m_2 = weight of oven dried sample

Specific Gravity

This is also called particle density. Specific gravity was conducted with 3kg of aggregates which were less than 10mm in diameter (BS 882, 1983). Apparatus used in the determination of specific gravity include, a balance which has the capacity not less 3kg, a thermostatically controlled oven that can maintain a temperature range of 105-110°C, a pycnometer and trays. Specific gravity was determined using density bottle (pycnometer). The **following steps were taken;**

1. Density bottle was weighed and recorded as m_1

2. Density bottle was filled with dry sample and weighed as m_2

3. Water was added to density bottle filled with sample and weighed as m_3

4. Density bottled was filled with water alone then weighed and recorded as m_4

Specific gravity (G_s) was then determined from the relationship:

$$G_s = \frac{m_2 - m_1}{[(m_4 - m_1) - (m_3 - m_2)]}$$

G_s has no unit since it is the ratio of weight to weight

Results and Discussion

Comparative studies of aggregates suitability for civil constructions entail running petrographic, physical and engineering properties tests on the aggregates. The results of petrographic studies of the aggregates presented in Table 1 below significantly explains the differences in the empirical deductions obtained in the cross-plots presented later in this work.

Results of petrographic analysis

Table 1: Average modal composition of aggregate from study area

Minerals	Quarry 1	Quarry 2	Quarry 3
Quartz	38	40	31
Microcline(alkali plagioclase)	25	24	24
Oligoclase(sodic plagioclase)	28	26	30
Hornblende	2	3	3
Muscovite	2	2	6
Biotite	3	3	4
Accessory minerals	2	2	2
Total	100	100	100
Rock name	GRANITE	GRANITE	GRANODIORITE

Table 1 indicates that the rock types in Quarries 1 and 2 are granites. In Quarry 3 granodiorites are found (Figures 4, 5 and 6)

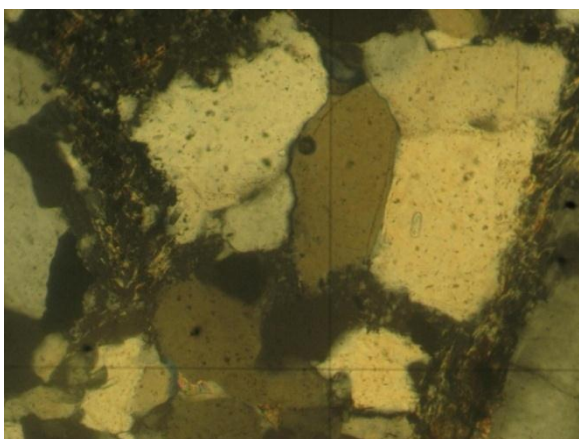


Fig. 4 Photomicrograph of representative sample from Quarry 2 (M x 100)



Fig. 5 Photomicrograph of representative Sample from Quarry1 (M x 100)

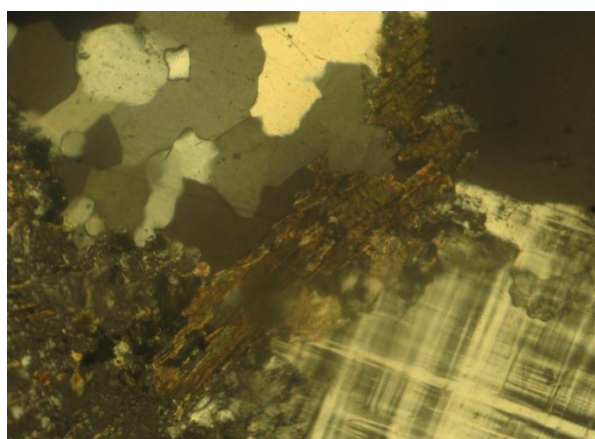


Fig. 6 Photomicrograph of representative Sample from Quarry3 (M x 100)

Physical and Engineering properties

The results of the physical and engineering properties of the rock aggregates are shown in Table 2. Table 3 indicates the average values of physical properties against acceptable specifications used in judging the aggregates suitability.

Table 2: Physical and engineering properties of aggregates from the three quarries in the study area

	QUARRY1 (operational)		QUARRY2 (operational)			QUARRY3 (proposed)			
	MIN	MAX	MIN	MAX	AVER	MIN	MAX	AVER	
Mechanical properties	MIN		MAX		MIN		MAX		AVER
	AVER								
Water Absorption (%)	0.3	0.96	0.66	0.43	1.01	0.73	0.87	0.92	0.90
Specific Gravity	2.60		2.65	2.60	2.66	2.64	2.66	2.72	2.69
	2.63								
sAggregate impact Value (%)	14	30	21	12	28	19	25	29	27
Aggregate Crushing Value (%)	12	31	19	12	21	16	26	33	29
Uniaxial Compressive Strength MN/m²	190	206	201	190	209	203	192	208	202
Flakiness and Elongation Index (%)	14	22	19	21	28	23	15	29	21
Los Angeles Abrasion Test (%)	14	29	20	12	31	18	39	42	41

Water Absorption

The values range from 0.66% in Quarry1, 0.73% in Quarry 2 to 0.9% in Quarry 3. There is an inverse relationship between water absorption and the rock strength which increases with depth. Samples from Quarry 3 showed higher water absorption (Table 2). This is due to the fact that they were taken on the surface as the intensity of weathering, to which they were subjected to was, high. This is as the result of socio-economic activities of the inhabitants of the area such as bush burning from farming practice which must have opened more cracks in these samples, hence, the higher water absorption value. Mallo and Sani, (2012) had suggested that the use of highly porous rocks as aggregate is not advisable as it may result in buoyancy effect. He favored the WAC value of < 1%. For the studied materials, the values of WAC are less than 1.0% which makes it acceptable for civil engineering construction (ASTM, 1990).

Specific Gravity

Specific gravity ranges from 2.60 to 2.65 in Quarry 1, 2.60 to 2.66 in Quarry 2 and 2.66 to 2.72 in Quarry 3. SG of rocks is a dimensionless value that shows the ratio of its density and unit weight of water. It gives indirect measures of rock strength and quality. Rocks with higher SG gives better results when used for construction as it tend to have higher value of uniaxial compressive strength. The values obtained for the present study correlate with what was reported by Bell, (1993).

Aggregate Impact Value (AIV)

Aggregate Impact Value measures relative resistance of aggregates to sudden impact or shock. The value ranges from 12 to 21% in Quarry 1, 12 to 28% in Quarry 2 and 25 to 25 in Quarry 3. Bell, (1993) reported similar values in his studies. Oyediran and Foghi, (2018) observed that AIV and ACV has similar, numerical value, hence an indication of similar strength properties.

The maximum allowable value of AIV for any construction work is 45% (Table 3) hence, the aggregates are judged suitable for civil engineering construction.

Aggregate Crushing Value (ACV)

This ranges from 12 to 31% in Quarry 1, 12 to 21% in Quarry 2 and 26 to 33% in Quarry 3. It measures resistance to crushing load. BS 812 (1983) specifies a range of 35 to 45% ACV for all construction works. Shetty, (2005) suggested that 45% value of ACV maybe allowed for wearing courses in pavement construction. The lower the ACV, the better the material will be for civil construction as such materials (low ACV) will resist crushing imposed by loads. Using that specification, the aggregates are considered suitable for civil construction.

Uniaxial Compressive Strength

The uniaxial compressive strength of rocks is the parameter most commonly used to evaluate rockmass properties or analyze slope stability. It is also effective in predicting "drillability and cuttability" of rocks according to Thuro, (1997). Rock materials from the three quarries show high compressive strength ranging from 190 to 208 MN/m². Using ASTM D 2988-71a (1990) specification, the rock is judged to be suitable for engineering construction.

Flakiness and Elongation Index

As far as construction is concerned, flaky aggregates should be avoided as much as possible. Williamson, (2005) observed that aggregates that are flaky are detrimental to the workability of mixes. The presence of elongated particles in concrete and bituminous mixes is undesirable as they cause inherent weakness with a possibility of breakdown. Flakiness values show a range less than 30% for the study area. The test results fall within the allowable limits for civil construction as indicated in Table 3.

Los Angeles Abrasion Value

This measures abrasive resistance to of aggregates to wear and polishing actions of vehicular movement under heavy traffic loads. A lower value of LAAV indicates a better construction material. Shetty, (2005) suggested LAAV of not more than 30% for wearing

courses and 50% for concrete, other than wearing courses. The result ranges from 18% in Quarry 2, 20% in Quarry 1 to 41 in Quarry 3. The high abrasion value in Quarry 3 can be attributed to weathering since sample from Quarry 3 showed higher degrees of weathering as these surface samples are more susceptible to weathering.

Table.3: Average values of physical properties of aggregates against acceptable specifications

Mechanical properties	Quarry 1	Quarry 2	Specifications	Test Designation	Engineering Judgment
Water absorption (%)	0.66	0.73	0.90	(0.1-1.0)%	BS 812, part 110, Accepted Clause 2005
Specific gravity	2.63	2.64	2.69	2.50-2.90	ASTM C 20-46 Accepted
Aggregate impact value (%)	21	19	27	(27-49)% Granite	BS 812 part 110 Accepted
Aggregate crushing value (%)	19	16	29	35% (max=45%)	BS 812, Clause 2003 Accepted
Uniaxial compressive strength (MN/m ²)	201	203	202	>190MN/m ²	ASTM D-71a Accepted
Flakiness and elongation index (%)	19	23	21	30%	BS 812, part 110, Accepted Clause 2005
Los Angeles abrasion test (%)	20	18	41	(27-49)%	ASTM C131 Accepted

Correlation Diagrams

Fig 7 shows a linear relationship between Los Angeles abrasion value and the aggregate crushing value. Since larger samples, higher cost and a more complex procedure is involved in running Los Angeles abrasion test compared to aggregate crushing test, aggregate crushing value can be used to estimated

the Los Angeles abrasion value. This implies that few Los Angeles test can be run to produce a correlation graph for the site under study. More ACV tests run for the site can assist in the estimation of accurate Los Angeles abrasion test data. For quarry 3, ACV actually is a good replacement for the Los Angeles abrasion test.

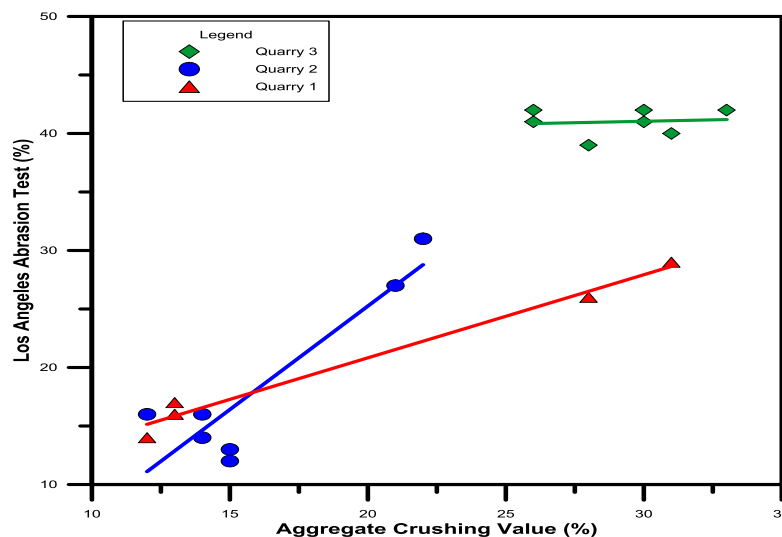


Fig 7. Los Angeles abrasion value vs Aggregate crushing value.

Fig 8. shows a relationship between water absorption and specific gravity. The plot shows a general increase in water absorption rate with decreasing

particle density (specific gravity) (Williamson, 2005). This indicates that very compact rock types have little pores in between. Hence, they do not have higher ability to absorb water making them more suitable for construction.

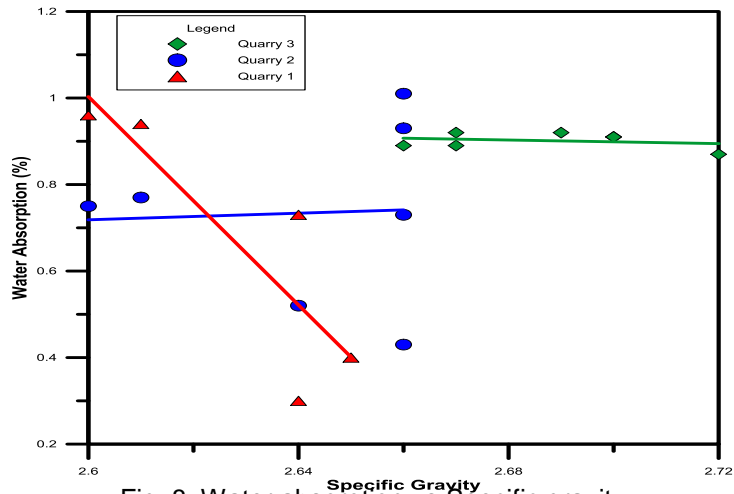


Fig. 8. Water absorption vs Specific gravity

Fig 9 shows an inverse relationship between the Uniaxial Compressive strength and the Los Angeles abrasion value. This suggests that aggregates with higher Uniaxial Compressive strength will have low Los Angeles abrasion value. This will give it a higher resistance to abrasive wear, making it suitable for

pavement and other civil constructions (Kazi and Al-Mansour, 1980a). For Quarry 3, UCS can serve as a good replacement to Los Angeles abrasion test but it is advisable to investigate each quarry site in its own right to avoid blind substitution of one parameter for another.

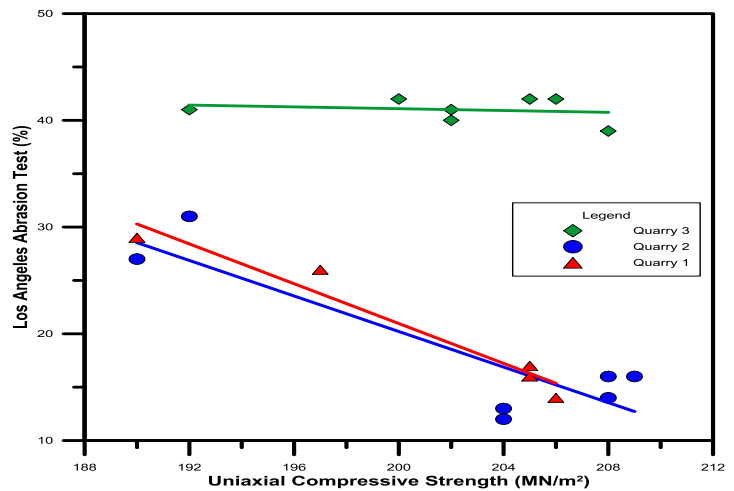


Fig. 9. Los Angeles abrasion value vs Uniaxial compressive strength

Applications

It is expected that aggregates assessed in this study would perform well in asphalt and concrete mix design for the construction of pavements and foundations as well as other civil engineering construction works. The high value of UCS, specific gravity and high resistance to crushing and impact load as well as the ability to withstand abrasion make the aggregates excellent materials for civil construction from engineering point of view.

Ranking of the Aggregates for the three Quarries

Aggregates from Quarry 3, in Okom-Ita, shows slightly lower quality compared to aggregates from Njahasang, this is attributed to greater impact of weathering on these surface samples. It is believed that when the weathered overburden is removed at the commencement of quarrying in Okom-Ita, the aggregate properties would improve in quality with depth. However, the materials are suitable for construction purposes since they fall within the ranges of acceptable standards in engineering construction.

CONCLUSIONS AND RECOMMENDATIONS

1. On the basis of the assessments, (Table 3), aggregates from Njahasang and Okom-ita which are part of Oban Massifs are judged to be suitable for civil engineering construction be it a pavement or a foundation.
2. Cross-plotting the parameters (Fig 7, 8 and 9) have produced useful and significant empirical

relationships which help to reduce number of expensive tests. However, it is important to note that treating each site by running the required physical and engineering properties tests would avoid blind substitution of one test for another.

3. The averages of the test result for all three quarries are suitable for pavement and for foundation works.

RECOMMENDATIONS

1. All quarries which produce rock aggregates should run the necessary geotechnical engineering tests on their products and display the test results on their bill boards and if possible in the print media for public consumption.
2. The general public should request for the results of the physical and engineering properties test prior to the purchase of rock aggregates for civil construction purposes.
3. All granitic rocks are not the same. They should be tested and ranked for civil construction purposes.
4. Relevant authorities should bring appropriate legislation on the necessary physical and engineering properties tests and ensure compliance by quarry operators.
5. It is anticipated that with proper designs of pavements and foundations and real supervision of civil works by geotechnically-informed personnels, characterization of rock aggregates employed for such works will surely increase the longevity of civil construction work in the country and elsewhere.

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