Geomechanical and Petrographical Characterisation of Crushed Aggregates from Pre- Cambrian Granitic rocks in Nigeria.

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Abstract

A total of ten samples of Pre – Cambrian granitic rocks were collected; (one inch and three-quarter inch sizes respectively) from five quarries in southwestern Nigeria for geo - mechanical and petrographic analyses to determine their suitability as construction materials. The aggregates collected were transported to the petrology and geotechnical engineering laboratory of Federal University of Technology Akure, Nigeria, where they were subjected to the following tests: thin section and modal analysis, aggregate crushing value, aggregate impact value, bulk density, specific gravity, flakiness index, porosity, ten percent fines value and water absorption capacity. Results from the petrographic analyses showed the aggregates samples to be biotite-granite, granites and porphyritic- granite based on their modal analysis. The engineering characteristics of the aggregate samples evaluated shows that the Aggregate Crushing Value ranged from 25.5 to 26.0, Aggregate Impact Value ranged from 17.9 to 18.5, Bulk density ranged from 26.77 to 27.43, Specific gravity ranged from 2.66 to 2.68, Flakiness index ranged from 24.9 to 28.3, Porosity ranged from 0.61 to 0.63, Ten percent fines value ranged from 135.30 to 159.46 and water absorption ranged from 0.49 to 0.68. The parameters of the aggregate samples analyzed falls within the acceptable limit set by the American Standard for testing and materials and British standard. The rocks in the study area fall within the Migmatite-Gneiss Quartzite Complex rocks which explains the high strength characteristics of the samples obtained. Therefore, crushed aggregates from Akure and its environs are of good quality and can be used in any engineering construction.

Keywords: Aggregates, strength, durability, engineering properties, Basement Complex,

1.0 Introduction

Aggregates are inert, granular and inorganic materials that normally consist of stone or stone-like solids. They can be divided into several categories according to size, origin, sources and unit weight/bulk density and screening method [1]. Aggregates form the major portion of pavement structure and they form the main materials used in pavement construction. The aggregates are specified based on their grain sizes, shapes and textures by various agencies such as ASTM, BSI, ISI and IRC. Based on strength property, the coarse aggregates are divided into hard and soft aggregates. If aggregates are weak, the stability of the pavement structures is likely to be adversely affected, the strength of coarse aggregate is assessed by aggregate crushing test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement, aggregate possessing low value should be preferred. The aggregates to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel loads, hence they should possess sufficient strength and resistance to crushing. In terms of unit weight, there are light weight aggregates with unit weight of less than 1120 Kg/m^3. The corresponding concrete has a bulk density less than 1800 kg/m^3. However normal weight aggregate has unit weight of 1520 to 1680 Kg/m^3. The corresponding concrete has a bulk density of 2300 to 2400 Kg/m^3 and heavy weight aggregate has a unit weight greater than 2100 Kg/m^3. The corresponding concrete has a bulk density greater than 3200 Kg/m^3. In accordance to screening method, sizes such as; ¾ inch down (oversize), 32 – 70mm; ¾ inch, 19 – 25mm; ½ inch, 5 – 19mm, Stone dust, 0 – 5mm have been established as well.

Aggregates can be used in a number of ways in roads and railway ballast to resist the overall load (static as well as dynamic), to distribute the load properly to the supporting ground and to drain the water off the surface. In concrete making, the aggregates are employed to reduce shrinkage and cracks which thereby strengthen the structure. They are also used in water filtration/ purification, emissions control, soil erosion control, and other environmental improvement products such as sewage treatment processes. Concrete aggregates are employed in the construction of many structures and substructures. Crushed aggregates is employed during the construction of rigid and flexible highway pavements, bridges, houses and other civil engineering projects [2]. Crushed aggregates is used for different purposes based on their source, size and texture. The large boulders (rip rap) are employed as fill in large construction projects, fine flour-sized particles are used in paint, glass, plastic, medicine, agricultural feed and soil conditioners, and many other industrial and household products [2]. They form concrete, motar or asphalt when mixed with appropriate proportions of water and a binding agent like cement or bitumen [3].

Crushed-rock aggregates are also required for use in the production of asphaltic concrete, because the angular surfaces provide the needed inter - granular strength. One km of a four-lane interstate highway requires nearly 50,000 tonnes of aggregate [4]. They are essential not only as a foundation for pavements, but also constitute the cement that makes the road itself. When a road is finished, the upper layers provide protection for the sub-base. Nevertheless, water can freely pass through the open structure, so the constituent rock must be able to maintain its properties when in the wet state.

The properties of crushed aggregate result from the origin and mineralogy of the source rock and its subsequent alteration and weathering. Some important properties of a rock are the type, size, shape, orientation, and proportions of mineral grains; the type of contacts between the mineral grains; the layering of minerals; and the presence and interconnectedness of voids [5]. The use of crushed-rock aggregates for engineering construction depends on the strength and durability characteristics of the aggregates [2]. The strength of the aggregates refers to the ability of the aggregates to resist compression due to external static or dynamic load [6]. It is not all rock type can serve as aggregate since the durability of the aggregates is directly related to its strength and indirectly refers to the life of civil engineering structures constructed with them. Most rock type used as aggregate are found in the Basement complex terrain, since they are made up of metamorphic and igneous rocks that are massive and extensive, examples of such rocks are granites, gneisses, and andesite. However, the Nigerian Basement complex rocks are grouped into the following main rock types; the migmatite gneiss quartzite complex, the slightly migmatized to non migmatized meta - sedimentary and meta - igneous rocks, the charnokitic, dioritic and gabbroic rocks, the older granite suites, the unmetamorphosed dolerite dykes, basic dykes and syenitic dykes and the metamorphosed to unmetamorphosed calc-alkaline volcanic and hyper--byssal rocks [7]. Selecting the right aggregate material is imperative to overcome the frequent problem of pavement failure. Due to various ways in which aggregates are being used, they are usually exposed to different types of stresses, and the response of the structure in which it serves for will largely depend upon the properties of the aggregates. They need to resist heavy loads, high impacts and severe abrasion, and it needs to be durable in the prevailing environmental conditions. These properties will need to be tested and assured before any engineering construction is done. Similarly, in the case of road construction after which the initial trafficking and removal of any surface bituminous coating has occurred, vehicles will be traveling on the actual aggregate used in the mixture for the bulk of the life of the road surface. Thus they undergo substantial wear and tear throughout their life and must therefore be able to withstand the weight and impact of such constructions. In general, aggregates should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities. About 52% of all construction aggregates are crushed stones, while 48% of the remaining is sand and gravel [8].

Therefore, the petrographic and geomechanical analyses of aggregates were carried out to determine their mineralogy, strength and their durability and their suitability as construction material in parts of southwestern, Nigeria.

2.0 Location, physiography and geology of the study area

The study area lies between latitude 7˚11′N - 7˚23′N and longitude 5˚7′E - 5˚18′E in Southwestern Nigeria. (Figure 1). It covers an area extent of 15,500 Km^2 (6,000 sq mi.). Elevations vary between 260 and 470 m above sea level [9].

The climate of the study area is tropical rain forest type, with distinct wet and dry seasons. The tropical climate is broadly divided into two: Dry season (Harmattan season) and raining season. The annual rainfall varies from 2,000mm in the southern areas to 1,150mm in the northern areas. In the southern areas relative humidity is over seventy five percent. In the northern part of the state, the mean monthly temperature and its range are about 30°C. The mean monthly relative humidity is less than seventy percent [9].

The average annual temperature in the study area is 25.9°C with a rainfall average of 1546 mm. The driest month is January, with 9 mm of rain, precipitation falls in September with an average of 247 mm and March is the warmest month of the year with a temperature average of 27.7°C. In August, the average temperature is 3.9°C which is the lowest average temperature of the whole year. The study area lies within the crystalline Basement Complex rocks of the Southwestern Nigeria. The rock types are predominantly migmatite gneiss and other rock types includes granites, quartzites and charnockites.

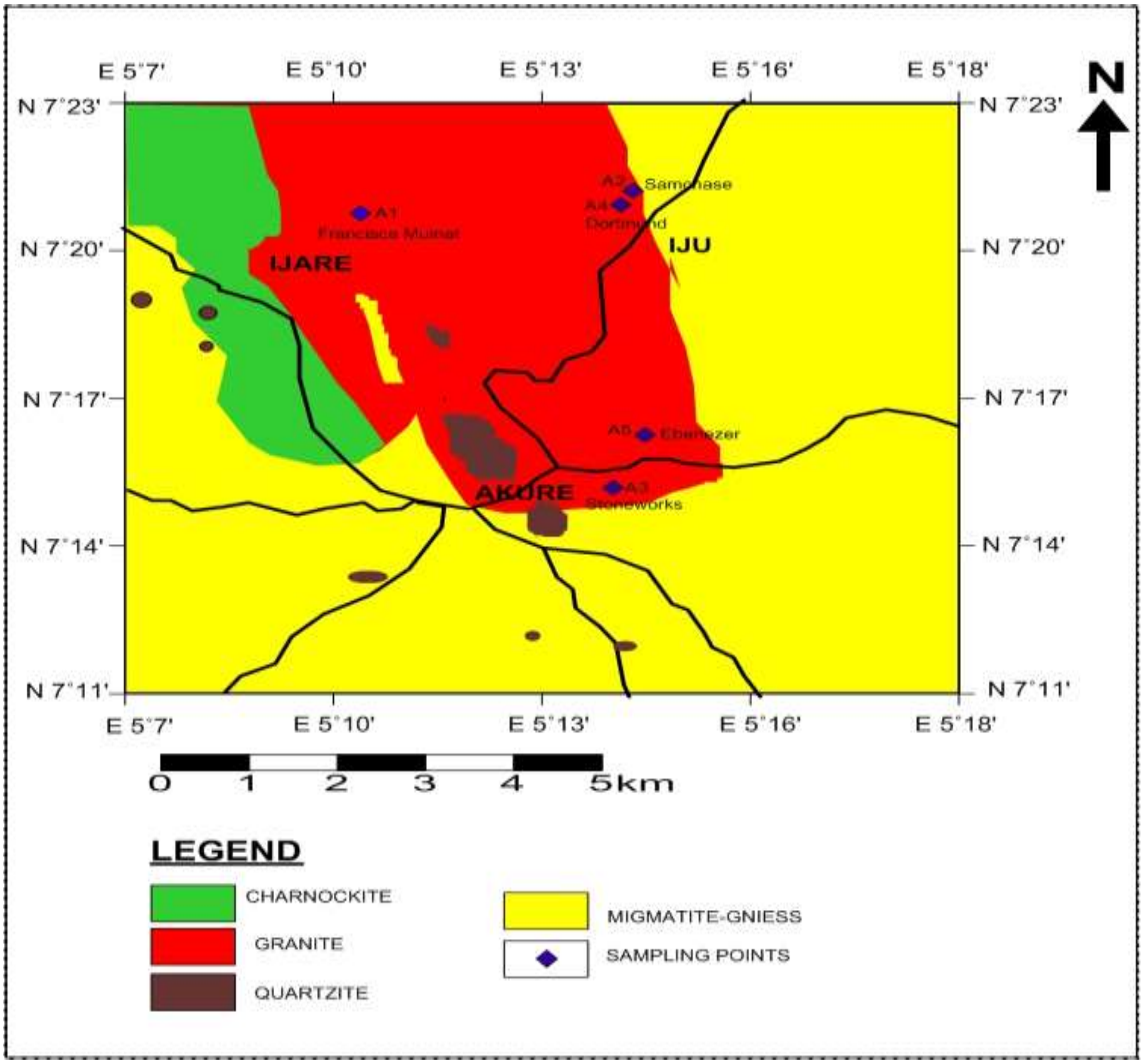

Figure 1: Geological Map of the study Area showing sampling points (AAUA Geology Department)

Quartzites occurred in form of ridges and have undergone series of tectonic activities and were exposed by weathering and erosion. Granite is a felsic intrusive (plutonic) igneous rock that is granular and large grain in texture. They are the most obvious manifestation of the pan- African orogeny. They occur as massive outcrops that are majorly seen along the North-Eastern part of the study area and occupy about 20% of the area. They also occur as pocket within the charnockite and the gneissic rocks. They are generally believed to be formed during the late stage of crystallization of magma, resulting in formation of large crystals as a result of slow cooling within the earth crust before it is exposed to the surface either by agent of weathering, stopping or assimilation. The Granite rocks which are member of the older granite suit occupy about 65% of the total area of Akure. Three principal petrographic varieties were recognized, the fine-grained biotite granite, medium to coarse grained, non-porphyritic biotite – hornblende granite and coarse –porphyritic biotite- hornblende granite [10]. The classification is based largely on the textural characteristics. The Granite at Ijare (Aaye town) has structures such as pegmatitic veins, fractures and unconformity. The charnockitic rocks of Akure intruded into the gneiss-migmatite-quartzite complex and the older granite suite. There are three types of charnockitic rocks in Akure area described on the basis of their textural characteristics, they are the: coarse-grained as exemplified by the Akure body, massive fine-grained which form along the margins of the granitic bodies as seen in Ijare and gneissic fine-grained types which were recognized within the bodies of the gneisses in Iju[11]. The charnockitic rocks of Akure-Ikerre-Ado Ekiti have been described as an association [10]. The field and petrographic relationships between the charnockitic and the associated granitic rocks of the Akure area was reported that the charnockitic rocks of Akure are younger than the granitic rocks bodies, of the Pan-African age and of igneous origin [12].

3.0 Materials and method

Aggregates were collected randomly around the stockpile at the base of the conveyor belts of the various quarries at their crushing section by using shovel. A total of ten samples of about 5kg each were obtained from five locations for laboratory analysis, with each location having two representative samples.

The samples collected were already crushed rock aggregates with sizes of one inch (32-70mm) and three-quarter inch (19-25mm). The description of each sample was based on location name as shown in Table 1. All the tests carried out in the laboratory for thin section, aggregate crushing value, aggregate impact value was done using the ISRM standard.

The samples from each location were mixed together at the laboratory before being subjected to several tests at the Engineering Geology and Petrology workshop, Federal University of Technology Akure, Nigeria. The tests were carried out on accurate precision to avoid error of measurement, counting and inconsistency was also in accordance to the standards suggested by [13], [14], [15]. The tests carried out includes modal analysis, flakiness index, specific gravity, porosity, water absorption, bulk density, grain size distribution, aggregate impact value and aggregate crushing value.

Table 1: Samples Coordinates

S/N	Sample name	Description	Latitude (N)	Longitude (E)
1	A1	Francisca Muinat Limited, Ijare.	7˚20′18″	5˚10′10″
2	A2	Samchase Nig. Limited, Itaogbolu.	7˚21′31″	5˚13′59″
3	A3	Stoneworks Limited, Akure.	7˚15′38″	5˚14′47″
4	A4	Dortmund Limited, Itaogbolu.	7˚21′28″	5˚13′57″
5	A5	Ebenezer Mining and Ceramics Ltd; Akure.	7˚16′30″	5˚14′49″

4.0 Results and discussion

The results of the various laboratory analyses carried out in the course of this research work such as modal analysis, thin section and the summary of the strength indices such as specific gravity, bulk density, porosity, water content, flakiness index, ten percent fines value, aggregate impact value and aggregate crushing value are presented in Table 2 and, Table 3 and Plates 1 to 10 respectively.

Table 2: Average modal analysis of the aggregate samples

Sample No	Quartz	Microcline	Plagioclase	Biotite	Hornblende	Orthoclase	Muscovite	Opaque	Pyroxene	Total
A1	69.4	4.1	9.4	14.1	-	-	0.9	0.9	-	98.8
A2	45.6	13.1	18.1	16.3	-	-	4.7	-	-	97.8
A3	72.5	12.5	-	6.9	-	5.3	1.3	-	-	98.4
A4	40.6	44.7	-	7.2	0.0	6.3	0.3	-	-	99.1
A5	19.4	43.1	-	11.6	20.6	-	3.8	-	3.8	98.4

A1: Biotite Granite

A2: Biotite Granite

A3: Granite

A4: Granite

A5: Porphyritic Granite

Table 3: Summary of the results of the engineering test carried out on the aggregate samples

Sample No	Aggregate Crushing Value (%)	Aggregate Impact Value (%)	Average Specific Gravity (%)	Flakiness Index (%)	Porosity (%)	Specific Gravity	Ten percent Fines Value (kN)	Bulk Density (kN/M^3)	Water Absorption Content (%)
A1	25.8	17.9	2.71	28.3	0.61	2.67	159.29	27.04	0.57
A2	25.5	18.3	2.69	28.3	0.62	2.66	140.31	27.43	0.49
A3	25.6	18.0	2.72	24.9	0.61	2.68	148.53	26.79	0.59
A4	25.9	18.5	2.71	28.0	0.63	2.67	135.30	26.77	0.61
A5	26.0	17.9	2.71	27.9	0.62	2.66	159.46	27.12	0.68

Biotite Granite (A1)

Micro-structures such as twinning and mineral inclusions were observed in the thin sections of the rock (Plate 1 – 2).

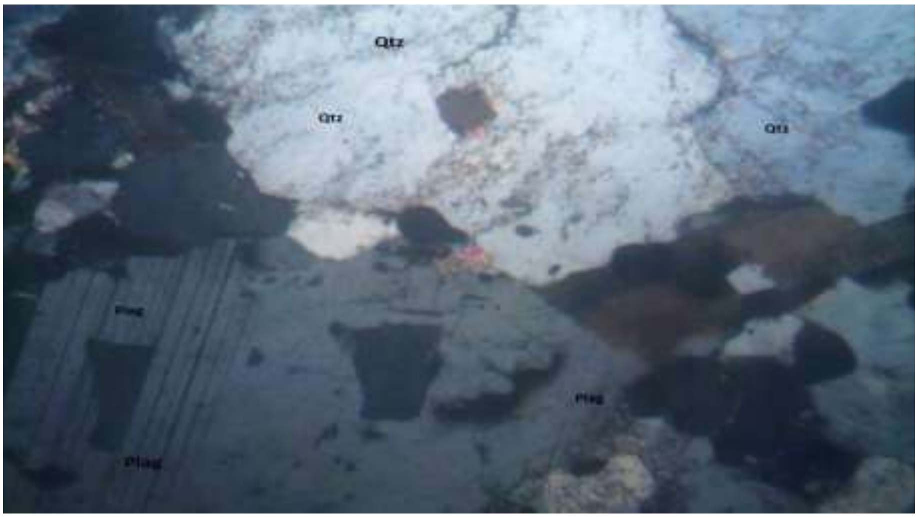

Plate 1: Photomicrograph of Biotite Granite in cross polarised light showing quartz (Qtz) and plagioclase (Plag).

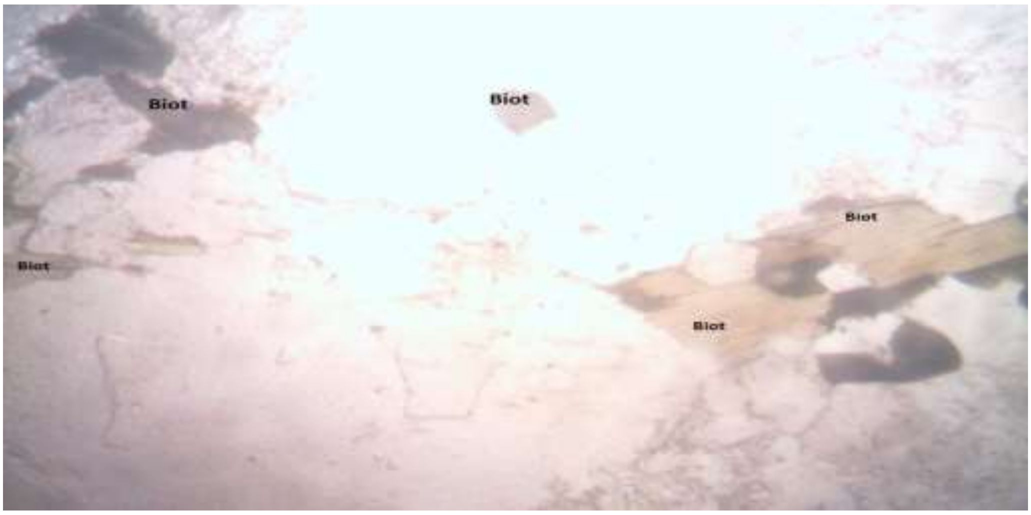

Plate 2: Photomicrograph of Biotite Granite in plane polarised light (Biot).

Biotite Granite (A2)

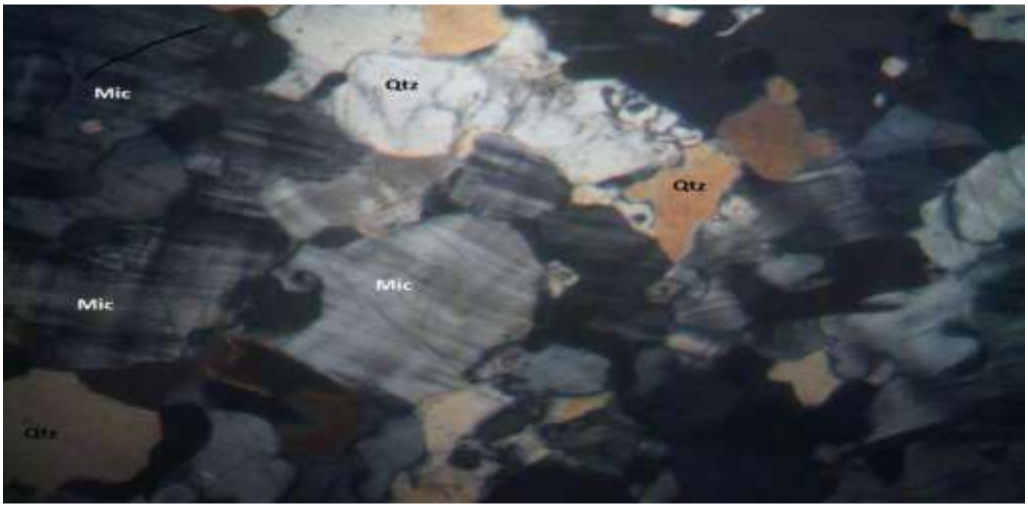

Plate 3: Photomicrograph of Biotite granite in cross polarised light showing quartz (Qtz) and Microcline (Mic).

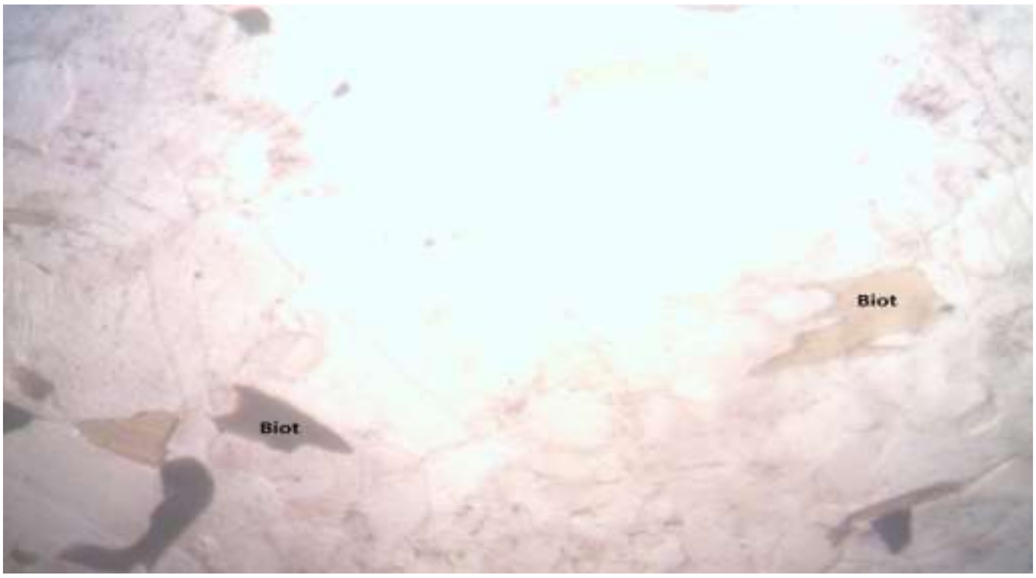

Plate 4: Photomicrograph of Biotite granite in plane polarised light showing Biotite (Biot).

<u>Granite (A3)</u>

The petrography of the rock revealed twinnings as the microstructures it exhibited (Plate 5 -6).

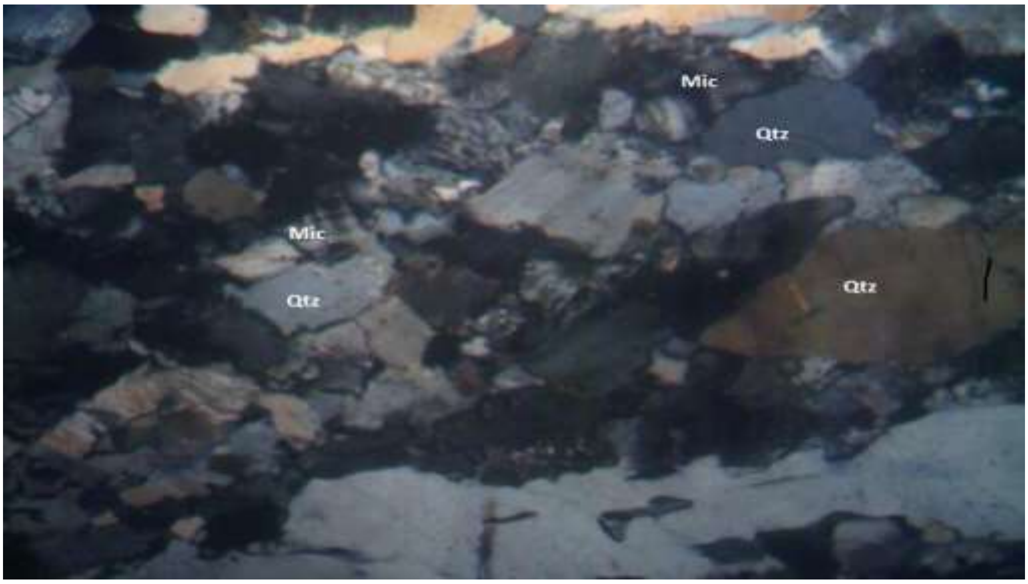

Plate 5: Photomicrograph of Granite in cross polarised light showing quartz (Qtz) and Microcline (Mic).

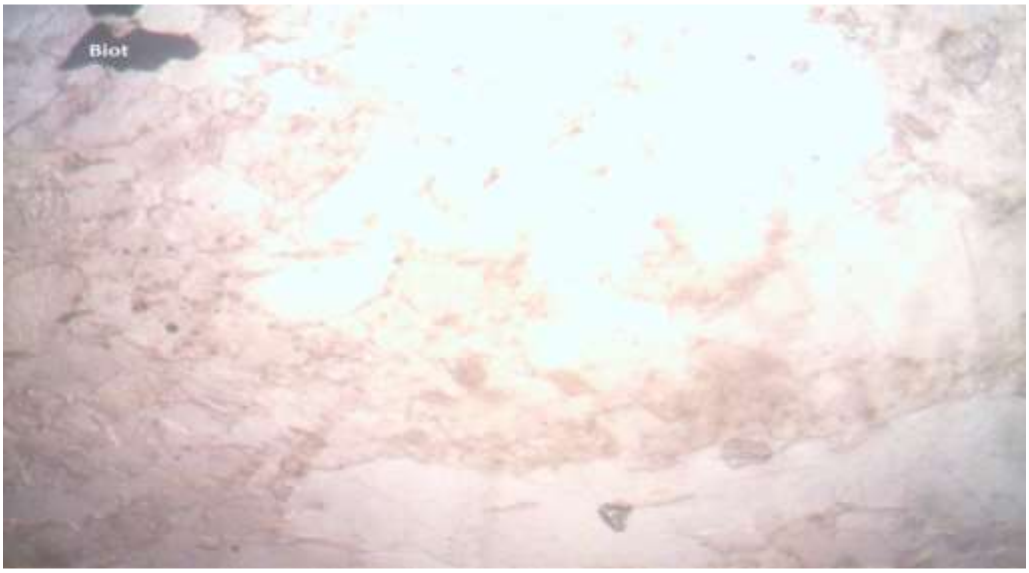

Plate 6: Photomicrograph of Granite in plane polarised light showing biotite (Biot).

Granite (A4)

The petrography of the rock revealed twinning as the microstructure it exhibited (Plate 7 – 8).

Plate 7: Photomicrograph of Granite in cross polarised light showing quartz (Qtz).

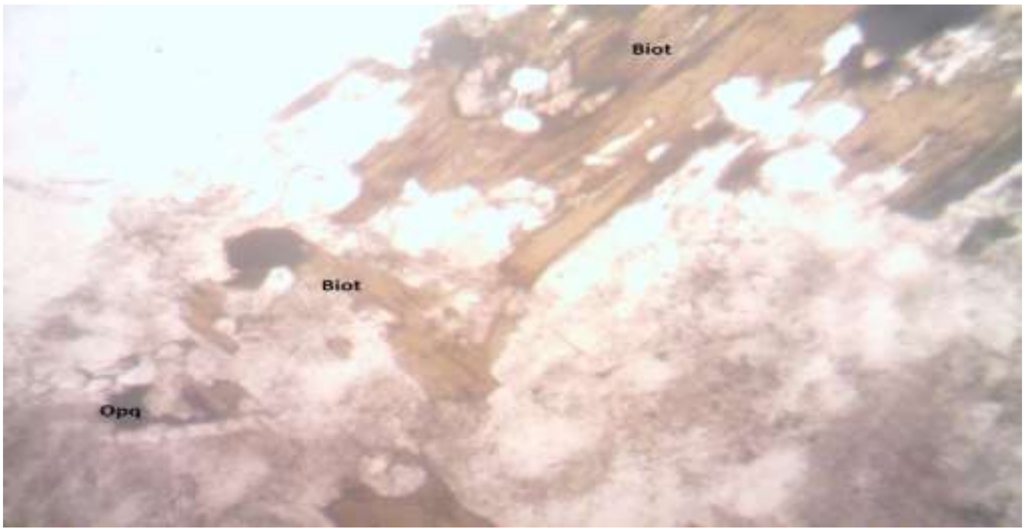

Plate 8: Photomicrograph of Granite in plane polarised ligh showing biotite (Biot) and opaque (Opq).

Porphyritic Granite (A5)

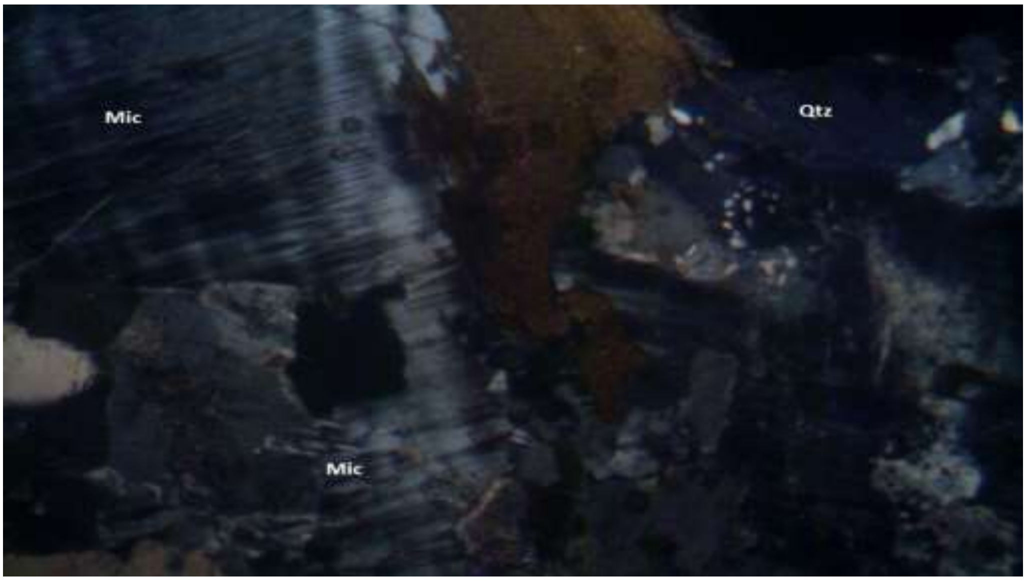

Plate 9: Photomicrograph of Porphyritic Granite in cross polarised light showing quartz (Qtz) and microcline (Mic).

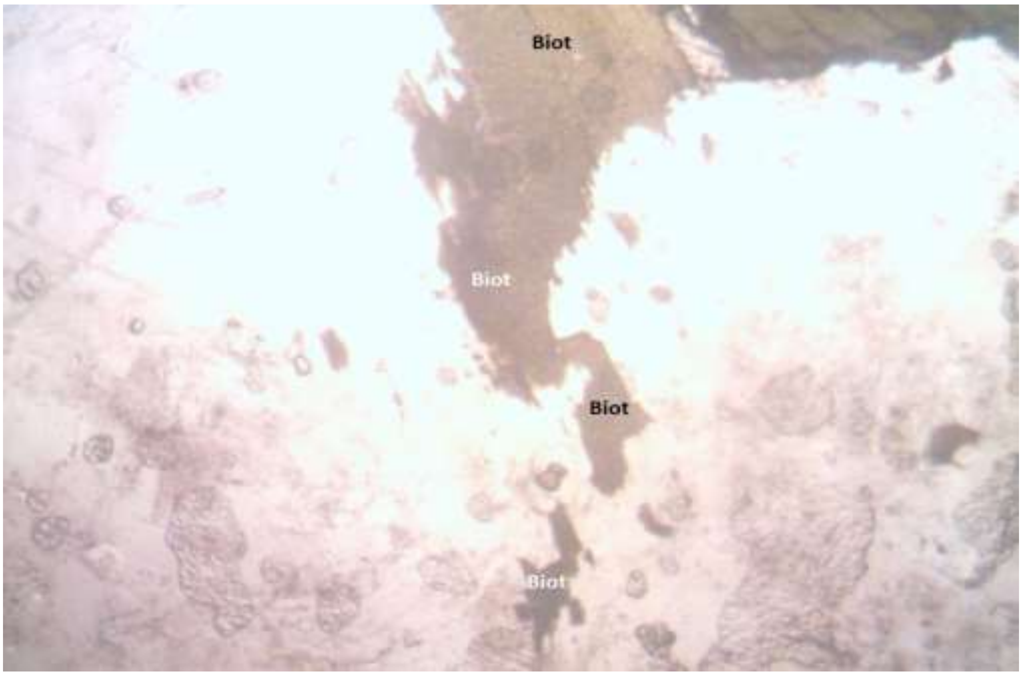

Plate 10: Photomicrograph of Porphyritic Granite in plane polarised light showing biotite (Biot).

4.1 Mineral composition

The Biotite Granite (A1 and A2) consists of quartz, microcline, plagioclase, biotite, muscovite and opaque minerals as major minerals. The average modal composition ranged from 69.4% to 45.6%, 4.1% to 13.1%, 9.4% to 18.1%, 14.1% to 16.3%, 0.9% to 4.7% and 0.9% respectively (Table 2).

The Granite (A3 and A4) consists of quartz, microcline, biotite, orthoclase, muscovite and hornblende as major minerals. The average modal composition ranged from 72.5% to 40.6%, 12.5% to 44.7%, 6.9% to 7.2%, 5.3% to 6.3%, 1.3% to 0.3% and 0.0% respectively (Table 2).
The Porphyritic Granite (A5) consists of quartz, microcline, pyroxene, biotite and hornblende as major minerals. The average modal composition ranges from 19.4%, 43.1%, 3.8%, 11.6% and 20.6% respectively (Table 2).
The average modal mineral composition of the aggregate samples from the study area is presented in Table 2.

4.1.2 Description of thin section of the study area

Quartz [SiO_2]
The mineral has almost the same characteristics in most of the rock aggregates in which it is found in the study area, the minerals occurred as euhedral prismatic crystals. Cleavage occurs on rare occasion appearing on the edge of the slide.
Plagioclase Feldspar [$(Ca,Na)AISi_3O_8$]
The cleavage of the plagioclase feldspar found in rock aggregate samples in the study area is generally not well pronounced and they have low relief and weak birefringence. It has parallel extinction.
Biotite [$K (Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$]
The colour of biotite varies from brown to yellowish brown in the thin section of the rock aggregates. The mineral undergoes pleochroism and cleavage is perfect in one direction.
Horneblende [$(Ca,Na)_{2-3} (Mg,Fe,Al)_5[(Al,Si)_8(OH)_2$]
The horneblende mineral has variable colour from light brown to green colour. Pleochroism occurs in shapes from yellowish green to pale brown. The crystals are elongated and prismatic in habit. The cleavage is in two directions to (110) at angle of 56^0 and 124^0. Relief is rather high and birefringence is moderate. The maximum interference colour is about middle second order; though the colour of the mineral modifies or even masks the interference colour. Maximum extinction angle varies from 12^0 to about 30^0 being symmetrical to the outline or to the cleavage trace.
Pyroxene [$XY (Si,Al)_2O_6$]
The mineral is neutral to pale green in thin section. Pleochroism is the most distinguishing factor from greenish to pale reddish. It is usually in subhedral crystal of prismatic habit with cross sections nearly square. Cleavage is parallel to (110) and sometimes parallel to (010) and (100) (Hypersthene). Double cleavage also characterise the mineral with inter cleavage angle ranging from 86^0 to 93^0in augite. The relief is high and birefringence is rather weak. Maximum interference colour is yellow to red of first order and extinction is parallel.
MicroclinE [$KAlSi_3O_8$]
Microcline is in the thin sections and exhibit perthite (cross-hatch) twinning under crossed nicol and it's colourless under plane polarised light. It has greyish colour. The cleavage of the microcline in the rock is perfect and it has weak birefringence. Its interference colour is grey and white of the first order.
MuscovitE [$KAl_2 (AlSi_3O_{10})(F,OH)_2$]
When muscovite is observed under Petrological microscope between crossed nicols, the interference colours are pure. However, second and third order tints of green and red crystals of muscovite were seen. They belong to the white mica which is grouped as felsic minerals. The muscovite crystals are porphyroblastic in nature, while the extinction angles of the crystals are parallel to the cleavage direction.
Orthoclase feldspar [$KAISi_3O_8$]
Orthoclase feldspar occurs slightly in most of the thin sections. The distinguishing factor from other feldspars is its Carlsbad twinning.

4.2.2 Strength characteristics

Table 4.3 represents the result of the test for strength and durability characteristics on samples (A1, A2, A3, A4 and A5) of crushed rock aggregates from the study area while Table 4.8 represents acceptance limits for test results of road -stones (after [16]. [17].

4.2.2.1 Flakiness index

The flakiness index values for the aggregates samples ranged from 24.9 to 28.3, while the average mean values was 27.48 (Table 4.3). Location A3 has the lowest value of 24.9, while location A1 and A2 have the highest value of 28.3. Flaky aggregates are to be avoided in any construction work because it causes weakness and breakdown under heavy traffic loads which reduces the workability of the aggregate in concrete pavement. The flakiness index of aggregate used for road construction should not be greater than 35% and value less than this is considered suitable for use in surfacing as well as lower layers. From the result obtained, the Flakiness index of all the aggregate samples falls within the acceptable limit for use as road construction and surfacing materials (Table 4)

4.2.2.2 Specific gravity

The specific gravity values for the aggregate samples ranged from 2.66 to 2.68, while the average mean value was 2.67 (Table 3). Locations A2 and A5 has the lowest value of 2.66, while location A3 has the highest value of 2.68. Generally, the Specific Gravity of aggregates used in pavements is usually between 2.6 and 2.7 with a maximum value of 2.9. From the result obtained all the aggregate samples falls within the "good" aggregate category and can be used in pavement construction.

Table 4: Summary of the strength and durability characteristics of crush rock aggregates from the study area

PARAMETER	A1	A2	A3	A4	A5	AVERAGE
ACV (%)	25.8	25.5	25.6	25.9	26.0	25.76
AIV (%)	17.9	18.3	18.0	18.5	17.9	18.12
WA (%)	0.57	0.49	0.59	0.61	0.68	0.59
TFV (kN)	159.29	140.31	148.53	135.30	135.46	148.58
FI (%)	28.3	28.3	24.9	28.0	27.9	27.48
SG	2.67	2.66	2.68	2.67	2.66	2.67
Porosity (%)	0.61	0.62	0.61	0.63	0.62	0.62
Bulk Density (kN/M^3)	27.04	27.43	26.79	26.77	27.12	27.03

4.2.2.3 Porosity

The porosity values for the aggregate samples ranged from 0.61 to 0.63, while the average mean value was 0.62 (Table 4). Locations A1 and A3 has the lowest value of 0.61, while location A4 has the highest value of 0.63. For any road construction work a certain degree of porosity value between 0 and 1 is desirable, as it permits the aggregate particle to absorb bitumen, which then forms a mechanical linkage between the bitumen film and the stone particle during road construction. From the result obtained all the aggregates samples falls within the acceptable limit for concrete and road construction

4.2.2.4 Water absorption

The water absorption values for the aggregate samples ranged from 0.49 to 0.68, while the average mean value was 0.59 (Table 4). Location A2 has the lowest value of 0.49, while location A5 has the highest value of 0.68. %. From the result obtained all the aggregates falls within the acceptable limit of material used as road stones and can be useful in road surfacing activities (Table 6).

4.2.2.5 Bulk density

The bulk density values for the aggregate samples ranged from 26.77 to 27.43, while the average mean value was 27.03 (Table 4) Location A4 has the lowest value of 26.77, while location A2 has the highest value of 27.43. Aggregates with values of bulk density greater than 26.0kN/m^3 are good for road construction and from the result obtained all the aggregate samples have values greater than that so they can be useful in road construction. All the aggregate samples are dense with high specific gravity values and are generally effective in any construction work.

4.2.2.6 TEN PERCENT FINES VALUE (TFV)

The results of the ten percent fines value for the aggregate samples ranged from 135.30 to 159.46, while the average mean value was 148.58 (Table 4). Location A2 has the lowest value of 135.30, while location A5 has the highest value of 159.46. In order to meet typical US and UK specifications (Specification for Highways Works, Clause 803,[18], the Ten percent Fines Value should not be less than 50 kN and specification for Ten percent fines value can vary from 50 to 110 kN and up to 160 kN where high quality and hard aggregate sources are common. The aggregate samples of the study area fall within the aggregate having high value of Ten percent fines, an indication that the aggregates are difficult to crush and are good materials for any construction work

4.2.2.7 AGGREGATE CRUSHING VALUE (ACV)

The aggregate crushing value result for the aggregate samples ranged from 25.5 to 26.0, while the average mean value was 25.76 (Table 4). Location A2 has the lowest value of 25.5, while location A5 has the highest value of 26.0. From this result the aggregates can be said to be of granitic origin. ACV varies from about 5% for strong aggregates to 30% for weaker aggregates. Aggregates having ACV less than 10% are considered very strong, between 10-20% are considered strong, and between 20-30% are good for roadstone, from the result obtained the aggregates falls within the good for roadstone category

4.2.2.8 AGGREGATE IMPACT VALUE (AIV)

The results of the aggregate impact value for the aggregate samples ranged from 17.9 to 18.5, while the average mean value s 18.12 (Table 4). Location A1 has the lowest value of 17.9, while location A4 has the highest value of 18.5. AIV <10% is exceptionally high, AIV between 10% and 20% is strong and good, 20% - 30% is satisfactory for road surfacing while an aggregate with an AIV >35% is very low and suitable for lower layers only Table 8. From the result obtained the samples falls within the satisfactory for road surfacing AIV range which is an indication that the samples have greater resistance to impact also they can serve as both surfacing and lower layers material as presented in (Table 5).

Table 5: Classification of rocks based on Aggregate Crushing Value [19] (BS 1990)

Rock type	ACV %	Range %
Basalt	16	16 – 17
Andesite	16	15 – 17
Dolerite	19	-
Granite	26	23 – 30

Table 6: Aggregate Impact Value and its relevance in road construction [20].

Location/ Source	Aggregate Impact Value (%)

	Value	Aggregate suitability(with specification)
A1	17.9	Surfacing and lower layers
A2	18.3	Surfacing and lower layers
A3	18.0	Surfacing and lower layers
A4	18.5	Surfacing and lower layers
A5	17.9	Surfacing and lower layers

Table 7: Classification of Aggregates based on Aggregate Impact Value (AIV) [19].

Average Impact Value	Classification
<10%	Exceptionally strong
10 - 20%	Strong
20 - 30%	Satisfactory for road Surfacing
>35%	Weak for road surfacing

Table 8: Flakiness Index and its relevance in road construction [13], [21].

Location/ Source	Flakiness index (%)	
	Value	Aggregate suitability(with specification)
A1	28.3	Surfacing and lower layers
A2	28.3	Surfacing and lower layers
A3	24.9	Surfacing and lower layers
A4	28.0	Surfacing and lower layers

A5	**27.9**	**Surfacing and lower layers**

Table 9: A Comparison of Aggregate Test Results with acceptable standards [8], [13], [17], [21], [19].

Test	Test Value+	Acceptance Limits	Use
Aggregate crushing value (ACV) (%)	**25.76**	**Maximum 30**	**C, R**
Aggregate impact value (AIV) (%)	**18.12**	**Maximum 30**	**C, R**
Water absorption (%)	**0.59**	**Less than 3**	**C, R**
Bulk density (kN/M^3)	**27.03**	**More than 26.0**	**C, R**
Ten percent fines value (TFV) (kN)	**148.58**	**More than 50**	**C, R**
Flakiness index (%)	**27.48**	**Maximum 35**	**C, R**
Porosity (%)	**0.62**	**Maximum of 1**	**C, R**
Specific gravity (SG)	**2.67**	**2.6-2.9**	**C, R**

Notes:

+ - Average of five test results

C - Concrete

R – Road Aggregate

5.1 Conclusion

Results of geomechanical tests and petrographical analyses on crushed rock aggregates from the study area were used to evaluate their strength, durability and suitability characteristics as materials for engineering construction. Aggregates having low specific gravity or high-water absorption are generally considered unsuitable and also higher porosity generally leads to a lower value of Specific Gravity and vice versa. All the aggregate samples have high specific gravity, low water absorption content and low porosity. All the aggregates strength indices are satisfactory for use in any engineering construction such as pavement and road construction and falls within the good for roadstone aggregate category [20]. Results of Thin section and ACV also indicates that Granite is the main rock type of the aggregates and that it possess higher strength value that fits the requirements necessary for use as construction aggregates in accordance with standard specifications[8],[13], [17] , [19], [21] .

The comparative study of results from analysis and reference standard limit showed that the parameters falls within the acceptance limit. Aggregate produced from all the quarries because of their low porosity, and high crushing strength; possess the necessary characteristics for use in pavement construction in accordance with [13], [16], [17] standards, It can therefore be deduced that the aggregates are good materials for engineering construction and the results of this work will be useful in selecting the aggregates that will be of optimum use in sustainable engineering construction such as road, bridges, storey buildings and where it can be readily available in Nigeria.

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