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Durability Tests and Evaluation of Engineering-Geological Rock Materials within Some Locations at Southern Part of Lower Benue Trough as Construction Aggregates in Ebonyi State, Nigeria

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***Abstract*— Dated back since the history of civilization, Construction Engineers has solely depended on geological aggregate materials as one of the unavoidably important materials in construction technology. At the study area, there are many aggregate quarrying industries with different geological materials, being patronized by government, construction companies and individuals at this time of infrastructure development. Therefore, the need to know the durability strength of these various rock materials, since their lithology varies. This is important because, the suitability of aggregates for construction actually relies on its testing against national and international standards. Some of these rocks assessed belong to and are found in Asu River Group sediment and Amasiri Sandstone. The rock materials evaluated were from Pyroclastic rocks (Ezza-Agu Hill), Baked-Shale (Umuohara), Limestone (Ngbo), Limestone (Amasiri) and Granodiorite (Ishiagu). The Ngbo Limestone, Amasiri Limestone, Umuohara Baked-Shale, Ezza-Agu Pyroclastic rock and Ishiagu Granodiorite aggregates gave the following values: Aggregate crushing value (ACV) of 8%, 8.7%, 10%, 12%, and 14.2%. Flakiness Index (FI) values of 12.5%, 13.5%, 15%, 21%, and 19.6%. Aggregate Specific Gravity value of 2.6, 2.61, 2.63, 2.64 and 2.81. Water Absorption Value of 1.54%, 1.56%, 1.57%, 2.25% and 0.32%and Aggregate Abrasion Value (AAV) of 24%, 24.4%, 25%, 23% and 15% respectively. This result indicates that granodiorite aggregate gave the best value and should be used more preferably than the others especially in road construction. In addition, Pyroclastic rock aggregates is good while others are fairly within the required range and can be used for building construction and not road.**

***Index Terms*— Engineering properties and Durability test, Rock Strength and Aggregates, Asu River Group, Southern Benue Trough.**

I. Introduction

Natural construction aggregate is one of the most abundant natural resources and one of the most widely used [20]. They have been used by mankind throughout life histories as a basic construction material. Reference [37] noted the huge variations within each type of aggregate, depending on their engineering properties. in various construction works such as dams, buildings, railway ballast, pavements, etc, Aggregate have been used.

Reference [6] shows that the fundamental raw material for all constructions are Construction aggregate and such sector is an important part of most modern developed economies. Therefore, the need for testing and specification of aggregate should not be overlooked or not considered. For if overlooked, it has a serious implication for the life and maintenance of infrastructures which can cost a lot of money in the future to repair or replace and at worst lead to lose of human lives and structural failure.

[11]) and [16] defined durability of rock as the ability of rock to maintain initial mechanical and physical properties in a required period of time with respect to a set of engineering serviceability requirements, whether it comes to its impact on construction, other rocks in the geological vicinity, or usability as building material. *These rock aggregates when considered as a construction material, are subject to intensive change of engineering properties. These changes can be caused by external influences and can manifest within a few months to several years. For this reason, the durability of construction aggregate relies on its testing against national and international standards*. Therefore, testing of these aggregates not only ensures its durability and suitability for different construction applications. But it is also the basis for consumer specifications which enables the assurance that it continues to meet the required properties needed. This paper focus on determining the durability strength of manufactured aggregate.

II. STUDY AREA LOCATION

The study area encompasses Southern Part of Lower Benue Trough located within Ebonyi state as shown at the location map (fig 1). The towns and village within the study area includes: AmofiaNgbo in Ohaukwu L.G.A, EzzaUmuoghara in Ezza North L.G.A, Ezza-Agu in Izzi L.G.A, AmaokwuIshiagu in Ivo L.G.A and Amasiri in Afikpo L.G.A.

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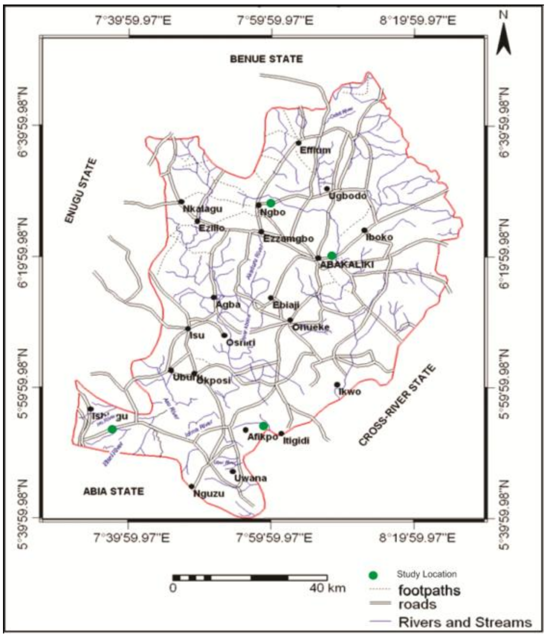

Figure 1: Study Area location Map.

III. GEOLOGICAL BACKGROUND

The sedimentary rock of the lower Cretaceous age –the Albian Abakaliki shale [38] and Amasiri Sandstone are exposed at the study area. The shale deposit is the first marine transgression of the Benue trough which is generally believed to have occurred during the middle - lower Albian. The marine transgression led to the deposition of the oldest sediment- the Asu River Group [38], [34] and [31, 32]. [38, 39],[19] and [20] reported that the sedimentary rocks are predominantly black carbonaceous shale with occasional intercalations of thin calcareous matter, constitute the Albian Asu River Group. [10],[44]), [41],[27, 28] and [24] noted that the deposits consist of poorly bedded Sandy shale, Sandstone, Siltstone with sandstone occurrences and Sandy limestone lenses. Figure 2 shows the distribution of the Asu River Group and other lithologic units in Southern Benue Trough, South-eastern Nigeria. The Asu River group sediments are predominantly shales, commonly referred to as the 'Abakaliki shale formation' in and around the Abakaliki environs (approximately 452sqkm).

Reference [19], [4] and [25]reported that emplaced in these Asu River group sediments are intermediates to basic intrusive, extrusive and Pyroclastic. And the group has average thickness of about 2000m and they rest unconformably on the Precambrian Basement [3]. The Abakaliki shale formation, which has an average thickness of about 500m [38, 39] is dominantly shale, dark grey in color, blocky, and non-micaceous in most locations. It is calcareous (calcite-cemented) and deeply weathered to brownish clay in the greater part of the part of the formation [26].

IV. LITERATURE REVIEW

Shale is one of the commonest types of sedimentary rock. it exhibits a wide spectrum of geotechnical behavior and has often been a cause for concern on environmental and geotechnical issues [15], [21]. Thus, he regarded it as a problem material. Reference [26], [15] and [23] shows that these environmental and geotechnical problems exhibited by shale in most cases, was influenced by its mineralogical content, especially the predominant clay mineral type(s) as well as the climate and physiography of the area under consideration. About 10,000 metric tons of crushed rock comprising baked shale, limestone and pyroclastic rock are produced on a daily basis in these areas [43].

[33] in their study indicate that Abakaliki shale is generally prone to material deterioration. Their study therefore suggests deep foundation method as the only appropriate foundation type to forestall the damages associated with failures of bridges underlain by Abakaliki shale.

A study of Geotechnical and environmental problems relating to Abakaliki shales by [6], indicatedthat shale samples have Atterberg limits that might be considered moderate to high; while Liquid Limit (LL) ranged from 49 – 54, the Plasticity Index (PI) ranged from 34 – 38. These relatively high LL and PI suggested presence of expansive clays, some swelling of the shale on moisture influx and high compressibility.This result reveals the reason behindstructural and foundation problems that are prevalent in Abakaliki environs.

ThisAbakaliki shale belongs to the Albian Asu River Group sediment. Reference [42] shows that Abakaliki shale is associated with intermediate pyroclastic flows and volcanic agglomerates which were interpreted by early workers ([29] and[45]) as products of late Cretaceous volcanism. [42], [32] and [20] reported that Abakalikipyroclastic are generally exposed in the cores of minor anticlines of the Abakaliki anticlinorium. [32] suggested that Abakaliki volcanic rocks represents the earliest phase of volcanic activity in the Southern Benue Trough. The petrology and geochemistry of the Abakaliki pyroclastic by early workers associated it to the origin of Benue Trough to the splitting of the Afro-Brazilian plate in early Cretaceous time [18].

it is now clear that Abakaliki shale needs a serious engineering attention during structural construction to avoid structural failures and loss of life. Therefore, one way to do this is to make sure that construction aggregates to be used meets the required standard. This exactly what this study stands for.

V. MATERIALS AND METHOD

The nature, distribution and types of rocks in the study area were delineated during a geological mapping exercise with base map showing the study location within Asu River Group Formation and Amasiri Sandstone Formation (Fig 1). Rock types used for this study included Limestone, Baked-Shale Pyroclastic rocks and Granodiorite. Both petrologic and petrographic techniques, which are systematic description of rocks based on observations in the field, in thin sections and hand specimen, were employed during the study. However, in assessing the potential of a rock for use as an aggregate, the first requirement is a full petrographic study of the rocks, which has been done by [42], [38], [34], [31, 32], [14],[10],[44], [41], [27, 28], [8] and [13] to mention but few.

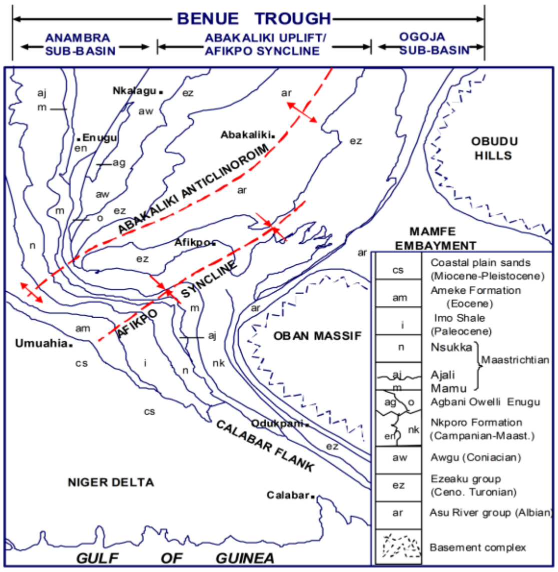

Figure 2.: Geological Sketch map showing the relationship between the Anambra Basin, Abakaliki Uplift, Afikpo Syncline and the Ogoja sub-basin to Benue Trough (modified from Nyong, 1995).

Ten representative samples of limestone, baked shale, pyroclastic rocks and granodiorite were collected from Quarry sites at five different locations (AmofiaNgbo in Ohaukwu, OnunwaforUmuoghara in Ezza North, Ezza-agu in Izzi, Cornrock at Amasiri and Crush rock at Ishiagu). The samples were crushed to coarse aggregates. More than 600 test samples were prepared from these crushed aggregates in the laboratory to determine their material and durability properties. The laboratory tests conducted on the physio-mechanical properties of these fresh aggregate samples were discussed below.

VI. LABORATORY EXPERIMENT AND RESULT

Durability tests are used to assess the suitability of aggregate for use in road or concrete construction. They are indicator tests, measuring the likely rather than the actual performance of aggregate. This strength test determines the resistance to wear and decay of aggregate, as well as to identify those aggregate that may be prone to degradation in saturated moisture conditions, elevated temperatures or freezing conditions.

A. Aggregate crushing value test (ACV)

This test determines the aggregate crushing value of these coarse aggregate as per 1S:2386 (part IV)-1963. The test is actually the measurement of the resistance of aggregate to crushing by compressive force.

The aggregate passing through 12.5mm and retained on 10mm IS sieve and are oven-dried at a temperature of 100 to 110^{0}C for 4 hours, was weighed to 1000g using the weighing balance. The cylinder of the apparatus was filled in 3 layers, each layer tamped with 25 strokes of a tamping rod. The surface of the aggregate was then levelled and the plunger inserted. The apparatus is thenplaced in the compression testing machine and loaded at a uniform rate so as to achieve 40th load in 10 minutes, which was then released and the sample sieved through a 2.36mm IS sieved with the fraction passing through the sieve weighed and compared with the original weight of 1500g to check for the percentage aggregate crushing value. Necessary calculations were done to find the percentage retained and percentage weighed passing. The result obtained for the three rock samples are tabulated below in table 1.

B. Flakiness Index Test (FI)

This test was done to determine the flakiness index of coarse aggregate, where the sizes of the coarse aggregate are larger than 6.3mm as par IS: 2386 (Part I) – 1963 [40]. The flakiness index of aggregates is determined by the percentage of flaky particles contained in it.

The aggregate passing through BS sieve 12.5mm and retained in 10mm are oven dry for 24hrs at a temperature range of 100-110^{0}C. It was weighed to 500g. In order to separate flaky materials, each fraction was then gauged individually for thickness on a thickness gauge 12.5mm.

The total amount of flaky material passing was weighed to an accuracy expressed as a percentage of the total weight of the sample gauged. The result obtained for the three rock samples are tabulated below in table 2.

Table 1: Result of ACV of the five rock samples.

Sample Description	Ngbo Limestone	Amasiri Limestone	Baked-Shale	Pyroclastic rock	Granodiorite
Original weight of aggregate (A)	1000g	1000g	1000g	1000g	1000g
Weight of aggregate passing sieve 2.36mm (B)	80g	87g	100g	120	142
Percentage aggregate Crushing value %ACV $= (B/A) * \frac{100}{1}$	8%	8.7%	10%	12%	14.2%

TABLE 2: RESULT OF FI VALUE OF THE THREE-ROCK SAMPLE.

Sample Description	Ngbo Limestone	Amasiri Limestone	Baked-Shale	Pyroclastic rock.	Granodiorite
Original weight of aggregate (A)	1000g	1000g	1000g	1000g	1000g
Weight of aggregate passing sieve 12.5mm (B)	125g	135g	150g	210g	196g
Percentage aggregate Flakiness Index value % FI = $(^B/_A) * \frac{100}{1}$	12.5%	13.5%	15%	21%	19.6%

C. Aggregate Specific Gravity and Water Absorption Test

About 1000g of aggregate passing BS sieve 12.5mm and retained 10mm was washed thoroughly to remove fines and oven dry. It was immersed in drum of distilled water at a temperature range of 22-32^{0}c and a cover of at least 5cm of water above the top of the basket. The basket and aggregate were left completely immersed in water for a period of 24hours. The basket and the sample where weighed while suspended in water at a temperature range of 22^0-32^{0}c. The weight while suspended in water was noted. The aggregates and basket were removed from water and allowed to drain for a few minutes and are surface dried with absorbent cloths till no further moisture coiled is removed by this cloth. Then the aggregate was transferred to the second dry cloth spread in single layer and allowed to dry for at least 10 minutes until the aggregates are completely surface dry. The surface dried aggregate is then weighed. The aggregate was placed in a shallow tray and kept in an oven maintained at a temperature of 110^{0}c for 24 hrs. It was then removing from the oven, cooled in air right containers and weighed. The specific gravity, apparent gravity and water absorption was calculated in percentage. Table 3 shows the slake durability test of the three rock samples.

D. Aggregate Abrasion Value Test (AAV)

This test is a common test method used to indicate aggregate toughness and abrasion characteristics. This test is usually carried out by AASHTO T 96 or ASTM C 131: Resistance to degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. It can be done with coarse aggregates as per IS: 2386 (Part IV) – 1963. 5000g of aggregate passing 12.5mm and retained in 10mm BS sieved was placed into the abrasion testing machine together with 12 steel balls and was allowed to rotate at a speed of about 500 revolutions. The hid was then unbolted and then the aggregate and balls were removed into a tray.The large pieces of aggregate and balls were picked from the tray and the remainder poured carefully into a BS sieve mesh of 1.8mm to collect all the fines. This was carried out in stages, sieved a little at a time.After all, the fine was then weighed and expressed as a fraction/percentage of the original sample weight. The result is tabulated in table 4 below using the following formula:

$$Abrasion\,Value = \frac{WF}{WC} \times 100$$

Where, WF = weight of fine aggregate
WC = weight of original sample (changed)

Table 3**:** Result of aggregate specific gravity and water absorption test from the three-rock type.

Sample Description	Ngbo Limestone	Amasiri Limestone	Baked-Shale	Pyroclastic rock	Granodiorite
Weight of sample	1000g	1000g	1000g	1000g	1000g
Weight of vessel + water + sample (A)	2712.10g	2714.86	2715.10g	2725.90g	2734.62g
Weight of vessel + water (B)	2089.80g	2089.80g	2089.80g	2089.80g	2089.80g
Weight of saturated surface dry samples (C)	1003.40g	1004.20g	1000.70g	1011.40g	1000.10

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Weight of oven dry sample (D)	988.10g	988.70g	985.20g	989.10g	996.93
Specific gravity $= \frac{D}{C-(A-B)}$	2.6g	2.61g	2.63g	2.64g	2.81g
Apparent specific gravity $= \frac{D}{D-(A-B)}$	2.70g	2.71g	2.74g	2.80g	2.83g
% Water absorption of dry sample $= \frac{C-D \times 100}{D}$	1.54%	1.56%	1.57%	2.25%	0.32%

Table 4: Result of aggregate abrasion value test from the three-rock sample.

Sample Description	Ngbo Limestone	Amasiri Limestone	Baked-Shale	Pyroclastic rock	Granodiorite
No. of revolution	500	500	500	500	500
No. of steel ball	12	12	12	12	12
Mass of original sample (changed) WC	5000g	5000g	5000g	5000g	5000g
Mass of fine aggregate passing 1.8 mm sieve, WF	1200g	1218g	1250g	1150g	750g
Abrasion Value	24%	24.4%	25%	23%	15%

VII. DISCUSSION

The principal mechanical properties required in aggregate for construction should be satisfactory resistance to crushing under the roller during construction and should be adequate resistance to surface abrasion under traffic load. Therefore, if aggregates are weak, the stability of the pavement structure will be adversely affected resulting to construction failure. In table 1, the percentage aggregate crushing value of Ngbo Limestone is 8%, Amasiri Limestone is 8.7%, Baked-Shale is 10%, Pyroclastic rock is 12% and Granodiorite is 14.2%. Since in IS-2386 Part 4, the recommended limit for cement concrete pavement is 30% and wearing surfaces is 45%. This indicates that granodiorite and pyroclastic rock aggregates should be used in construction instead of Shale and Limestone aggregate. Even though both shale and Limestone are within recommended limit, both are sedimentary rock whose strength cannot be compared with igneous rock. Shale is very fissile and of lesser strength. If not that the shale was baked by an intruded hot fluid which did not metamorphose completely into slate, the possibility of using it would be zero. And Limestone in the other hand has a high tendency of dissolution as it goes into reaction with water.

The determination of particle shape of aggregates was done by the percentages of flaky and elongated particles. For base course and construction of bituminous and cement concrete types, the presence of flaky and elongated particles is considered undesirable as these can cause inherent weakness with possibilities of breaking down under heavy loads. Therefore, the result of Percentage Flakiness Index obtained in table 2 shows that Ngbo Limestone is 2,5%, Amasiri Limestone is 13.5%, Baked-Shale is 15%, Pyroclastic rock is 21% and Granodiorite is 19.6%. with a permit range of 0-45%. Since this shape tests give only a rough idea of the relative shapes of aggregates, Flaky and elongated aggregates of Pyroclastic rock must not be avoided in pavement construction, particularly in surface course. But note that when high percentages of flakiness index of aggregates are present in appreciable proportions, the strength of pavement layer would be adversely affected due to possibility of breaking down under traffic loads. Workability with it is reduced for cement concrete [11]. Meanwhile the aggregates should be free of flaky and elongate particle before usage. Even though both granodiorite and pyroclastic rock aggregates are within permit range and are very fair for usage. Since Specific gravity is a measure of a material's density (mass per unit volume) as compared to the density of water at 73.4°F (23°C), this aggregate specific gravity can be used in a number of applications including Superpave mix design, material property changes identification and deleterious particle identification and separation. And water absorption gives an idea of strength of aggregate. The result of aggregate specific gravity and water absorption test obtained as shown in table 3 indicates that the specific gravity of Ngbo Limestone is 2.6 and Amasiri Limestone is 26.1 with fairly range of 2.7, Baked-Shale is 2.63 and Pyroclastic is 2.64 and Granodiorite is 2.81 with an approved limit of 2.5-3.0. This result show that both aggregates are within range limit, but granodiorite has the highest and so is highly recommended. Meanwhile, percentage water absorption test value of Ngbo Limestone is 1.54%, Amasiri Limestone 1.56%, Baked-Shale is 1.57%, Pyroclastic is 2.25% and granodiorite is 0.32%. From this result, pyroclastic aggregates are the highest water absorber. But this test has a range limit of 0-5%. But the value of Pyroclastic indicates that it is a durable aggregate and also suggests a minimal amount of asphalt binder the aggregate will absorb to be suitable. According to [1], it is generally desirable to avoid highly absorptive aggregate in Hot Mix Asphalt (HMA). This is because asphalt binder that is absorbed by the aggregate is not available to coat the aggregate particle surface and is therefore not available for bonding. Note that pyroclastic rock is very fairly within the range limit. But the aggregate is granodiorite aggregates.

The cause of high absorptive nature of Pyroclastic aggregate can be attributed to the origin of pyroclastic rock. Pyroclastic deposits are commonly formed from airborne ash, lapilli and bombs or blocks ejected from the volcano itself, mixed in with shattered country rock during acidic volcanic eruption. Therefore, during the time of Pyroclastic rock formation numerous pores can form in it. On the other hand, Shale and Limestone are very fine grain sediments which are naturally impermeable. According to [35] some lightweight shales (not used in HMA production) can have absorptions approaching 30 percent, while other aggregate types can have near zero absorption. Typically, aggregate used in HMA production will have absorption between just above zero and 5 percent. Absorptions above about 5 percent tend to make HMA mixtures uneconomical because extra asphalt binder is required to account for the high aggregate absorption.

The result of Aggregate Abrasion Value Test (AAV) shown in table 4 indicates that Ngbo Limestone has 24%, Amasiri Limestone has 24.4%, Shale has 25%, Pyroclastic aggregate has 23% and that of Granodiorite is 15% respectively. AAV is an estimate of the surface wear of road surface aggregate and is an indicator test for abrasion resistance. Aggregates undergo substantial wear and tear throughout their life [8], [6]. But [36] noted that they generally should be hard and tough to resist crushing, degradation and disintegration from any associated activities including manufacturing, stockpiling, production, placing and compaction. And they must be able to adequately transmit loads from pavement surface to the underlying layers and eventually the sub-grade. Meanwhile[9], [8]and [10] noted that aggregates that are not adequately resistant to abrasion and polishing may cause premature structural failure and/or a loss of skid resistance.Reference [46] and [17] reported that the ability to adequately transmit loads from pavement surface to the underlying layers is a property that are so especially critical for open or gap graded HMA, which do not benefit from the crushing effect of the fine aggregate and where coarse particles are subjected to high contact stresses. Poor resistance to abrasion can produce excessive dust during HMA production resulting in possible environmental problems as well as mixture control problems.

The result shows that granodiorite aggregate has the lowest AAV. But [7] and [22] noted that rock materials with Aggregate Abrasion Values below 30 percent are regarded as strong, while those above 35 percent would normally be regarded as too weak for use in road surface. Therefore, lower AAV loss values indicate aggregate that is tougher and more resistant to abrasion ([1], [46], [12]). According to [35] and [17], there is no standard aggregate abrasion specification for Superpave mix design; specifications are typically established by state or local agencies. Typically, U.S. state specifications limit the abrasion of coarse aggregate for HMA use to a maximum ranging from 25 to 55 percent, with most states using a specification of 40 or 45 percent. Requirements for Portland Cement Concrete (PCC) tend to be similar, while requirements for specialized mixes such as Stone Matrix Asphalt (SMA) tend to be lower; [1] specifies a maximum aggregate abrasion loss of 30 percent for SMA.

VIII. CONCLUSION

Aggregates are fundamental raw material for all constructions. They are principal materials in pavement construction. Aggregates are often used as either unstabilized or stabilized or base or sub-base courses. Knowledge of the properties of these aggregates is crucial in designing high quality construction especially pavement.

Aggregate produced from granodiorite because of their high crushing strength, high specific gravity with a very moderate porosity, low abrasion value and a contained flakiness index value, possess the necessary characteristics for use in construction especially in pavement construction in accordance with AASHTO, ASTM and BS standards. However, in the very absence of granodiorite aggregates, pyroclastic rocks, shale and limestone aggregates can be used. Results of this work will be useful in selecting the rock types to quarry for the production of aggregates for optimum use in sustainable road construction. It is important to note that the costs of these materials at the study area are the same. Therefore, the choice of granodiorite aggregate should supersede the other ones, while deciding for aggregate material for pavement.

IX. RECOMMENDATION

1. For best optimum sustainable road construction, granodiorite aggregates should be used.
2. The quarry industry should try to eliminate the flaky and elongate nature of aggregate during preparation. Although, the values obtained are within limit range.

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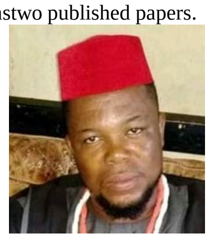
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