PETROGRAPHY AND QUALITY ASSESSMENT OF CRUSHED-SANDSTONE AGGREGATES ASSOCIATED WITH NSUKKA AND AMEKI FORMATIONS IN OKIGWE AREA, SOUTHEASTERN NIGERIA, IN RELATION TO HIGHWAY PAVEMENT AGGREGATES.

***Onyeocha, N.C., Okeke, O.C., Obioha, Y.E.,Ikoro, D.O., and Amadi, C.C.**

Department of Geology, Federal University of Technology Owerri, Imo State, Nigeria.

IJASR 2021
VOLUME 4
ISSUE 5 SEPTEMBER – OCTBER **ISSN: 2581-7876**

Abstract: Sandstones from Nsukka and Ameki Formations are crushed and used for construction purposes without any qualitative and quantitative backing of their strength and durability characteristics.This research is aimed at to study the petrography and assess the quality of crushed sandstones fromNsukka and Ameki Formations found in the Southeastern part of Nigeria in relation to their use as highway pavement aggregates. Sandstone samples were collected from the two locations and taken to lab for physico-mechanical tests to know the strength and durability characteristics and also thin sections were produced for the petrographic studies.Samples collected from IhubeOkigwe area (Nsukka Formation) and Ikperejere (Amaeki Formation) are bothdarkish in color and have angular and sub angular to sub rounded quartz, monocrystalline quartz and opaque minerals. These two samples are ferruginisedbecause of the presence of iron oxide (hematite) as their cementing minerals. Physico-mechanical tests carried to study the strength and durability characteristics of the samples, shows that sandstone fromAmaeki Formationand Nsukka Formationhave Aggregate Crushing Value (ACV) of 24.4% and 25.2% respectively, these values are within the acceptable limit of 30% maximum. The Los Angeles Abrasion Value (LAAV) fors and stone sample from Nsukka Formationis 42.96% while that of the sandstone sample from Ameki Formation is 49.78%. These two values are above the standard limit of 40% maximum. The Aggregate Impact value ofNsukka Formation and Ameki Formation are 31.40% and 39.20% respectively. This study also found that WaterAbsorption (WA) and Specific Gravity (SG) values of the samples from Nsukka Formation are 0.8% and 2.94 and Ameki Formation are 3.30% and 3.02 respectively. From the values obtained in the laboratory analysis of the strength and durability characteristics, the studied sandstone samples are not suitable to be used as highway pavementaggregates because of their failure to meet the strength durability acceptable limits/standard and the poor framework of the grains which has generally lose and floating grains.

Keywords: Sandstones, Highway pavement, aggregate, petrography, physico-mechanical.

1.0 INTRODUCTION

Sandstones are detrital sedimentary rocks formed by cementation of individual sand grains and composed of quartz minerals, Richard (2006). EGSA (2009) general dictionary of geology defined sandstone as a sedimentary rock that is composed of sand sized particles (1/16–2mm in diameter). Furthermore, Williams, Turner, and Gilbert (1954) stated that sandstones are detrital sediments containing abundant grains of sand and coarse silt. Sandstones could be clean consisting mostly of sand grains, and could also be a mixture of sand, silt and clay with authigenic minerals serving as binders or precipitated cement.

Classification of sandstones are based on their component materials, nevertheless, occurrence of various cement materials in them are acknowledged by a suiting adjective in their naming, like calcareous sandstone and siliceous sandstone (Williams, et al. 1954). Sandstone are classified by degree of sorting into two types;

Arenites are sandstones consisting of pure sand grains that is relatively well sorted and contains little or no clay. They contain less than 10% argillaceous matrix.

Wackes are impure and poorly sorted sandstones with mixture of clay and silt. They contain over 10% argillaceous matrix. According to Williams, et al. (1954), arenites are well washed by currents and are accumulated in a selectively slow manner while wackes are rapidly deposited without proper selection.

It is believed generally that sandstone aggregates are relatively weak and friable but improves in its properties as it metamorphoses towards quartzite (Mackechnie, 2003). Crushed rock aggregates are rock materials broken down to relatively smaller varying sizes for various engineering construction to achieve desired purpose/target. Some aggregates are natural while others are products of human activities in quarries. Production of sandstone aggregate is generally done in quarries in diverse methods ranging from the most common method of open pit or surface mining (quarrying) to other sophisticated methods like using rock drills, explosion of dynamites e.t.c. According to Ukpong, (2012), the choice of any particular method is dependent on the nature of the rock deposit, mode of occurrence and location of the deposit.

Aggregate either natural (such as gravels) or man-made (such as crushed sandstones) is combined with binding materials; cement and water, to form concrete, mortar or asphalt, it could also be treated alone to form railroad ballast, filler beds or fluxed material (Adeyi, Mbagwu, Ndupu and Okeke, 2019, Langer 1983). The mixture of aggregates and binders are used for construction of roads, bridges, houses, landscaping, parks etc., it is, therefore, very necessary that aggregates should be strong enough to crushing, abrasion and degradation. Soil erosion control, road embankments, water purification and reduction of sulphur dioxide emissions at electric power plants, these are some of the various ways aggregates are being used in environmental protection. In all the ways aggregates are put into use, they are exposed to stresses, therefore should be durable to withstand prevailing harsh environmental conditions, high impacts and severe abrasion (Adeyi, et al. 2019).

Using crushed rocks (e.g. crushed sandstone) as engineering construction aggregate is dependent on the durability characteristics and strength of the aggregate (Okeke, 2005). Crushed rock aggregates are essential as an aggregate for road pavements. They also form part of the component of concrete.

The strength of any rock aggregate is its ability to resist and withstand compression from external load, either dynamic or static (Prentice, 1984).

Crushed rock aggregates are not only essential as a foundation for road pavement; they also form part of the cement that makes road itself. Due to the fact that open engineering structures like roads are exposed to direct impact of water, aggregate used in their construction must be able to maintain its properties (stability) when it comes into contact with water (Iwuoha, Iwuji, Adiela and Okeke, 2016)

The mineralogical composition and framework of grains in sandstone can be considered to be a product of tectonism, source rock composition, weathering and transportation and diagenetic processes (Ingersoll, Bullard, Ford, Grimm, Pickle and Sares, 1984; Carozzi, 1993). Any sandstone grain framework that have not been altered significantly either by diagenesis and/or transportation can provide information on the composition and tectonism of the source environment, it therefore, means that the mineralogical composition of sandstone grains is key in the study of provenance (Ingersoll et al., 1984; Carozzi, 1993).

To unravel the mineralogical composition of any sandstone sample (and by extension all other rock types- igneous, metamorphic or sedimentary) it has to be subjected to petrographic studies and examined under microscope. Only then can one quantitatively and qualitatively classify the constituent minerals of the sample. Petrography is simply the geological description and classification of a rock usually by means of microscopic examination (Brenda, 2000).
Sequel to these stated facts, the choice of a quality suitable aggregate material is necessary to ensure durability of engineering structures and to overcome recurrent failure of road pavements. Aggregates in all the aspects of their usage in engineering construction, are prone to stresses from heavy loads, high impacts and severe abrasion occasionally harsh environmental conditions, it therefore, should be of good quality so as to be durable in civil structures.

To ascertain the durability and strength (i.e quality) of an aggregate with respect to road construction, it should be tested based on the following geotechnical parameters; Los Angeles Abrasion Value (LAAV), Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Specific Gravity and Water Absorption test.

By testing these parameters, an aggregate can qualitatively and quantitatively be certified strong enough or otherwise to withstand degradation, disintegration and crushing from external loads and heavy impacts. The quality of construction aggregates directly affects the durability of engineering structures.

The use of sandstone as aggregate for engineering constructions is a common practice though there is no known qualitative and quantitative scientific backing or proof of the aggregate quality of sandstone samples found in various geologic formations in Southeastern Nigeria to be used as road pavement aggregates

2.0 LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located in the Okigwe area, Southeastern Nigeria. Samples for the for the studywere picked atIhube (Nsukka Formation) with coordinates Lat. 5°51'51"N and Long. 7°21'24"E and I kperejere (Ameki Formation) with coordinates Lat. 5°37'09"N and Long. 7°22'26"E.

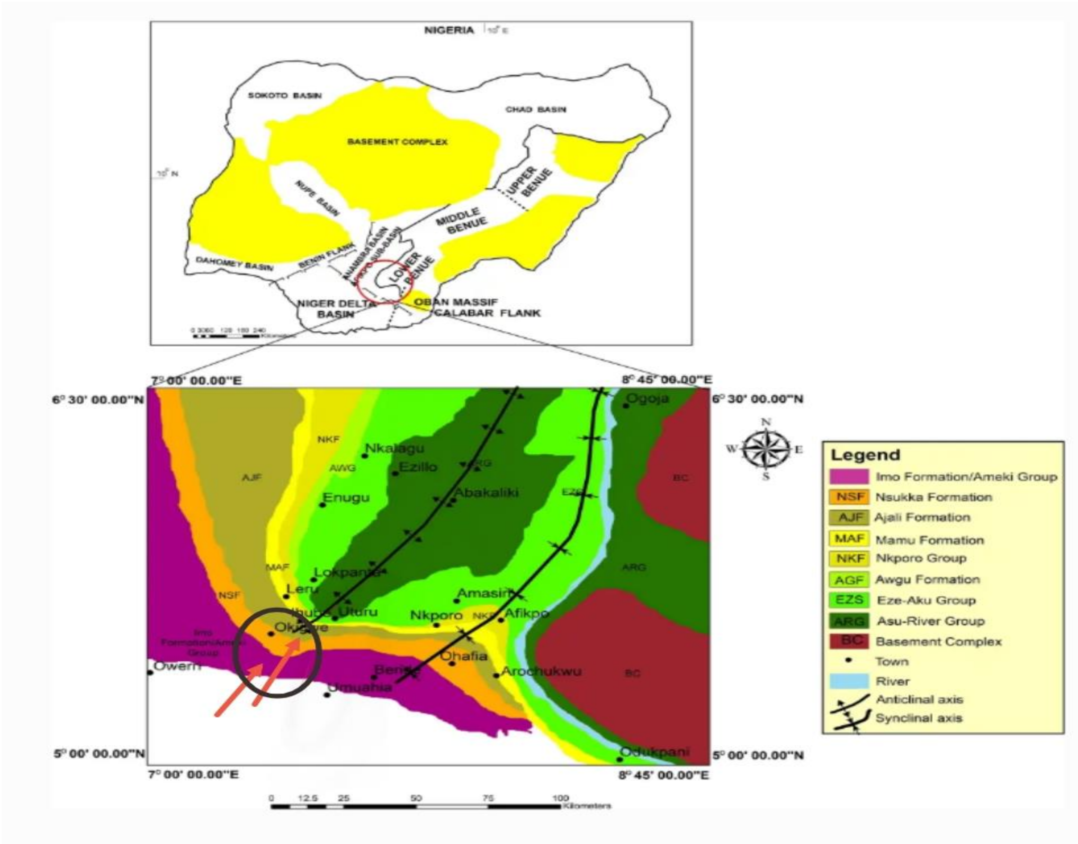


Fig.1 Geologic map of Southeastern Nigeria showing the study area (Modified after Okoro and Igwe, 2014).

2.1 NsukkaFormation.

Nsukka Formation (Maastrichtian-Danian) also known as the Upper Coal Measure (Reyment, 1965 and Obi, 2000) is underlaid by Ajali sandstone and overlaid by Imo Shale (Paleocene) Nwajide, (1990). Nsukka comprises of clayeyshale with occasional ironstone and thin sandstone with the occurrence of carbonized plants remains (Kogbe, 1989). Nsukka Formation marks the onset of the Sokoto transgression (Murat, 1972) it records a return to paludal conditions. The process of sedimentation in this formation was mainly of fluvial origin. The microfossils identified from the Nsukka Formation are: AfrobolivinaAfra, Bulimina, etc. (Reyment, 1965). The formation ranges from the Maestrichtian to probably lower Paleocene. Lithologically, the Nsukka Formation consists of alternating sequences of sandstone, dark shale, sand, and thin coal seams (Uma, 1989).

2.2 Ameki Formation.

Theregressive phase which characterized the Eocene age led to the deposition of Ameki Group (Obi, 2000). The lithologic units of the Ameki Formation is placed in two general groups (Reyment, 1965), namely, an upper grey-green sandstones and sandy clay; and a lower fine/coarse sandstones, which has intercalations of calcareous shales and thin shelly limestones. In southeastern Nigeria, Ameki displays rapid lateral facies changes and also locally show shaly inclusions of white and mottled claystones. The Nanka sand is a lateral equivalent of the Ameki Formation. The type locality of the sand is Nanka where gully erosion has carved the landscape into beautiful geomorphic scenery (Emberga, 2019). Ameki Formation constitutes the main bulk of Eocene strata overlying the Imo Shale. Generally, the Ameki Formation has a series of highly fossiliferous greyish-green sandy-clay with calcareous concretions and white clayey sandstones. The thickness may attain as much as 1,400 metres in places (Reyment, 1965). This Formation is divisible into two lithologic units; Upper and Lower Ameki. Upper beds of the Ameki Formation contain coarse-grained, cross-bedded sandstone, bands of fine, grey-green sandstone and sandy clay. It is sandier than the lower Ameki. However, the lower beds consist of massive dark grey to brownish sandy mudstone, fine to coarse-grained sandstones, intercalations of calcareous shale and thin shelly limestone. Shales are more prominent in the lower Ameki section. The lithologic units are made up of sands, sandy shales, mudstone, and clayey sandstone, argillaceous sandstone with thin limestone bands, calcareousshale, thin shelly limestone and claystones. The formation is good for groundwater exploitation (Emberga, 2019).

Table 1: Generalized regional stratigraphy of Southeastern Nigeria (Modified from Reyment, 1965 and Offodile, 1975).

Era	Age	Formation	Lithology
Tertiary	Recent	Recent Sediments	Alluvium/Deltaic Plains
	Miocene-Recent	Benin Formation	Unconsolidated sandstone with lenses of clay
	Oligocene-Miocene	Ogwashi-Asaba Formation	Unconsoliddated sandstones, mudstone, clay and lignite seams.
	Eocene	Ameki Formation	Grey to green argillaceous sandstone, shale and limestone units
Upper Cretaceous	Paleocene	Imo Formation	Blue to dark grey shales and subordinate sandstone members (Umuna and Ebenebe)
	Maastritchian	Nsukka Formation	Alternating sequence of shale, sandstone and coal seams
		Ajali Formation	Friable sandstone with iron stains
		Mamu Formation	Sandstone, shale, siltstone with coal seams
	Campanian	Nkporo Formation/Enugu Shale	Mudstone and shale with thin beds of sandstone
	Santonian Coniacian	Awgu Formation (Awgu Shale)	Shale with intercalations of sandstones and shaly limestones
	Turonian	Ezeaku Formation (Ezeaku Shale)	Siltstone and shale with sandstone lenses
	Cenomanian	Odukpani Formation	Alternating sequence of sandstone, shale and limestone
Lower Cretaceous	Albian	Asu River Group, Abakaliki Shale and Awi Formation	Sandy shales, sandstone and sandy limestone lenses
	Precambrian	Basement Complex	Older granites and gneisses

3.0 MATERIALS AND METHODS

Field work is one very first and important step in every geological research. At the commencement of this research work, two Geologic Formations (Nsukka and Ameki) bearingsandstones in the Okigwe area, Southeastern Nigeria were visited and samples collected. Samples were collected with the aid of geologic hammer and shovels to ensure that the collected samples are fresh and unweathered. The locations visited are listed in tablebelow.

Table 2. Locations Visited.

Location	Coordinates	Identity of Collected Sample	Geologic Formation
IkperejereNdiowerreIhitte-Uboma Imo state	Lat. 5°37'09"N Long.7°22'26"E	Ikperejere Sandstone	Amaeki Formation
IhubeOkigweAbia State	Lat. 5°51'51"N Long.7°21'24"E	Ihube Sandstone	Nsukka Formation

3.1 Physico-mechanical Parameters (Analysis)

The collected sandstone samples were taken to the quality control laboratory of Arab Contractors Ltd. OwerriNigeria for analysis. The physico-mechanical analysis carried out on the samples was to determine their strength and durability characteristics based on the following parameters; Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Los Angeles AbrasionValue (LAAV), Water Absorption (WA), Specific Gravity (SG) and Bulk Density (BD). The standard limit used for the analysis is that of British Standard BS 885, 1973 and Government of East Central State of Nigeria Standard, 1972.

3.2 Petrographic Studies

Petrographic analysis carried out on the sandstone samples was aimed at;

- Thin Section preparation.
- Identification of constituent minerals by examining the thin sections under a petrographic microscope.

The petrographic analysis was carried out at the geology laboratory of the University of Ilorin, in Ilorin Kwara state, Nigeria.

4.0 RESULTS AND DISCUSSION

4.1 Physico-mechanical Analysis.

Table 3 below shows the result of the physico-mechanical analysis carried out to determine the strength and durability characteristics of the two sandstone samples from Nsukka and Ameki Formations in the Okigwe area, Southeastern Nigeria and the reference standard after BS 885, 1973 and Government of East Central State of Nigeria Standard, 1972 showing the acceptance limits for each of the parameters analyzed.

Table 3. Analysis Results of Physico-mechanical Parameters of the Samples and Acceptance Limits (After BS 885, 1973 and Government of East Central State of Nigeria Standard, 1972)

Parameters	Sample ID		
	IH(Nsukka Formation)	IK (Ameki Formation)	Acceptance Limits
ACV (%)	25.2	24.40	Maximum 30
AIV (%)	31.40	39.20	Maximum 30

LAAV (%)	42.96	49.78	Maxiumum 40
WA (%)	0.80	3.30	Less than 3
SG	2.94	3.0	2.6 – 2.9
BD (Mg/m^3)	2.74	2.80	More than 2.6

Sample Identities

IH= Ihube-Okigwe Sandstone (NsukkaFormation)
IK= Ikperejere Sandstone (AmaekiFormation)

Parameters

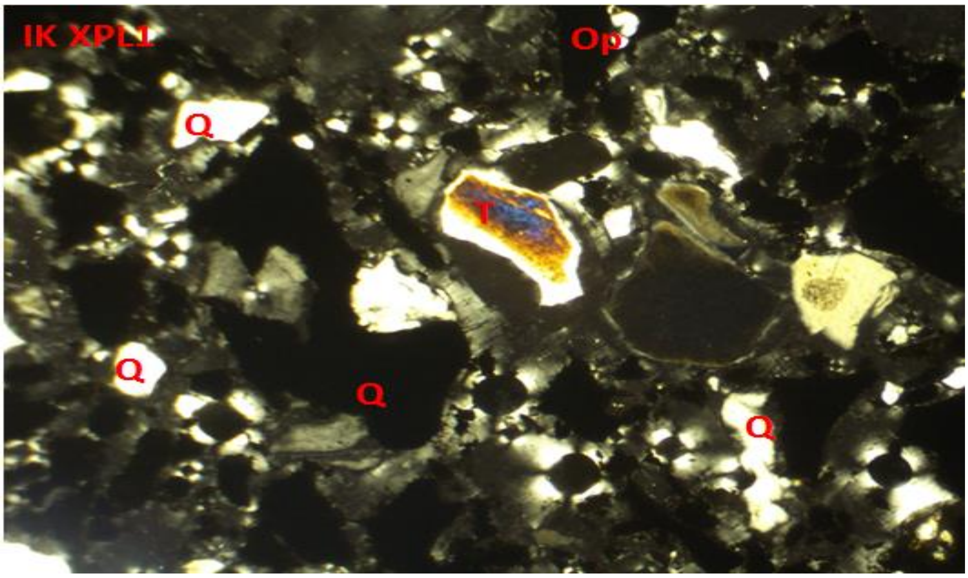
ACV= Aggregate Crushing Vapid
AIV= Aggregate Impact Value
LAAV= Los Angeles Abrasion Value
WA= Water Absorption
SG= Specific Gravity
BD= Bulk Density

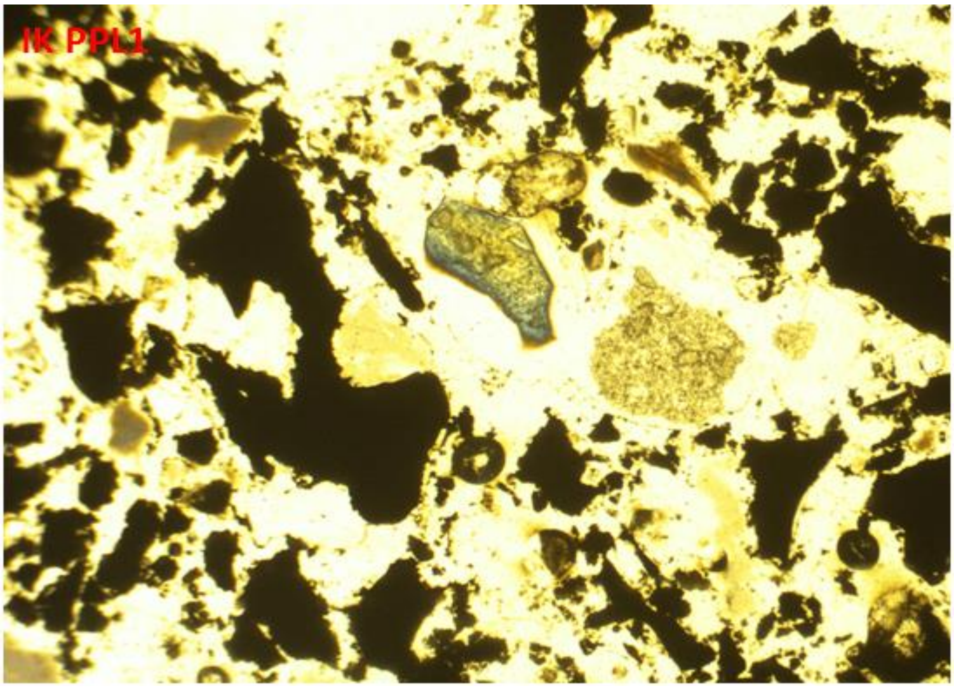
4.2 Petrographic Analysis.

Petrographic analysis was carried out on the sandstone samples with thin sections prepare for microscopic examination. The sections were allowed to cool and washed with acetone or methylated spirit, soap solution and finally rinsed with distilled water.

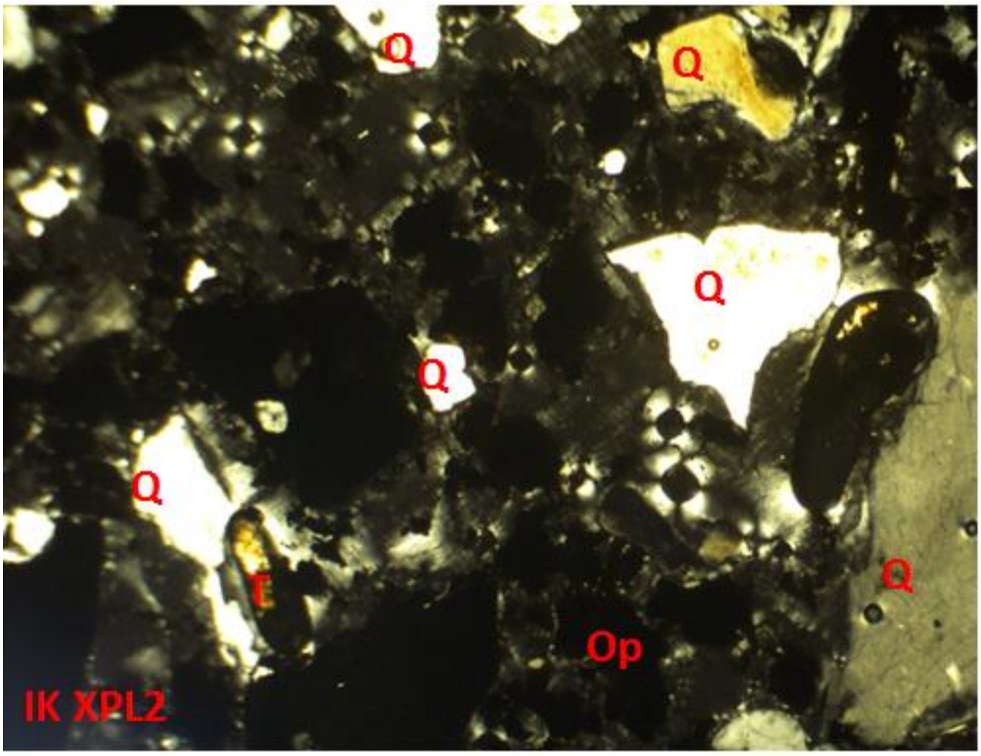
Photomicrographs were taken on the section by using Amscope camera attached to the petrological microscope and connected to the computer. The photomicrograph were taken under the plain polarized light (PPL) first, i.e. (analyzer out) then it was proceeded to crossed polarized light (XPL) where the two polariod sheets are at right angle to each other (analyzer in) with the magnification of x4 under the objective lenses.

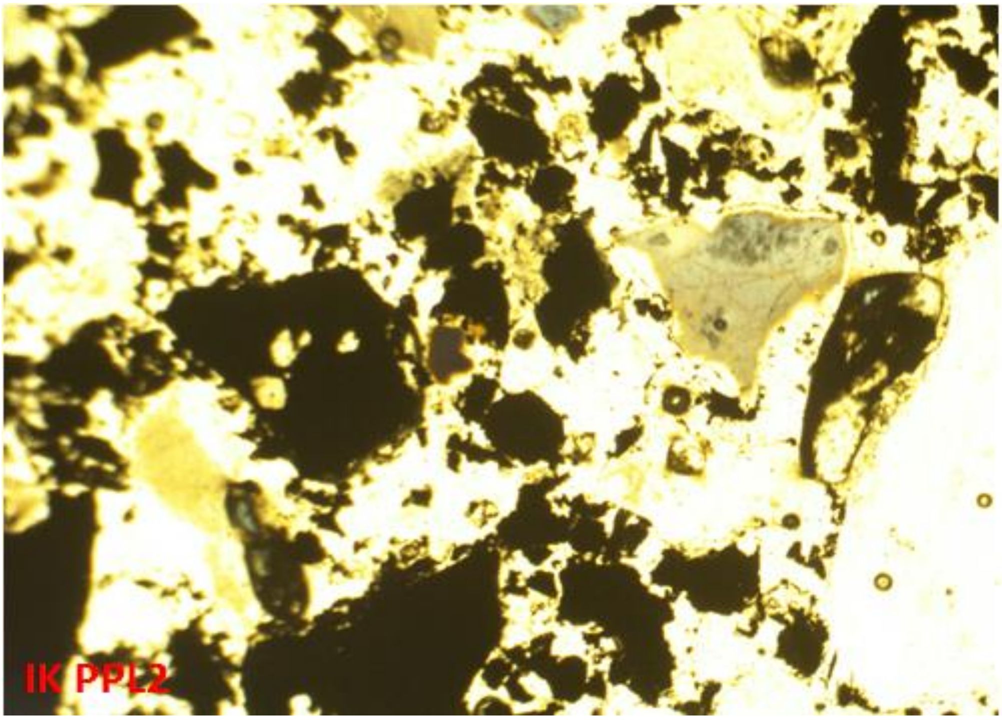
PHOTOMICROGRAPHS



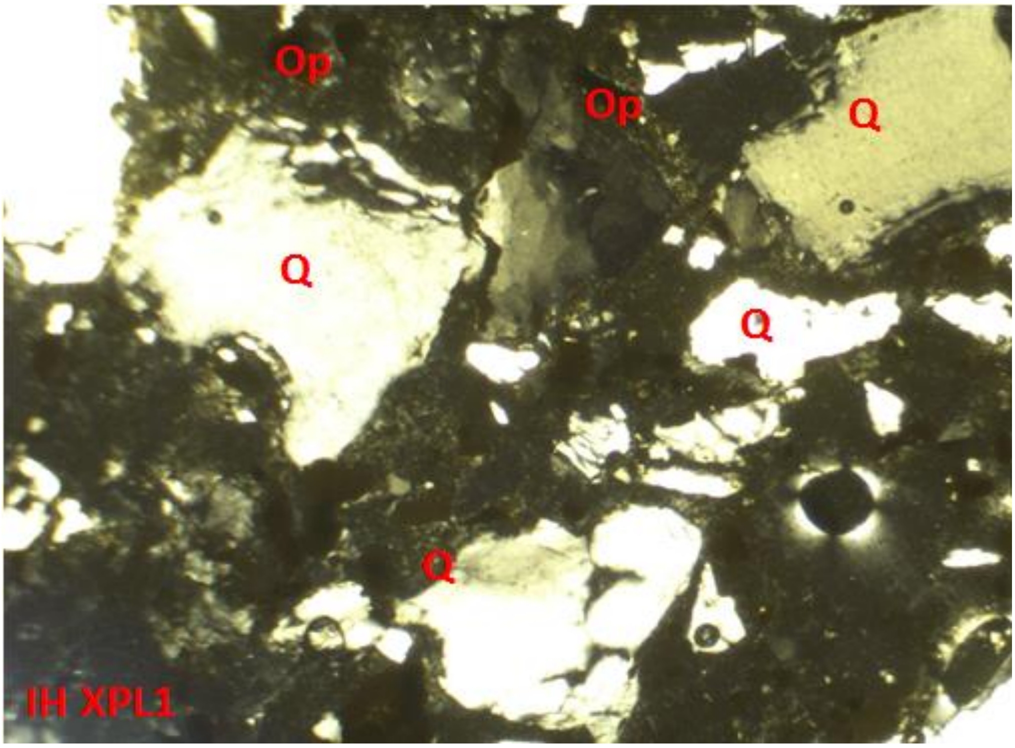


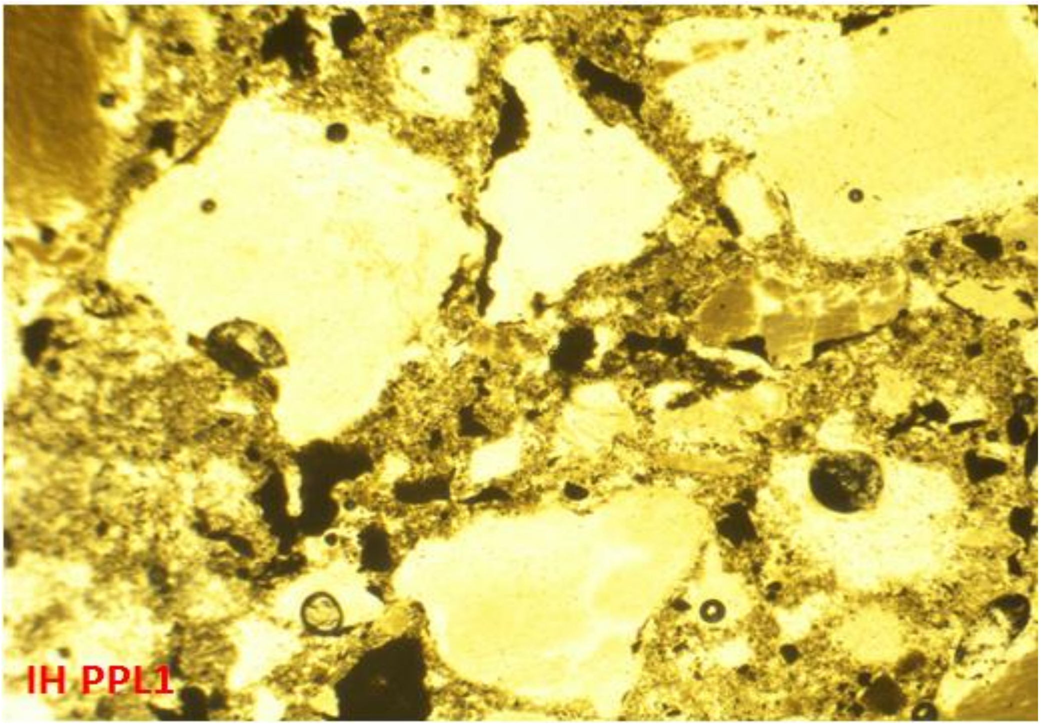
Q – Quartz (Angular, sub angular and sub rounded monocrystalline quartz grains), P – Plagioclase, T - Tourmaline, and Op – Opaque minerals. MG. X4



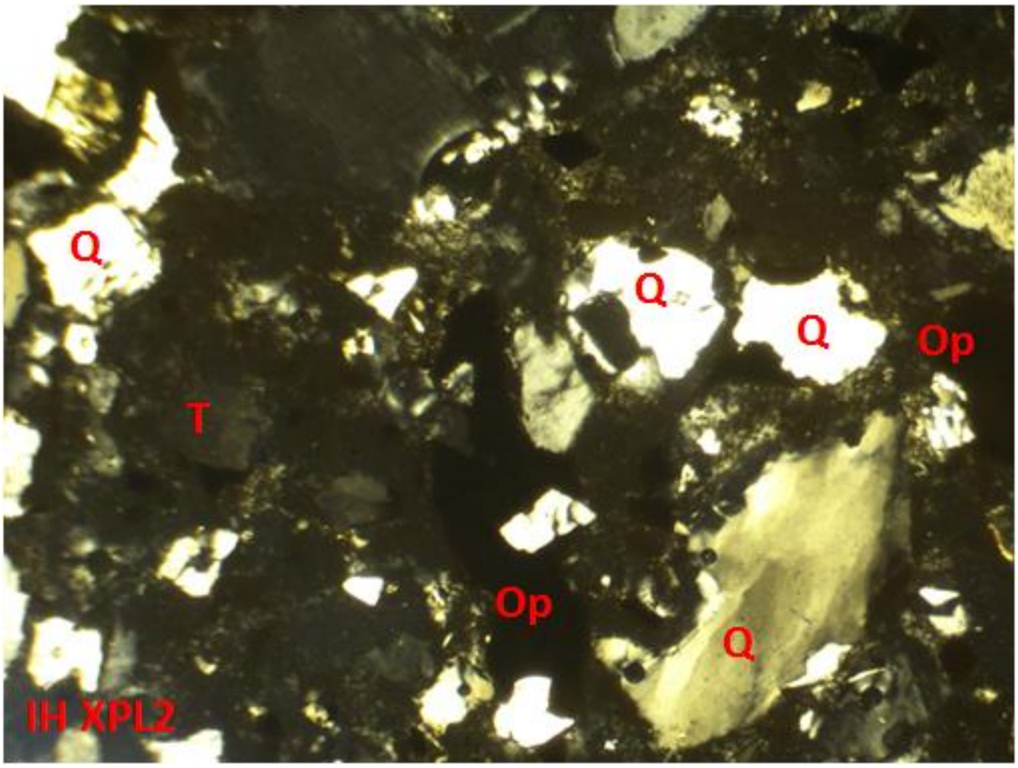


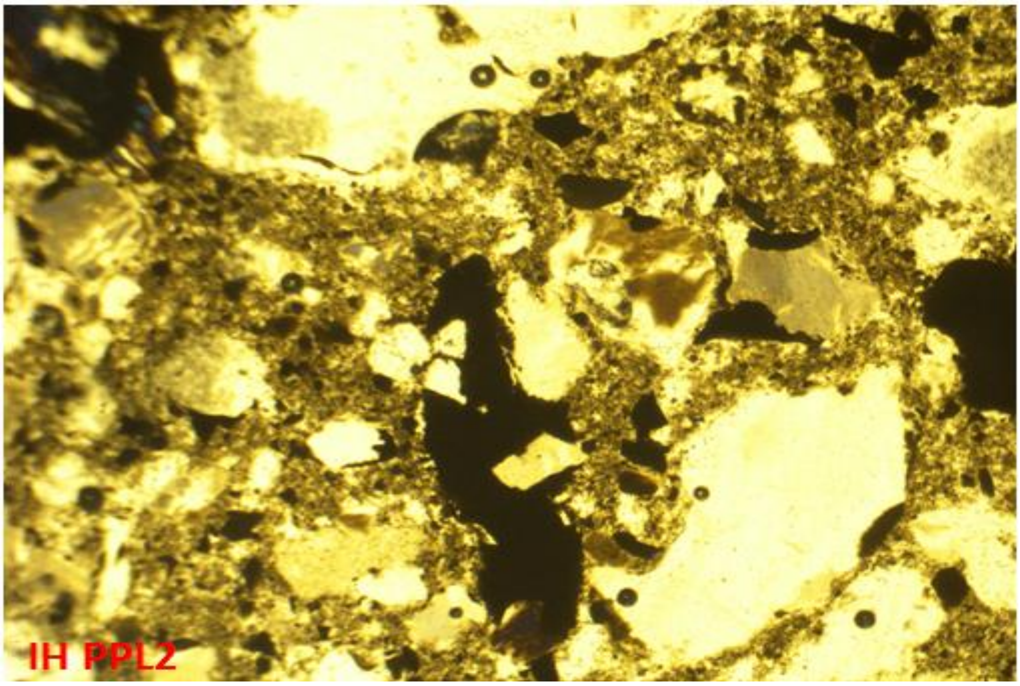
Q – Quartz (Monocrystalline and polycrystalline angular and sub angular quartz grains. The quartz grains are mainly monocrystalline quartz grains), T – Tourmaline and Op-Opaque minerals. MG. X4





Q – Quartz (Angular, sub angular and sub rounded monocrystalline and polycrystalline quartz grains) and Op – Opaque minerals. MG. X4





Q – Quartz (Angular, sub angular and sub rounded monocrystalline quartz grains), T – Tourmaline and Op – Opaque minerals MG. X4

Table 4. Samples and their constituent minerals

Sample	**Geologic Formation**	**Colour**	**Constituent Minerals**	**Name of Sandstone**
Ikperejere	Amaeki	Darkish	Quartz (Angular, sub angular and sub rounded monocrystalline quartz grains),Plagioclase, Tourmaline, and Op – Opaque minerals (Iron-oxide)	Ferruginous Sandstone
Ihube Sandstone	Nsukka	Darkish	Quartz (Angular, sub angular and sub rounded monocrystalline and polycrystalline quartz grains) and Opaque minerals (Iron-oxide).	Ferruginous Sandstone

4.3 Discussion

The acceptance limit for **Aggregate Crushing Value (ACV)** from the table 3 above is a maximum of 30%, it therefore implies that any aggregate with ACV higher than 30% is not suitable to be used as a road aggregate.

Crushed sandstone aggregates from NsukkaFormation (Ihube sandstone) and Ameki Formation (Ikperejere sandstone) have ACV of 25.2% and 24.4% respectively, (table 3). These values are within the acceptance limits and in agreement with the reference standard.

Aggregate Impact Value (AIV) is another crucial parameter in assessing the strength of road aggregates. The acceptable limits for AIV according toBS 885, 1973 and Government of East Central State of Nigeria Standard, 1972is maximum of 30%, therefore, aggregates with AIV above 30% are unsuitable to be used for road construction. This study found from analysis carried out that AIV of the samples from the study area exceeds the acceptance limit.Nsukka Formation has AIV 31.40% while AmekiFormation has 39.2%. These values fail the reference standard limit.

A measure of the resistance of the aggregates to surface wear by abrasion is termed **Los Angeles Abrasion Value (LAAV)**. From the results in table 3 as obtained from the analysis, all two crushedsandstone aggregate samples have LAAV above the acceptable limit of 40% maximum; NsukkaFormation 42.96% and AmekiFormation 49.75%. Aggregates with lower LAAV have greater resistance to wear and are very durable when used for road construction, those with higher values like that of the studied samples haveweak resistance and not durable.

Water Absorption of road aggregates control the quantity of binder material required to properly design a road surface. The acceptable water absorption limit is less than 3%. The sample fromNsukka Formation (Ihube-Okigwe sandstone) has water absorption of 0.8%, the other sample fromAmeki Formation (Ikperejere sandstone) has water absorptionvalue of 3.3% whichslightly exceeds the acceptable limit.

Bulk Density And Specific Gravity are indirect measures and determinants of strength and durability of road aggregates. While the acceptable limit for Specific gravity is between the ranges of 2.6 – 2.9, that of Bulk density is above 2.6Mg/m^3 (BS 882, 1973 and Government of East Central State of Nigeria, 1972).Thevalues obtained for the samples are NsukkaFormation 2.94, AmekkFormation 3.02 these two values did not meet the acceptance limit. Furthermore, the sandstone samples have bulk densities within the acceptable limit (more than 2.6 Mg/m^3).Nsukka Formation 2.74Mg/m^3 and Ameki Formation 2.80Mg/m^3 .

For the **Petrography**, photomicrographs from the prepared thin sections show the dominant minerals in the samples. These minerals identified from the thin sections, reviewed literatures, (Pettijohn, 1949, Milner, 1940, Williams, et al., 1954) and field observations as the cementing minerals were used in naming the sandstone samples.

The two sandstone samples from IhubeOkigwe area (Nsukka Formation) and Ikperejere (Amaeki Formation) are both darkish in colour and both have angular and sub angular and sub rounded quartz, monocrystalline quartz,opaque minerals and iron oxide. These two samples are ferruginous because of the presence of iron oxide (hematite). Also the two samples are derived from paralicformations and sandstones derived fromparalic formations are known to be ferruginous (Milner, 1940, Pettijohn, 1949)

The framework of the sandstones as observed from the photomicrographs shows a floating arrangement of the grains and constituent minerals of the samples. The grains are loosely and freely packed, there are gaps in between them showing that they are not closely or firmly packed. This arrangement and framework of the sandstone grains also contributed to their weakness and poor strength and durability property. Having loose and floating grains means that the sandstone aggregates can easily be crushed and collapse upon impact from heavy weight.

5.0 CONCLUSION

The crushed sandstone aggregates derived from Nsukka and Ameki Formations in the Okigwe area Southeastern Nigeria studied in this research failed the strength and durability test because their strength and durability parameter values did not meet the required standard limits as contained in table 3 (BS 885, 1973 and Government of East Central State of Nigeria, 1972). Therefore, the samples are not good enough and unsuitable to be used as road aggregates.

Although the actual percentages of each of the constituent minerals were not quantified, the samples were found to have some similar minerals with quartz predominantly occurring in the samples studied. In naming the sandstones, field observations, some related literatures and cementing minerals identified from the petrographic studies were used to give the samples the most suitable and appropriate name.

6.0 CONTRIBUTIONS TO KNOWLEDGE

This studyhas successfully achieved the following:

i. Carried out petrographic studies by preparing thin sections, examine them under petrographic microscope andidentify, tabulate the mineral constituents of these sandstone aggregates

ii. Cementing mineral materials identified have been used to name the sandstones ferruginous (hematite and ilmenite).
iii. Crushed sandstones from the study area have been confirmed through physico-mechanical analysis of their strength and durability parameters, to be unsuitable to serve as road aggregates due to their poor strength and durability quality and high water absorption values.

REFERENCES.

1. Adeyi, G.O., Mbagwu, C.C., Ndupu, C.N. &Okeke, O.C., (2019). Production and uses of crushed rock aggregates: An overview. International journal of advanced academic research 2019. 5(8), 92-110.
2. Brenda, F., (2000). The role of petrography in the selection of sandstone for repair. A seminar material. New South Wales heritage office, 2000.
3. British Standard Institute BS 882,(1973). Specifications for aggregate from natural sources for concrete and roadstones , British Standard Institute London.
4. Carozzi, A.V., (1993). Sedimentary petrography: Englewood Cliffs, New Jersey, PTR Prentice Hall, 263.
5. Emberga, T.T., (2019). Comparative analysis of techniques for estimating geohydraulic and vulnerability characteristics in Imo River basin, Southeastern Nigeria. Ph.D. Thesis; Department of GeologyFederalUniversity of TechnologyOwerri Nigeria.
6. English, B.F.,(1965). Use of sandstone in highway base course. Eighteenth annual road school.
7. Environmental geographic student association (EGSA), Bulaksumur, Yogyakarta, Indonesia (2009). General dictionary of geology. First edition. Edited by Alva, K., Jasmine, A.P. and Mc Kenzie, J. 2009.
8. Government of east central state of Nigeria, (1972). General specifications for roads and bridges. (Nigerian Standard). Contract No.58 1972.
9. Ingersoll, R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickle, J.D., &Sares, S.W., (1984). The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point counting method: Journal of Sedimentary Petrology.'54(1), 103-116.
10. Iwuoha, P.O., Iwuji, C.C., Adiela, U.P., &Okeke, O.C., (2016). Quality assessment of crushed rock aggregates from Lokpaukwu/Umuchieze in Okigwe area, Southeastern Nigeria, for engineering construction. International Journal of Advanced Academic Research 2(7), 27-36.
11. Kogbe, C.A., (1989). The Cretaceous and Paleogene Sediments of Southern Nigeria: In Kogbe C.a. (Ed.), Geology of Nigeria. Elizabethan Publ. Vo., Lagos, Nigeria. 273-286.
12. Mackechnie, J. R., (2003). Quality of Western Cape Sandstone as Concrete Aggregate. Concrete Beton. 104 11-13, August 2003.
13. Mackechnie J.R., (2004). Shrinkage of concrete containing graywacke sandstone aggregate. ACI Mater J 2004;103:390–6.
14. Milner, H.B., (1940). Sedimentary petrography. Thos. Murby& Co., London 1940.
15. Murat, R.C., (1972). Stratigraphy and Paleogeography of the Cretecous and Lower Tertiary, Southern Nigeria, In: African Geology (Dassauvagie, T.F.J., and Whiteman, A.J. eds.) University of Ibadan Press, Nigeria. 251-268, 425.
16. Nwajide, C.S., (1990). Cretaceous Sedimentation and Paleogeography of the Central Benue Though. In Ofoegbu, C.O; (Ed.), The Benue Tough structure and Evolution International Monograph Series, Braunschweig, 19-38.
17. Obi, C.G., (2000). Depositional Model for the Campanian Maastrichtian Succession, Anambra Basin, Southeastern Nigeria. Ph.D Thesis, University of Nigeria, Nsukka, Nigeria.
18. Offodile, M.E. (1975). A review of the Cretaceous of the Benue valley. In: Geology of Nigeria (C.A. Kogbe, ed.). Elizabethau Publishing Company, Nigeria, 319-330.
19. Okeke, O.C. &Iwuoha, S.C.,(2005). Strength and durability characteristics of crushed-rock aggregates from Oban Massif, Southeastern Nigeria. Journal of Science, Engineering and Technology 12(3), 6259-6269.
20. Okoro, A.U. &Igwe, E.O., (2014). Lithofacies and depositional environment of the Amasiri Sandstone, Southern Benue Trough, Nigeria. Journal of African Earth Science 100 179-190.
21. Onyekuru, S.O., Chima, C.G. &Ikoro, D.I., (2019). Sedimentology of the stratigraphic successions in Afikpo area Southeastern Benue Trough, Nigeria. International journal of advanced academic research 2019. 5(8), 72-92.
22. Pettijohn, F.J., (1949). Sedimentary Rocks. Harper & Row, New York 1949
23. Pettijohn, F.J., Potter, P.E. &Siever, R., (1972). Sand and sandstones. Springer-verlag, New York, USA.
24. Prentice, J.E., (1984). Geology of construction materials. Edward Arnold, London

25. Reyment, R.A., (1965). Aspect of the Geology of Nigeria. Ibadan University Press. 145.
26. Richard, S., (2006). Dictionary of geology. Academic publishers, New Delhi.
27. Ukpong, E.C., (2012). Environmental impact of aggregate mining by CrushedRock Industries in Akamkpa Local Government Area of Cross-River State. Nigerian Journal of Technology, 2012. 31(2), 128-138.
28. Uma, K.O., (1989). An Appraisal of the Groundwater Resources of the Imo River Basin. Nigerian Journal Mining Geology.19 (25) 305-315.
29. Uzoegbu, U.M., Uchebo, U.A. &Okafor, I., (2013). Lithostratigraphy of the Maastrichtian NsukkaFormation in the Anambra basin Southeastern Nigeria. IOSR journal of environmental science, toxicology and food technology 2013. 5(5), 96-102.
30. Williams, E.G., (1952). Report Nō 1 on a test road for the evaluation of sandstone as an aggregate in plant-mix bituminous pavements. Research report Nō 77, Division of research, Kentucky department of highways, April 1952.
31. Williams, H., Turner, F.J. & Gilbert, C.M., (1954). Petrography: An introduction to the study of rocks in thin section. W.H. Freeman and company (Inc) San Francisco.