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Research Article

PETROGRAPHIC AND AGGREGATE-QUALITY STUDIES OF AFIKPO SANDSTONE AND AMASIRI SANDSTONE OUTCROPS IN AFIKPO AREA, SOUTHEASTERN NIGERIA,IN RELATION TO SUITABILITY OF CRUSHED-SANDSTONE AGGREGATES AS HIGHWAY PAVEMENT MATERIALS

***Onyeocha, N.C., Okeke, O.C.,Ikoro, D.O.,Amadi, C.C. and Kalu, Q.A.**

Federal University of Technology Owerri, Nigeria.

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ABSTRACT

Over the years, there is a continued used of sandstone from Afikpo and Amasiri area South-eastern Nigeria for construction purpose even though their mineralogy and strength and durability characteristics were unknown. This research was carried out to properly identify the mineralogical composition of the sandstone samples (petrography) and ascertain their suitability to serve as highway pavement aggregate materials through the physico-mechanical study. Samples used are collected from the AfikpoSandstone (Nkporo Formation) and AmasiriSandstone(Ezeaku Formations) outcrops in South-eastern Nigeria. The collected samples were crushed and thin sections were prepared and viewed under cross polarized and plain polarized microscope to determine their mineralogical composition. Physico-mechanical analysis were also carried out to study their parameters like "Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Los Angeles Abrasion Value (LAAV), Water Absorption and Specific Gravity, so as to determine their strength and durability characteristics". AfikpoSandstone contains monocrystalline quartz, microcline, opaque minerals and Silica minerals (opal/chalcedony). The presence of opal/chalcedony as the silica cementing minerals informed the naming of this sample as siliceous sandstone. However, AmasiriSandstone, observed in the field to have milk-whitish colour, contains angular-"sub rounded monocrystalline and polycrystallinequartzgrains" (Oladeji*et al.,*) calcite and plagioclase mineral, it is a calcareous sandstone. AmasiriSandstone (Ezeaku Formation) and AfikpoSandstone (Nkporo Formation) have ACV values of 80.95% and 76.95% respectively. Aggregate Impact Value (AIV) are; Afikpo 80.60%, and Amasiri 88.90%, Los Angeles Abrasion Values (LAAV) for AfikpoSandstone is 83.86% and AmasiriSandstoneis 96.94%, water absorption values for AfikpoSandstone is 5.4% while AmasiriSandstone is 5.52%. The specific gravity of AfikpoSandstone 2.78 whereas that of AmasiriSandstone is 2.94. Also, the AfikpoSandstone has bulk density of 2.60Mg/m³ and AmasiriSandstone has its bulk density as 2.75Mg/m³ which is below the acceptable limit. The samples are not suitable to be used as road aggregate because they have poor/weak strength and durability characteristics which is evident in their failure to meet the acceptable standard limits for highway pavement aggregates.

Keywords: Crushed-sandstone, Aggregates, Highway, Pavement, Construction, Aggregate-quality, Petrography, Physico-mechanical, Afikpo, Amasiri, Mineral.

INTRODUCTION

Background Information.

"General dictionary of geology defined sandstone as a sedimentary rock that is composed of sand sized particles (1/16–2mm in diameter), EGSA, (2009). Williams, Turner, and Gilbert (1954) stated that sandstones are detrital sediments containing abundant grains of sand and coarse silt, they are detrital sedimentary rocks formed by cementation of individual sand grains and composed of quartz minerals, Richard, (2006).Sandstones are classified 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).

By degree of sorting, sandstones are classified into two arenites and wackes. Arenites are sandstones consisting of pure sand grains that is relatively well sorted and contains little orno 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"(www.ijasr.org) .

***Corresponding Author: Onyeocha, N.C.,**
Federal University of Technology Owerri, Nigeria.

Sandstones are also classified on the basis of the stability and/or instability of their mineralogical components. Some sandstones, either arenites or wackes, contain stables minerals like quartz, quartzite and muscovite which makes them stable and able to resist any mineralogical changes/alterations, whereas some others (both wackes and arenites) on the contrary, contain unstable minerals like feldspar, pyroxene and hornblende (ferromagnesian silicates), which makes them unstable and easily broken. This class of unstable sandstones results from rapid erosion and deposition in areas having tectonic activities and climatic conditions favorable to mechanical weathering rather than chemical weathering of parent rock (Williams, *et al.,* 1954).

> *"Aggregates materials be it natural (such as gravels) or artificial (such as crushed sandstones) are combined with binding materials like cement and water to form concrete, mortar or asphalt, they can also be used alone to form railroad ballast, filler beds or fluxed material (Adeyi, Mbagwu, Ndupuand Okeke, 2019, Langer 1983). The mixture of aggregates and binders is used for construction of roads, bridges, houses, landscaping, parks etc., it is, therefore, very necessary that aggregates should be strong enough to withstand crushing, abrasion and degradation. 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, www.ijasr.org).*

The use of sandstone as aggregate for engineering constructions is a common practice in Nigeria, 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.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area covers part of Afikpotown (Front of NYSC Camp) Ebonyi state, Lat. 5°53'38''N, Long.7°55'18''E (AfikpoFormation) and Amasiri town, along Afikpo-Uturu-Okigwe road, Ebonyi state, Lat. 5°54'16''N, Long.7°53'48'' (Ezeaku Formation) Southeastern Nigeria.

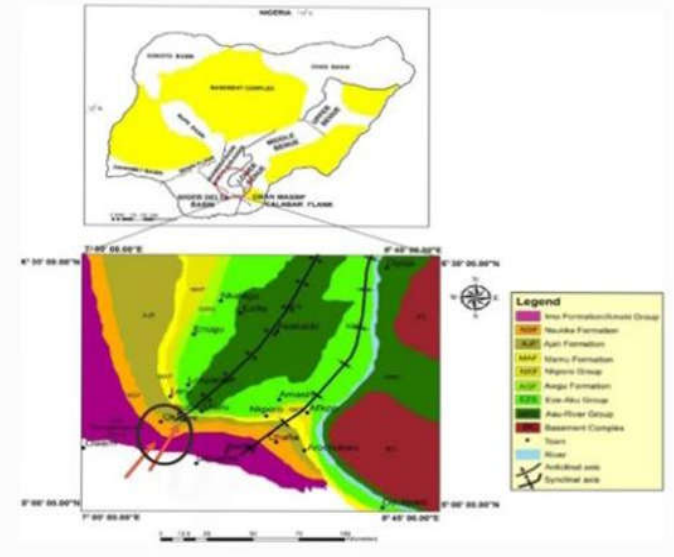


Fig 1. Geologic map of Southeastern Nigeria showing the study area (Modified after Okoro and Igwe, 2014).

Nkporo Formation.

It was deposited into the basin in Late Campanian, comprising Nkporo Shale, Owelli Sandstone and Enugu Shale (Reyment, 1965 and Obi, 2000). Nkporo Formation is made up of basal alluvial sediments and conglomerate, overlain by alternation of sandstones, siltstones shales mudstones and coal beds. The lower part of Nkporo Formation is characterized by a series of lithofacies of braided rivers and alluvial fans (Odigi, 2012). Mamu Formation which was deposited in Early Maastrichtian (Kogbe, 1989 and Obi, 2000) and comprises of succession of siltstone, shale, coal seam and sandstone is overlaying the Nkporo Formation (Kogbe, 1989). Mamu Formation is overlaid by AjaliSandstone (Maastrichtian), Reyment, (1965) and Nwajide, (1990) AjaliSandstone is mainly unconsolidated coarse-fine grained with poorly cemented mudstone and siltstone (Kogbe, 1989).

> *"Nkporo Shale and its lateral equivalents, the Enugu Shale and Owelli Sandstone (Nkporo Group), constitute the basal beds of the Campanian period. The broad Shallow sea gradually became shallower because of gradual subsidence, initiating regressive phase during the Maastrichtian that deposited deltaic foresets and flood plain sediments of the MamuFormation" (Murat,1972; Okeke, Iwuoha, Eberendu, Omoko, Amadi and Nwachukwu, 2020).*

Ezeaku Formation.

The Ezeaku Formation (Abakaliki Basin) was deposited during Turonian-Coniacian times by the most extensive marine transgression the occurred in the Benue trough. The Ezeaku Formation comprises of paralic sequences of two marine transgressive cycles: the Late Cenomanian-Early Turonian and Late Turonian-Early Coniacian strata that is uncomfortably overlaying the Middle Albian-Early Cenomanian Asu River Group (Odigi, 2007). The Ezeaku group consists of shales, limestones and sandstone ridges. The sandstones are parallel to elongate features, the beds of the Ezeaku group represents the second transgressive depositional cycle which occurred during the Upper Cretaceous (Murat, 1972).

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

Age	Formation	Lithology
Recent	Recent Sediments	Alluvium,Deltaic Plains
Miocene-Recent	Benin Formation	Unconsolidated sandstone with lenses of clay
Oligocene-Miocene	Ogwashi-AsabaFormation	Unconsoliddated sandstones, mudstone, clay and lignite seams.
Eocene	Ameki Formation	Grey to grees argillaceous sandstone, shale and limestone units
Paleocene	Imo Formation	Blue to dark grey shales and subordinate sandstonemembers (Umuna and Eberebe)
Maastritchian	NsukkaFormation	Alternating sequence of shale, sandstone and coal seams
	Ajali Formation	Friable sandstone with iron stains
	Mamu Formation	Sandstone, shale, siltstone with coal seams
Campanian	NkporoFormation/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
Albian	Asu River Group, Abakaliki Shale and Awi Formation	Sandy shales, sandstone and sandy limestone lenses
Precambrian	Basement Complex	Older granites and gneisses

MATERIALS AND METHODS

Sample Collection.

Field work was carried out for the collection of samples for this research work – Petrographic And Aggregate-quality Studies On Afikpo Sandstone And Amasiri Sandstone Outcrops In Afikpo Area, Southeastern Nigeria, Geological harmer, compass, GPS, shovel etc., were used to collect fresh and unweathered sandstone samples from the following locations.

Table 2:Locations visited for sample collection.

Location	Coordinates	Identity of Collected Sample	Geologic Formation
AfikpoTown (Front of NyscCamp)Ebonyi State	Lat. 5°53'38"N Long. 7°55'18"E	Afikpo Sandstone	Nkporo Formation
Amasiri town (Along Okigwe-Uturu-Afikpo road) Ebonyi State	Lat. 5°54'16"N Long. 7°53'48"E	Amasiri Sandstone	Ezeaku Formation

Figure 2: Field Occurrence of the AfikpoSandstone Outcrop at sample collection location.

Fig 3: Field Occurrence of the AmasiriSandstone Outcrop at sample collection location.

PetrographicStudy

Petrographic Study is the identification of the mineral constituents of a rock sample. This was achieved through two main processes:

- Thin section preparation.
- Microscopic examination of thin sections.

Then sandstone samples studied were taken to the laboratory for the preparation of their thin sections.Impregnation was done on samples i.e. unconsolidated sand stone using araldite and cool moulding impregnation method before thinning is done. The impregnated samples were cut into size of about 1.0 cm thick and their surfaces were smoothened with carborandum 70 and 90 grits to remove saw marks from the surface after thorough washing. The samples were them placed on hot plate at about 95°C. Prepared araldite was used to mount the samples on glass slide and the glass was pressed together using forceps to remove the air bubbles. The samples mounted were then allowed to cool at room temperature before reduction of about 3 – 4 mm using automated Logitech machine. The final reduction and the thinning of the samples involved grinding and smoothening of it with carborandum 120, 400, 600, 800, 1000 and 1200 grits respectively. The thinning was done with occasional observation under the petrological microscope until a thin section of 0.03mm normal thickness was obtained for each section. At this thickness the section became transparent under the petrological microscope. The sections were then covered with cover slip by using Canada balsam to preserve the sections when it has thinned to a satisfactory level. The sections were allowed to cool and washed with methylated spirit, soap solution and finally rinsed with distilled water.The thin sections photomicrographs were taken on the section by using Amscope camera attached to the petrological microscope and connected to the computer.

Aggregate-QualityStudy

Physico-mechanical Studies were also carried out on the sandstone samples under study in other to ascertain their strength and durability characteristics. The strength and durability characteristics of rocks are used to study their aggregate-quality under the following parameters

Aggregate Crushing Value (ACV %)
Aggregate Impact Value (AIV %)
Los Angeles Abrasion Value (LAAV %)
Water Absorption
Specific Gravity and Bulk Density.

These parameters are indicators of the ability of the samples to withstand crushing, abrasion and the impact from heavy weights. The values obtained from the samples were compared and analyzed using the British Standard BS 885, 1973 and the Government of East Central State of Nigeria Standard, 1972.

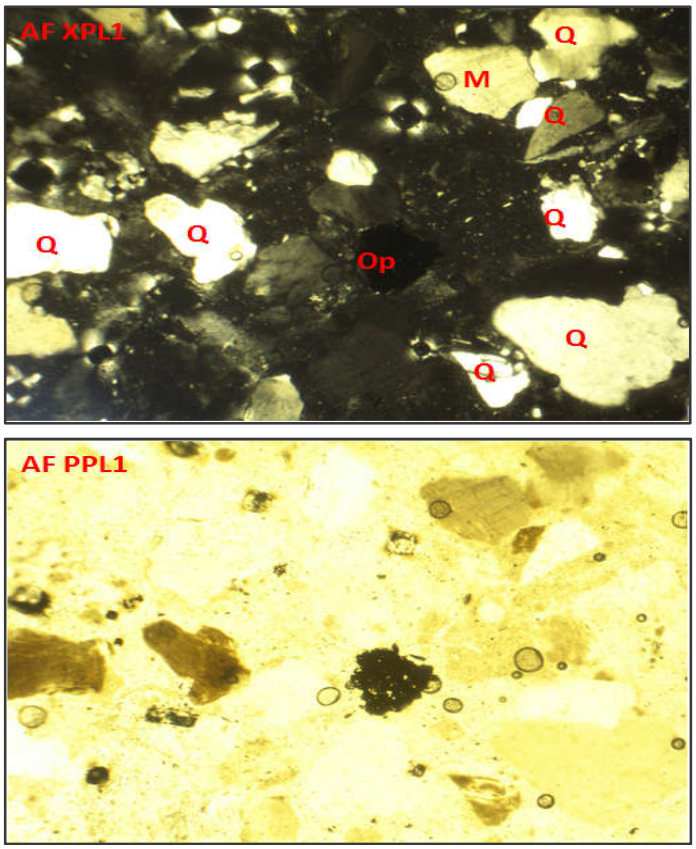
RESULTSAND DISCUSSION

Results

PetrographicStudy.

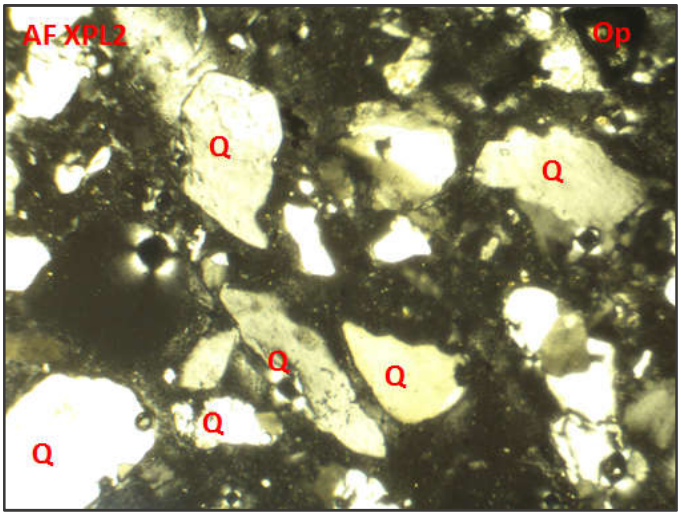
The thin sections prepared from the samples were examined under the microscope and photomicrographs were taken under the plain polarized light (PPL) first, i.e. (analyzer out) then it was proceeded to crossed polars (XPL) where the two polariod sheets are at right angle to each other (analyzer in) with the magnification of x4 under the objective lenses.

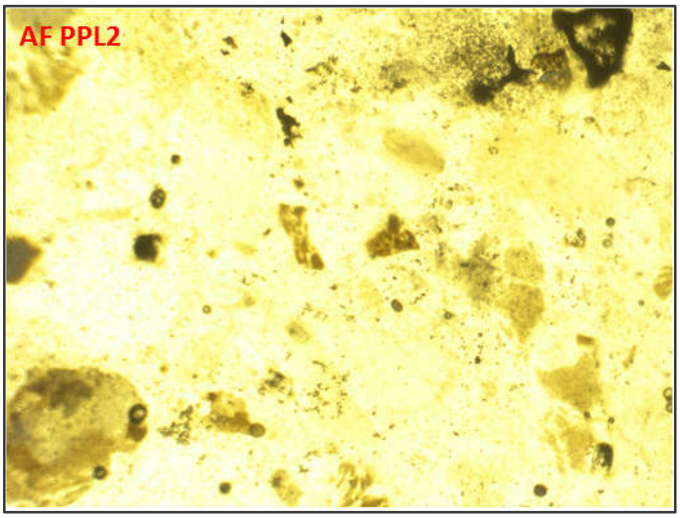
Photomicrographs of the Afikpo Sandstone (AF) and AmasiriSandstone (AM).



Q – Quartz (The grains are mainly monocrystalline quartz grains), M - Microcline and Op – Opaque. MG. X4

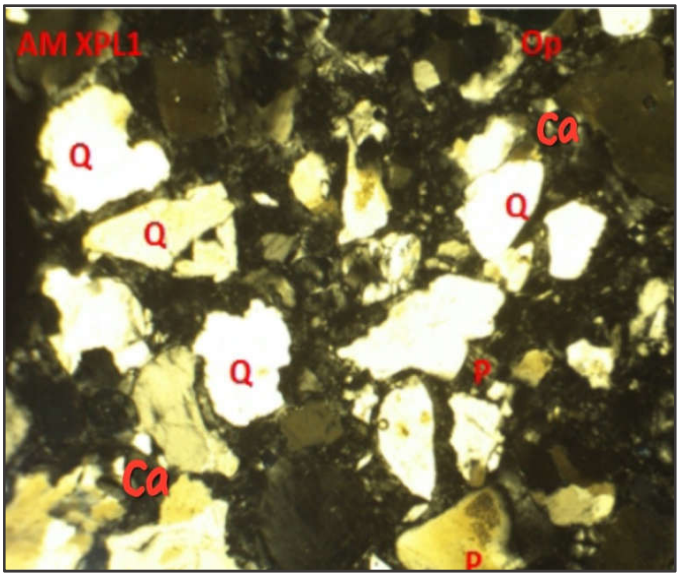
Fig.4a: Photomicrographs of the Afikpo Sandstone under plain polarized and cross polarized microscope.

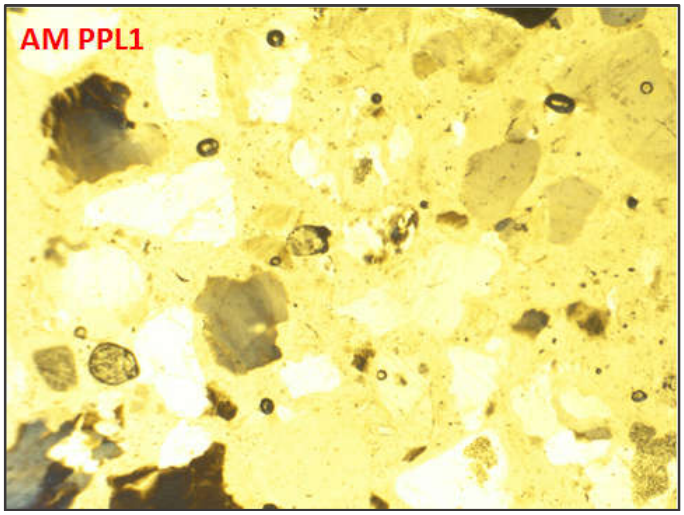




Q – Quartz (Mono crystalline and poly crystalline sub angular to sub rounded quartz grains) and Op – Opaque minerals MG. X4

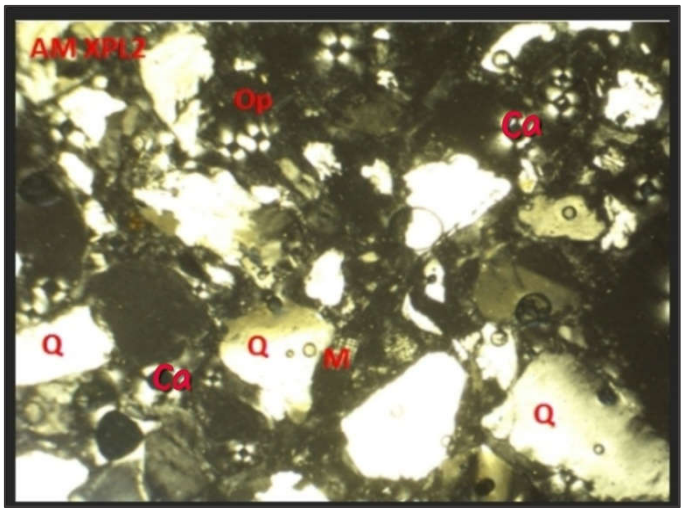
Fig.4b: Photomicrographs of the Afikpo Sandstone under plain polarized microscope

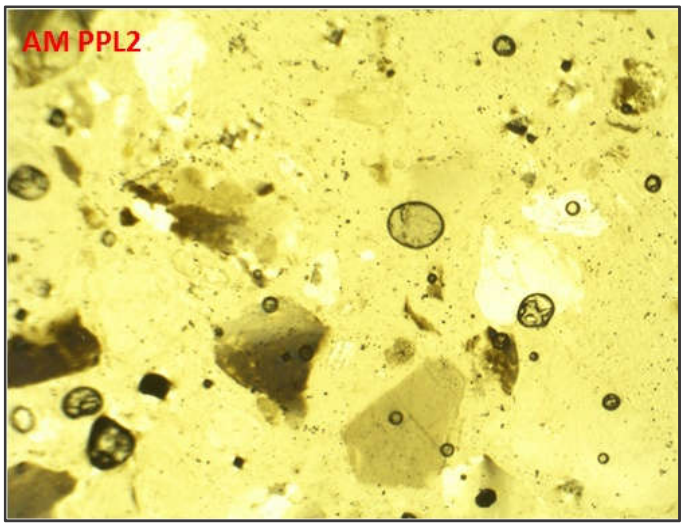




Q – Quartz (Angular – subrounded monocrystalline and polycrystalline quartz grains), P – Plagioclase and Op – Opaque minerals, Ca – Calcite. MG. X4

Fig.5a: Photomicrographs of the Amasiri Sandstone under plain and cross polarized microscope.





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

Fig.5b: Photomicrographs of the Amasiri Sandstone under plain and cross polarized microscope.

Table 3: Samples and their mineral constituents

Sample Identity	Geologic Formation	Color of Sample (As seen in the field)	Constituent Mineral	Name of Sandstone (After Petijohn, 1946, Williams, et al., 1954)
Afikpo Sandstone	Nkporo Formation	Brownish	Quartz (mainlymonocrystallinequartz grains), Silica (opal and chalcedony), Microcline and Opaque minerals.	SiliceousSandstone
Amasiri Sandstone	Ezeaku Formation	Milk-Whitish	Quartz (Angular – sub rounded monocrystalline and polycrystalline quartz grains), Plagioclase, Opaque mineral and calcite.	Calcareous Sandstone

Aggregate-Quality Study.

The aggregate quality of any rock sample is determined by the strength and durability characteristics of the sample this is determined through physico-mechanical analysis which helps to determine values of various parameters such as the aggregate crushing value, aggregate impact value, Los Angeles abrasion value, water absorption among others.The result of the Physico-mechanical analysis of the Afikpo and AmasiriSandstones are shown in table 4 below together with a comparative standard limits of British Standard BS 885, 1973 and the Government of East Central State of Nigeria Standard, 1972.

Table 4: Physico-mechanical Analysis Results and the Standard Limits (After British Standard BS 885, 1973 and the Government of East Central State of Nigeria Standard, 1972.

Parameters	Sample Identity		Standard Limit
	Afikpo Sandstone	AmasiriSandstone	(After BS 885, 1973 and the Government of East Central State of Nigeria Standard, 1972)
Aggregate Crushing Value (ACV %)	76.95	80.95	Maximum of 30%
Aggregate Impact Value (AIV%)	80.60	88.90	Maximum of 30%
Los Angeles Abrasion Value (LAAV %)	83.86	96.94	Maximum of 40%
Water Absorption (%)	5.40	5.52	Less than 3%
Specific Gravity (SG)	2.78	2.94	2.6–2.9
Bulk Density (BD Mg/m³)	2.60	2.75	More than 2.6 Mg/m³

DISCUSSION

Petrographic Interpretation of the Samples.

The minerals identified from the thin sections (as shown in the photomicrographs above), 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 study and examination of the thin sections under plain polarized and cross polarized microscope reveals that the AfikpoSandstone contains monocrystalline quartz, microcline, opaque minerals as well as Silica minerals (opal/chalcedony) (Pettijohn, 1949). The presence of opal/chalcedony as the silica cementing minerals informed the naming of this sample as siliceous sandstone.On the other hand, the AmasiriSandstone observed in the field to have milk-whitish colour, contains angular-sub rounded monocrystalline and polycrystalline quartz grains,calcite and plagioclase mineral. The AmasiriSandstone is a calcareous sandstone.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.

Aggregate-Quality (Physico-mechanical Properties).

Table 4 above shows the physico-mechanical properties of the sandstone samples, values for all the strength and durability parameters which includes Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), LosAngels Abrasion Value (LAAV), Water Absorption, Specific Gravity (SG) and Bulk Density were obtained.

Table 5: Acceptance Limits for Physico-mechanical parameter after British Standard BS 885, 1973 and the Government of East Central State of Nigeria Standard, 1972

Parameter	Acceptance Limits
Aggregate Crushing Value	Maximum of 30%
Aggregate Impact Value	Maximum of 30%
Los Angeles Abrasion Value	Maximum of 40%
Water Absorption	Less than 3%
Specific Gravity	2.6–2.9
Bulk Density	More than 2.6Mg/m³

Aggregate Crushing Value (ACV) acceptable limit according to British Standard BS 885, 1973 and the Government of East Central State of Nigeria Standard, 1972 (table 5)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. AfikpoSandstone (Nkporo Formation) has ACV of 76.95% while AmasiriSandstone (Ezeaku Formation) has ACV of 80.95% these values are not within the acceptable limits. Singh (1991), stated that aggregates with ACV less than 10% are very strong, values ranging from 10% – 20% are strong, while values ranging from 20% – 30% are considered good enough to be used as road aggregates. Afikpo and Amasiriby the values obtained, are definitely not good in terms of their ACV.

Aggregate Impact Value (AIV) is another crucial parameter in assessing the strength of road aggregates. The acceptable limits for AIV from table 5 above is maximum of 30%, therefore, aggregates with AIV above 30% are unsuitable to be used for road construction. The analysis results as presented in table 4 shows that the

aggregate samples studied have, 80.60% AIV for AfikpoSandstone and 88.90% AIV for AmasiriSandstone. Comparing these values to the standard limits in table 5, they exceed the acceptable limit and fall short of the acceptable standard.

Los Angeles Abrasion Value (LAAV)– measure of the resistance of the aggregates to surface wear by abrasion, from the results in table 4 it was discovered that while AfikpoSandstone has 83.86%, AmasiriSandstone has 96.94% these values are above the acceptable limit of 40% maximum. Aggregates with lower LAAV have greater resistance to wear and are very durable when used for road construction.

Water Absorption of road aggregates control the quantity of binder material required to properly design a road surface. The acceptable water absorption limit from table 5 above is less than 3%. Both samples used for this research have water absorption values that exceed the acceptable limit. AfikpoSandstone 5.4%, AmasiriSandstone 5.52%.

> *"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 range of 2.6 – 2.9, that of Bulk density is above 2.6Mg/m³ (BS 882, 1973 and Government of East Central State of Nigeria, 1972)".*

The AfikpoSandstone with specific gravity of 2.78 has value within the acceptable limit range, on the contrary, the AmasiriSandstone has 2.94 and does not conform with the acceptance limit. AmasiriSandstone have bulk density within the acceptable limit, 2.75Mg/m³ while the AfikpoSandstone has bulk density of 2.60Mg/m³ which is below the acceptable limit.

CONCLUSION

The petrographic study of the AfikpoSandstone and AmasiriSandstone samples showed that both contain quartz mineral, while the sample from Afikpocontains silica mineral, the AmasiriSandstone has plagioclase mineral.

> *"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 all the samples studied. In naming the sandstones, field observations, some related literatures and cementing minerals identified from the thin sections were used to give the samples the most suitable and appropriate name" (www.ijasr.org).*

The result of the physico-mechanical analysis of the samples for their Aggregate-quality studies shows that the samples have weak strength and durability characteristics. The values of their strength and durability parameters fell short of the acceptable standard limits. These two sandstone aggregates studied, failed the strength and durability test because their strength and durability parameter values did not meet the standard limits as contained in table 5 (after 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.

This study has successfully achieved the following:

i. Petrographic studies of the samples and identified (tabulate) the mineral constituents of these sandstone aggregates.
ii. The identified (cementing) mineral materials from the petrography informed naming the sandstones, silicious (silica) sandstone for Afikpo and calcareous (calcite)sandstone for Amasiri.
iii. Sandstones from the study area, from the results of the physico-mechanical analysis done, have poor strength and durability characteristics, so, are unsuitable to serve as road aggregates.

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