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Research Paper

Suitability of Ugbo-Odogu and Gariki Shale, Southeastern Nigeria as Construction Materials

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Abstract: *Shale is notoriously unpredictable material for which a number of failures have been reported. However as a result of its abundance, with the absence of suitable alternative in place, in addition to the prohibitive cost of haulage of more suitable options, the need for a pre-use assessment of shale for construction works becomes imperative. Particle size distribution, consistency limits, specific gravity, compaction parameters, California Bearing Ratio and Unconfined Compressive Strength as well as the mineralogy of Shales from Ugbo-Odogu and Gariki, areas of southeastern, Nigeria were examined with respect to their suitability as construction materials. Results of the various tests indicate that the Shales will perform well as barrier materials. However they are not suitable for use either as sub-base, base course and subgrade materials in road construction but upon compaction become suitable for use as general filling and embankment materials and they may also perform well as good brick making materials. Furthermore the presence of Pyrite and Jarosite in the shales may have negative influence on its use as aggregates in construction works. Hence the need for a suitability assessment of Shale to prevent failure is important and justified.*

Keywords: Shale, suitability, subgrade materials, swell potential, construction.

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1. Introduction:

The choice of construction materials essentially depends on their suitability. Thus the search for appropriate and suitable materials for construction works has brought about the need to qualitatively determine the usefulness of materials available for use. Shale is the commonest and the most abundant type of sedimentary rock found in sedimentary basins worldwide (King, 2013) covering a vast area of the earth's surface, accounting for approximately half of the stratigraphic column (Kuenen, 1941) which is frequently encountered in road cuts and other construction sites where economic and environmental considerations often recommend its use (Agbede and Smart, 2007; Solomon et al., 2013) in the construction of embankments.

Shales have varied behaviour depending on the geotechnical and mineralogical properties. Some are hard and behave similarly as other hard rocks in civil engineering projects while others are soft and like most other soft rocks are inappropriate for use as aggregates or stones in construction projects. As indicated by Yagiz (2001), it is the most problematic weak rock that causes many problems in the field before and after construction or excavation. Soft rocks and expansive soils are most often associated with non-durability (Gamble, 1971; Ezeribe, 1994), foundation problems and structural failures (Holtz and Kovacs, 1982; Coduto, 1999; Punmia et al., 2005).

Owing to the abundance of shale in the southeastern part of Nigeria (Aghamelu et al., 2011) and high cost of haulage of the other alternative and often more suitable construction materials, it is utilized both as subgrade and as aggregates in most road and highway constructions and as landfill liners (Mohamedzein et al., 2005). Ofoegbu and Amajor (1987) noted the abundance of shale particularly in and around the Abakaliki metropolis covering about 452 km^2. In this area shale is the predominant lithology and constitutes about 2/3 of the underlying sediments (Reyment, 1965; Aghamelu and Okogbue, 2011). However highways and other civil engineering projects constructed with shale and on shaly formations have developed serious structural damage soon after completion (Okagbue, 1988; Ezeribe, 1994; Okogbue and Aghamelu, 2010) resulting in projects suffering incessant failures and the damages often very expensive to remediate (Aghamelu and Okogbue, 2011). Several lives and property have been lost on failed highways and other structures founded on or constructed with shale. Nandi et al., (2009) noted that shales are often intensely fractured and weathered and have highly variable geotechnical characteristics, which cause significant construction problems and damage to civil structures each year. King (2013) opined that shales and the soils derived from them are some of the most troublesome materials to build upon due to their susceptibility to volume change and competence which make them unreliable construction substrates. As a result of the very unpredictable behavior (Yagiz, 2001), problematic nature (Adesunloye, 1987), shale's are the most difficult rock to classify and sample to obtain reliable test data for engineering purposes. Hence the need for a careful pre-use assessment of the geotechnical properties of shale to determine its suitability for use as construction materials becomes imperative.

2. Study Area:

The study area lies within Latitudes N 06^0 28′ 07″ and Longitudes of E 07^0 28′ 15″ (Figure 1.) with a comparatively congenial climate and particularly equable in the hilly and ecologically transitional region of Nsukka and is easily accessible through a network of roads.

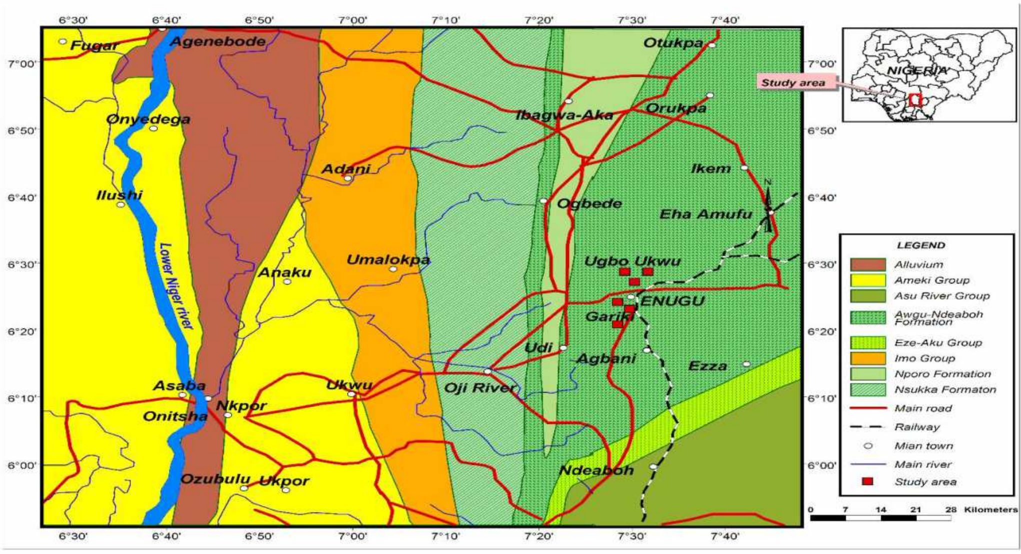

Figure 1: Map of the Study Area Showing Sampling Location

The mean monthly temperature in the hottest period of February to April is about 33 °C and the annual rain fall ranges between 152 and 203 cm. The rain is almost entirely seasonal, most of it falling between May and October. The area is drained by one main river system, the Anambra-Mamu River System in the West. In terms of Geology, the study area falls within the Anambra basin. Anambra Basin is one of the major Cretaceous depo-centres in the southern Benue Trough formed during the Abakaliki folding phase. It forms a link between the Cretaceous Benue Trough and the Tertiary Niger Delta (Akaegbobi and Boboye, 1999). The origin of Anambra Basin is related to the evolution of the Benue Trough, which is also associated with the separation of the African plate from the South American plate in the Mesozoic (Tijani et al., 2010). It has an approximate thickness of 5000 m (Uma and Onuoha, 1997).

The Awgu Formation consists of grey to black well bedded fissile shales, with thin inter-beds of shelly limestone and fine to medium grained/moderately sorted sandstone. The thickness of Awgu Formation has been estimated to be 350 -1000 m (Simpson, 1954; Kogbe, 1989). Based on the foraminiferal content, Agagu et al. (1985) assigned a Turonian-Santonian age and a shelf depositional environment to the Awgu Formation.

Three locations each from exposures of shale at Ugbo-Odogu along Abakaliki expressway and at Gariki, Enugu area were sampled for this work.

3. Materials and Methods:

Bulk disturbed shale samples were taken from shale exposures at Ugbo-Odogu and Gariki areas (Awgu shale formation) of the Anambra basin, southeastern Nigeria. The Ugbo-Odogu shales were dark in colour, fissile and crumbled easily with finger pressure. The samples under finger pressure feel likes clay (mud) with sand size particles in between. The Gariki shales on the other hand were light grey, relatively dense and hard and do not crumble easily under finger pressure.

The shales which were laminated and blocky in shape were crushed, air-dried to reduce the effect of clods on hydraulic conductivity and subjected to laboratory geotechnical tests including Particle size distribution analyses, Consistency limits, Specific gravity, Compaction (at both Modified and West Africa level), California Bearing Ratio (Soaked and Unsoaked CBR) and Unconfined Compressive Strength (UCS) in accordance with BSI 1377 (1990) standard test procedures. The samples were air dried so as to obtain reliable results because some clay materials undergo irreversible changes when oven dried at temperature of 100 °C to 110 °C.

The mineralogy of the soils was determined at the ACME Analytical laboratories, Canada using the X-Ray diffraction (XRD) method. Powdered samples of the soil were pelletized and sieved to 0.074 mm. These were later mixed with acetone to produce a thin slurry and each sample mixture was applied to a glass was scanned through the Siemens D500 Diffractometer (using MDI Data Scan and JADE 8 softwares) for the determination of XRD.

4. Results and Discussions:

Specific Gravity

Specific gravity is closely linked with the mineralogical, chemical composition and the degree of weathering of a soil. The values of the specific gravity for the studied soils (Table 1) ranges from 2.42 to 2.60 with a mean value of 2.53 and 2.54 respectively for Ugbo-Odogu and Gariki shales respectively. The very close values of specific gravity for shales from both areas also suggest shales with similar mineralogy. Gidigasu (1976) noted that the specific gravity of soil grains is an important property in the identification and evaluation of aggregate parameters for construction purposes. The higher the specific gravity of the soil, the better it is for construction purposes. Moreover, Reidenouer (1970) indicated that rocks with low specific gravity (< 2.65) are usually weak and potentially non-durable.

The low specific gravity observed may be due to the presence of organic impurities in the shale which affects the strength properties of the shale as a result of high porosity leading to low strength. A close look at the values of specific gravity for the soils under investigation reveals materials that are weak and potentially non-durable. The result obtained for these shale's is in conformity with findings of Ezeribe (1994) from slake durability testing of some shales from the Asu River Group and Nkporo formation.

Particle Size Distribution

A summary of the particle size distribution and the corresponding grading curves (Table 1 and Figures 2; 3) show the shales contain low amounts of sand size particles with a mean value ranging from 6-10 %, while the mean amount of fines ranges from 90-93 %.

Table 1: Particle size distribution and specific gravity of the shales

Location	**Sample Code**	**Specific Gravity (Gs)**	**Particle Size Distribution**				**$k = CD^2_{50}$ C = 0.00357 (McKinlay, 1961)**
			% Sand	**% Silt**	**% Clay**	**% Fines**	
UGBO-ODOGU	EN1A	2.49	7	30	63	93	1.7×10^{-7}
	EN1B	2.51	6	24	70	94	5.1×10^{-7}
	EN1C	2.58	6	30	63	93	5.1×10^{-7}
	MEAN	**2.53**	**6**	**28**	**65**	**93**	$\mathbf{3.8 \times 10^{-7}}$
GARIKI	EN2A	2.60	9	25	66	91	3.6×10^{-7}
	EN2B	2.59	9	32	61	91	3.2×10^{-7}
	EN2C	2.42	11	33	56	89	6.0×10^{-7}

	MEAN	**2.54**	**10**	**30**	**61**	**90**	**4.3 x 10^{-7}**

Gariki shales contain more amounts of sand size particles than Ugbo-Odogu shales while in terms of amounts of fines the situation is vice-versa. These may not be unconnected to degradation of grains during mechanical sieving. Shale samples from both locations are well graded and are expected to compact to a lower porosity and permeability than uniformly graded materials (Oyediran and Adeyemi, 2011a). However as noted by Oyediran and Williams (2010), soils with amounts of fines less than 50% are expected to possess better engineering properties while those with amounts of fines greater than 50 % are expected to pose field compaction problems when used either as sub-base or sub-grade materials. Hence it can be concluded that on the basis of amounts of fines the studied shales will pose problems when used as sub-base or sub-grade materials in the construction of roads. Furthermore on the basis of the recommendation by the Nigerian Federal Ministry of Works and Housing (FMWH, 1997) specification (amounts of fines ≤ 35 % for general filling and embankment materials and 5-15 % for base-course materials) for highway construction, the materials do not qualify as general filling and embankment materials as well as for use as base course materials.

The aforementioned assertions may in part be responsible for the structural damages and failures noticed on highways constructed in this area (Okagbue, 1988; Ezeribe, 1994) and those observed within sections of roads underlain by shales (Uduji et al., 1994). The relatively higher clay contents indicate that the samples are rich in certain clay minerals which could influence their geotechnical behaviours. The estimated permeability coefficient for the shales (Mckinlay, 1961) which ranges from 1.7 x 10^{-7} to 6.0 × 10^{-7} cm/s falls within the range specified by Mohammed and Antia (1998) of 1×10^{-7} cm/s if a soil is to be used as a single liner/ isolation barrier.

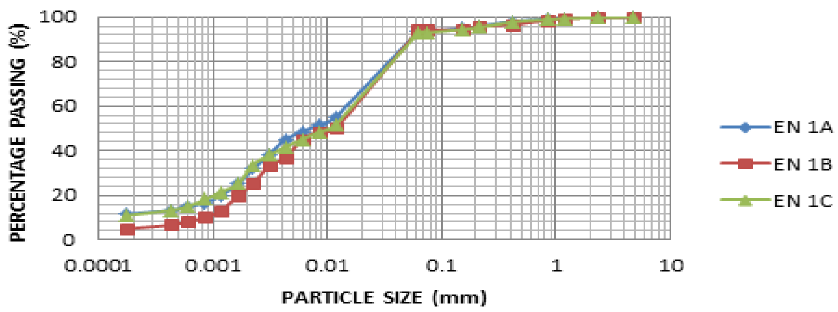

Figure 2: Grading curves of Ugbo-Odogu shales

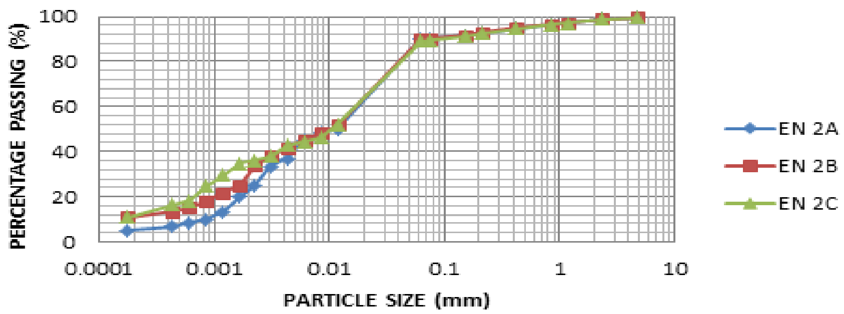

Figure 3: Grading curves of Gariki shales

Benson et al. (1994) and Rowe et al. (1995) recommended that materials with at least 30% fines and less than 30 % gravel is suitable for landfill liners, this means that the shale samples could be used as landfill liners. Furthermore the low permeability exhibited by the shale may be due to its small particle sizes leading to small interstitial spaces which impede flow and movement.

Consistency Limits

All the shales examined based on the Casagrande chart classification (Figure 4), show medium plasticity and hence compressibility (Table 2) except EN2A which exhibits high plasticity. Furthermore all the samples from both areas cluster above the A-Line indicative of materials with similar clay mineralogy. From the limits of plasticity prescribed by Gidigasu (1972), the shales all show low to medium plasticity except EN2A. The high plastic nature of EN2A is further corroborated by the relationship established by Ola (1982) between plasticity index and swelling potential of clays as it is expected to exhibit very high swelling potential. The plasticity indexes of the Gariki shales is higher than those of the Ugbo-Odogu shales, thus are expected to exhibit higher swelling potential because the more plastic the material the higher the swell potential (Mitchell, 1993) and as they are likely to have higher percentage of expansive clays. FMWH (1997), specified that a good sub-base material must have liquid limit and plasticity index of <35 % and <16 % respectively.

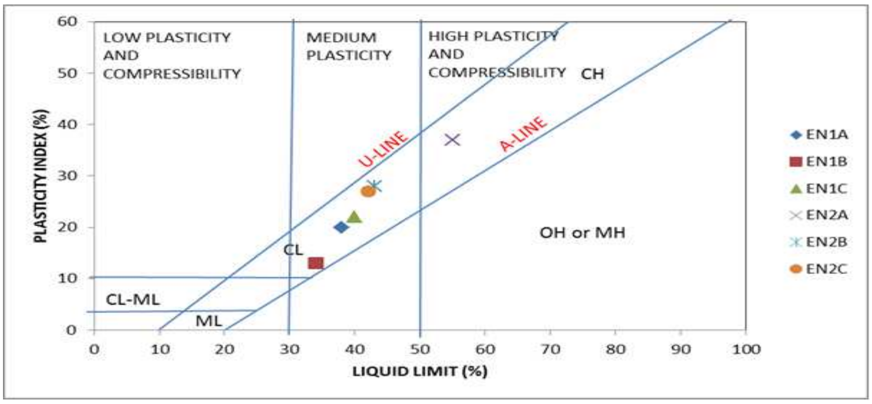

Figure 4: Casagrande chart classification of the shales

Table 2: Consistency limits and classification of studied shales

Location	Sample Code	CONSISTENCY LIMITS				Limits of Plasticity (Gidigasu, 1972)	Swelling Potential (Ola, 1982)
		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Casagrande Chart Classification		
UGBO-ODOGU	EN1A	38	18	20	MEDIUM	MEDIUM	MEDIUM (PI between 15 and 25)
	EN1B	34	21	13	MEDIUM	LOW	LOW (PI between 0 and 15)
	EN1C	40	18	22	MEDIUM	MEDIUM	MEDIUM (PI between 15 and 25)
	MEAN	**37**	**19**	**18**			
GARIKI	EN2A	55	18	37	HIGH	HIGH	VERY HIGH (PI greater than 35)
	EN2B	43	15	28	MEDIUM	MEDIUM	HIGH (PI between 25 and 35)
	EN2C	42	15	27	MEDIUM	MEDIUM	HIGH (PI between 25 and 35)
	MEAN	**47**	**16**	**31**			

All the shales examined except EN1B (which is also the only shale which displays low plasticity and swelling potential based on Gidigasu, 1972 and Ola, 1982) do not meet the requirement and hence will not perform creditably as sub-grade and sub-base materials. This conclusion corroborates results obtained from the grain size analyses and subsequent classification of the soils. The AASHTO classification of the soils indicate that they fall within the A-7-5 sub-group which is an indication that they are fair to poor sub-grade materials.

FMWH (1997) recommends the liquid limit and plasticity index of materials to be considered as base course materials must be ≤ 30 % and ≤ 13 % respectively. None of the materials examined from both locations satisfy this requirement. The high liquid limit and plasticity index which may lead to structural damage through differential heave may be attributed to the high fines content noticed from the particle size distribution. However the shales from both locations can be used as landfill liner materials because they meet up with the specifications of minimum liquid limit of 20%, and plasticity index greater than 7% (Benson et al., 1994) and maximum liquid limit of 90% recommended by Declan and Paul (2003).

Compaction

The shale samples were compacted at both the West African (WA) and Modified AASHTO (MA) levels of compaction because shale can withstand a higher energy level without mechanical instability (Mohamedzein et. al., 2005). The results of the tests (Table 3) shows the Maximum Dry Density (MDD) for the shale samples ranges from 1095-1933 kg/m^3 and 1244-1961 kg/m^3 respectively at the WA and MA levels while the Optimum Moisture Content (OMC) ranges from 12 - 48.4 % and 10.60 - 33.60 % respectively WA and MA levels of compaction. The high MDD may be associated with the high clay content of the shales. It was observed that there was a higher % increase in the mean value of MDD for the Ugbo-Odogu Shale at the Modified AASHTO level; while on the other hand the mean value of OMC showed a higher % decrease for the Gariki Shale also at Modified AASHTO level. Noteworthy is the fact that for all samples from both locations the observed results show that the higher the level of compaction, the higher the MDD and consequently, the lower the OMC as observed by Oyediran and Kalejaiye (2011).

The results of the MDD and OMC shows that the samples can be used as filling and embankment materials because they fall within the specification by the FMWH (1997) which recommends MDD should be greater than 1680 kg/m^3 and OMC less than 18 %. Also Madedor (1992) recommended a minimum MDD of 1650 kg/m^3 for bungalow bricks, indicating that the examined shales may perform well as good brick making materials.

California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS)

California Bearing Ratio (CBR) is the ratio of the actual load required to produce a 2.5 mm deflection to that required to produce the same deflection in a certain standard crushed stone (Mannering and Kilareski, 1998; Wignall et al., 1999). The Unconfined compression test is often used to estimate the shear strength of engineering soils. For clayey soils, the shear strength is about half of the Unconfined Compressive Strength (Krynine and Judd, 1957). The CBR and Unconfined Compressive Strength (UCS) are often used to estimate bearing capacity of highway sub-grade materials (Gidigasu, 1980). Moreover CBR is often used to establish design parameters for pavement thickness (Mannering and Kilareski, 1998; Wignall et al., 1999; Sowers and Sowers, 1970) as it has been correlated with pavement performance.

Table 3: Compaction parameters of the studied shales

Location	Sample Code	MAXIMUM DRY DENSITY (kg/m^3)			OPTIMUM MOISTURE CONTENT (%)		
		West African Level	Modified AASHTO Level	% Increase In MDD	West African Level	Modified AASHTO Level	% Decrease In OMC
UGBO-ODOGU	EN1A	1741	1841		14.50	12.00	
	EN1B	1781	1944		15.80	13.30	
	EN1C	1709	1831		12.00	11.70	
	MEAN	**1744**	**1872**	**7.35**	**14.10**	**12.33**	**12.55**
GARIKI	EN2A	1933	1961		14.30	10.60	
	EN2B	1620	1740		15.80	14.40	
	EN2C	1860	1832		14.70	12.00	
	MEAN	**1804**	**1844**	**2.22**	**14.93**	**12.33**	**17.42**

OMC = OPTIMUM MOISTURE CONTENT, MDD = MAXIMUM DRY DENSITY

Soaking of the shale samples helps to simulate natural conditions to which sub-base materials are exposed to as a result of ingress of water (Oyediran et al., 2008). The results of the soaked and unsoaked CBR of the shales compacted at both Modified AASHTO and West Africa levels of compaction (Table 4), shows a reduction in strength as a result of soaking is evident. This is an indication that, moisture influx and ingress of water would be detrimental to sub-grades of pavements and foundations of other engineering structures constructed on this shale samples (Aghamelu et al., 2011). The Gariki shales had the higher mean CBR values for both soaked and unsoaked CBR at both levels of compaction. The same trend noticed in the mean specific gravity of the shales. Gidigasu (1980) pointed out that when the CBR values are below 3% as in the case of the studied shales, then we have a weak sub-grade, and usually a suitable thick road pavement is recommended with capping to spread the wheel load over a greater area of the weak sub-grade so as not to deform the weak sub-grade material, which may cause the road pavement to fail.

The Unconfined Compressive Strength (UCS) of the shales range from 70.70 to 110.65 kN/m^2 with a mean value of 84.23 and 91.47 for Ugbo-Odogu and Gariki shales respectively. The Gariki shales show higher strength properties than the Ugbo-Odogu shales. This is consistent with observations of the Specific Gravity, CBR and MDD for the shales investigated. The mean values fall short of the greater than 103 kN/m^2 specifications for base course materials (FMWH 1997), thus the shales are not suitable as base course materials for road pavements.

Table 4: CBR and UCS of the studied shales

Location	Sample Code	CALIFORNIA BEARING RATIO (UNSOAKED %)		CALIFORNIA BEARING RATIO (SOAKED %)		UNCONFINED COMPRESSIVE STRENGTH (kN/m^2)
		West African Level	Modified AASHTO Level	West African Level	Modified AASHTO Level	
UGBO-ODOGU	EN1A	0.32	0.45	0.29	0.32	81.80
	EN1B	0.35	0.58	0.28	0.45	100.20
	EN1C	0.35	0.46	0.28	0.33	70.70
	MEAN	**0.34**	**0.50**	**0.28**	**0.37**	**84.23**
GARIKI	EN2A	0.50	0.58	0.45	0.50	75.21
	EN2B	0.53	0.50	0.48	0.46	88.56
	EN2C	0.58	0.45	0.42	0.37	110.65
	MEAN	**0.54**	**0.51**	**0.45**	**0.44**	**91.47**

Mineralogy

Generally, the mineral content (Table 5) and representative diffractograms (Figures 5 and 6) shows Kaolinite as the most abundant clay mineral at varying proportions in the shales. Ugbo-Odogu shales contain almost double the amount of kaolinite in the Gariki shales.

The mean percentage of kaolinite is 44.69 % and 25.85 % for Ugbo-Odogu and Gariki shales respectively. The presence of kaolinite can be linked to the high clay content observed in the shales and may not be unconnected with the favourable permeability characteristics displayed by the shales which make them suitable as liner materials in landfill. The lower plasticity index and swelling potential of the Ugbo-Odogu shales compared to the Gariki shales may not be unconnected with the presence of higher amounts of kaolinite. The shale from Gariki contains more quartz (50.28 %) than that from Ugbo-Odogu (35.00 %). The presence of quartz in significant amounts gives strength and durability to a brick. This is attributable to the fact that during the vitrification period, quartz combines with the basic oxides of the fluxes released from the clay minerals on firing to form glass, which improves the strength (Bell, 2007).

However the pyrite observed in all the shales can only have negative effects on construction materials as its presence in aggregates used for construction works leads to severe deterioration as the pyrite oxidizes (Tagnithamou et al. 2005). Furthermore, the presence of Jarosite in the Gariki shales may account for its high plasticity index and swelling potential because Jarosite (basic hydrous sulphate of potassium and iron commonly associated with acid sulphate environments) is a mineral whose presence is associated with large amount of water. In addition the presence of this mineral may also confer other negative attributes to the soil including through the corrosion and disintegration of concrete, and other road works leading to infrastructural damage which may also in part account for some of the failures noticed.

Table 5: Mineral content of the studied shales

Location	Sample Code	MINERAL CONTENT (%)				
		Quartz	**Kaolinite**	**Pyrite**	**Albite**	**Jarosite**
UGBO-ODOGU	EN1A	36.94	44.77	18.29	-	-
	EN1B	33.88	45.87	20.25	-	-
	EN1C	34.20	43.42	22.38	-	-
	MEAN	**35.00**	**44.69**	**20.31**	**-**	**-**
GARIKI	EN2A	51.92	25.82	11.69	5.50	5.06
	EN2B	48.76	25.63	15.63	5.00	4.98
	EN2C	50.15	26.10	14.50	4.15	5.10
	MEAN	**50.28**	**25.85**	**13.94**	**4.88**	**5.05**

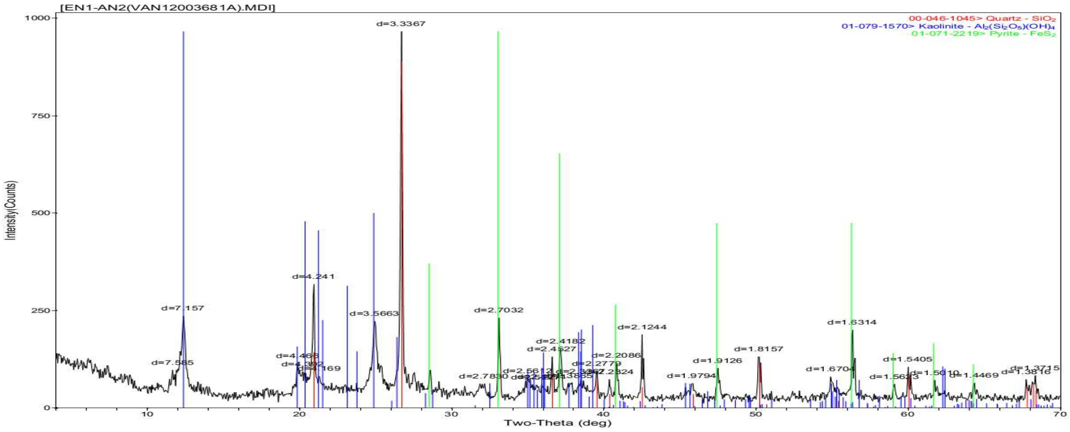

Figure 5: Diffractogram of Ugbo-Odogu shale

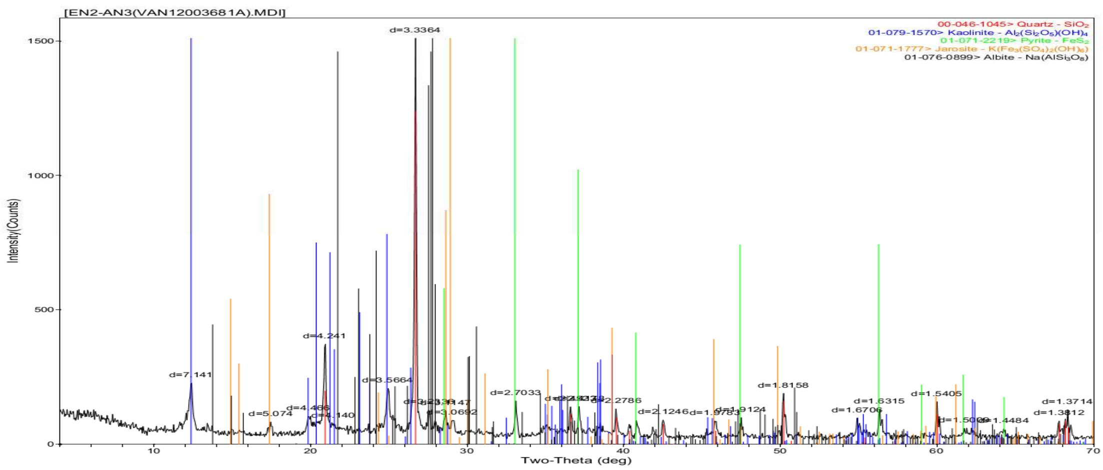

Figure 6: Diffractogram of Gariki shale

5. Conclusion:

A study of shales from Ugbo-Odogu and Gariki areas, Southeastern Nigeria, for use as construction materials revealed that;

I. The shales possess very high amounts of fines and are expected to pose field compaction problems when used as sub-base, sub-grade and base course materials in the construction of roads with the AASHTO classification corroborating the fact that they are fair to poor sub-grade materials.
II. They neither satisfy requirements as fill and embankment, nor as sub-base, sub grade and base course materials as a result of their high plasticity indexes and swelling potential but may be used as landfill liner materials because they possess requisite consistency and permeability coefficients.
III. Moreover compaction of the shales was observed to have improved and possibly made them useful as filling and embankment materials while they may also perform well as good brick making materials.
IV. The CBR of all the shales indicates weak subgrade materials while the mean values of UCS also fall short of specifications for base course materials and thus the shale's are not suitable.
V. Furthermore, although the presence of Kaolinite in all the samples may have influenced the favorable permeability characteristics exhibited, the unsatisfactory behavior of the shale may not be unconnected with the observed presence of Pyrite (which leads to severe deterioration of aggregates as pyrite oxidizes) and Jarosite (which aids corrosion and disintegration leading to infrastructural damage).

Conclusively, pre-use suitability assessment of shale not minding its abundance is of great importance and is justified to forestall failure of structures and prevent loss of lives and property.

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