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Geotechnical Properties of Lateritic Soils Derived from Various Geologic Formations in Okigwe Area, Southeastern Nigeria

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Abstract

Roads constructed with laterites in Okigwe area of Southeastern Nigeria, often fail or deteriorate in value within few years of completion. The quality of laterites when used as road construction materials depend on the parent geologic formation (or rock) from which they were derived. In this paper, the geotechnical properties of some lateritic soil derived from geologic formations in Okigwe area were determined and evaluated in terms of their suitability for road construction. Five (5) lateritic soil samples were collected (1 sample from Umulolo to represent Nsukka formation; 2 samples to represent Ajali formation: 1 each from Ihube – Okigwe and Nkoto – Okigwe, respectively; and 2 samples to represent Mamu Formation: 1 each from Leru and Lokpanta, respectively). The samples were subjected to some geotechnical tests including Atterberg limits, linear shrinkage, particle-size analysis, compaction and California Bearing Ratio (CBR) in the laboratory. Results of the study show that lateritic soil derived from Nsukka formation have liquid limit of 38.00 %, plasticity index of 14.30 % and California Bearing Ration (soaked of 22 % and unsoaked of 67 %). The average values for lateritic soils derived from Ajali formation are: liquid limit, 28.00 %, plasticity index, 9.85 %, linear shrinkage 4.80 %; and California Bearing Ratio (soaked, 29 % and unsoaked, 75 %). Similarly, the average values for lateritic soils derived from Mamu formation are: liquid limit, 53.00 %; plasticity index, 19.25 %; linear shrinkage, 9.10 %; and California Bearing Ratio (soaked, 25 % and unsoaked, 43 %). Comparison of results of the geotechnical tests with standard specifications of materials for roads (sub-base and base course materials) by Federal Ministry of Works (liquid limit < 36.00 %, plasticity index < 12.00 %, linear shrinkage < 8.00 %, soaked CBR >30 % and unsoaked CBR >80 %) show that only the soils derived from Ajali formation (located at Ihube-Okigwe and Nkoto – Okigwe) satisfy every aspect of the geotechnical properties except CBR values (test results are lower than standard), as good road construction materials. Soils derived from Nsukka formation (located at Umulolo) and soils derived from Mamu Formation (located at Leru and Lokpukwu) do not satisfy any aspect of the geotechnical properties. They are therefore likely to deteriorate faster than soils derived from Ajali Formation when used as road pavement (sub-base and base course) materials. The quality of the lateritic soils may however be improved by treatment/ stabilization with cement or lime to increase the CBR values of all the soils used in the study, and in addition reduce the liquid limit and plasticity index and linear shrinkage of soils derived from Nsukka formation and Mamu formation.

Keywords: Lateritic soils, geotechnical properties, Atterberg limits and geologic formations.

1. Introduction

Lateritic soils are reddish brown residual soils that are formed by chemical weathering of pre-existing soils such as granite, sandstone, shale and quartzite (Gidigasu, 1976; Okeke, Ogbuniba and Chukwujekwu, 2013). They are commonly formed in tropical climatic regimes of the world (Amu, Ogunniyi and Oladeji, 2011). Over 85 % of major oxides constituents of laterites is made up of SiO_2, Al_2O_3 and Fe_2O_3 (Adeyemi 2002, Matheis and Pearson, 1982). The reddish brown coloration of these soils are due to their Fe_2O_3 contents. Fe_2O_3 and Al_2O_3 are called sesquioxides and they constitute the cementitious materials of the laterites (Aguwa, 2013; Meigniem 1966). Sesquioxides are oxides with three atoms of oxygen and two atoms of another element. According to Bell (1993a), lateritic soils may also be defined on the basis of the molecular ratio of silica (SiO_2) to sesquioxides (Fe_2O_3 and Al_2O_3). In laterites, the ratios are below 1.33 and in lateritic soils, the ratios are between 1.33 and 2.00. When the ratios are greater than 2.00, the soils are classified as non laterites. Chemically, laterites and lateritic soils may be described as hydrous aluminum-iron oxide (Singh, 2004). The dominant clay minerals in most laterites and lateritic soils are kaolinite. Occasionally, laterites and lateritic soils may contain montmoronitic clay mineral, and when this occurs, the soil may develop the tendency to swell when in contact water, thereby becoming a problem soil (Gidigasu, 1973; Gromko, 1974; Ola, 1981). Lateritic soils are widely used in the construction industry for road construction (highway sub-base and base course materials) and fills in dams, building foundations and levees (Simon, Giesecke and Bidlo, 1973; Gidigasu, 1976). They are generally well-graded with mechanically stable particle-size distribution which enables them to perform satisfactorily as sub-base and base course materials in road construction (Thagesen, 1996). When lateritic soils do not meet the expected quality as road construction materials in terms to high strength or negligible plasticity/swelling characteristic (problem soils), they are generally stabilized or improved by use of additives including cement, lime, sharp sand, bitumen and fly ash (Ola, 1975 and 1977; Ingles and Metcalf, 1992; Bell, 1993b). Previous works on the geotechnical properties of lateritic soils in Nigeria include Ola, 1983, Alao, 1983, Okeke, Ezeoke and Onuoha, 2011 and 2016 and Adeyemi, 2002. Failure of roads constructed with laterites causes engineering problems in Nigeria. In this paper, geotechnical properties of 5 lateritic soil samples derived from 3 geologic formations (Nsukka Formation, Ajali Formation and Mamu Formation) in Okigwe Area, Southeastern Nigeria were determined and the results used to evaluate the influence of geologic formation (parent rock) on the quality of the laterites as road construction materials.

2. Study Area Description

The study area, Okigwe Area, lies between latitude $5^{0}45^{1}$ - $5^{0}56^{1}$.N and longitude $7^{0}15^{1}$- $7^{0}25^{1}$E with an attitude of about 300m above sea level. The major towns in the area are Okigwe Town, Ihube-Okigwe Nkoto-Okigwe, Umulolo, Anuro-Okigwe, Leru, Lokpaukwu, Lekwesi and Ubaha towns (Fig.1). There are two distinct seasons in the area, the rainy season that lasts from April to October and the dry season that lasts from November to March. The average annual rainfall in the area is 2000 mm (Nigeria Meteorological Agency, 2007) Okigwe Area, geologically, lies within the Anambra Basin, which constitutes a major depocenter of clastic sediments in the southern portion of the Benue Trough (Nwajide 2005; Mode, 2004). The Benue Trough is a rift basin in Central West Africa that exceeds NNE-SSE from about 800km in length and 150km in width (Obaje, Wehnar, Scneider, Abubakar and

Jauro, 2003). It is a major structural feature in Southeastern Nigeria and was developed during the separation of South America and opening of South Atlantic Ocean at the site of RRR triple junction (Burke, Dassavague and Whiteman, 1972, Peters 1978, Olade, 1975). The geologic formations of Anambra Basin are Nkporo Formation, Mamu Formation, Ajali Formation, Nsukka formation Imo Shale, Ameki Formation and Ogwashi Asaba Formation (Reyment, 1964 and 1965; Offodile, 1975; Hoque, 1977; Ofoegbu, 1985; Agumanu, 1986; Nwajide, 2005). Most of these formations outcrop in the study area.

Table 1 is a generalized stratigraphic sequence of sedimentary rock in the study area.

Table 1: Generalized stratigraphic sequence in Okigwe Area (Modified from Reyment, 1965, Offodile 1975, Mode 2004 and Ofoegbu, 1985).

Age	Formation	Lithological Characteristics
Paleocene (55-65 m.y.)	Imo Formation (Imo Shale)	Blue to dark grey shales and subordinate sandstone member (Umuna and Ebenebe sandstone)
Maastricitian (65-68 m.y.)	Nsukka Formation	Alternating sequence of sandstone and shale with coal seams.
	Ajali Formation	Friable sandstone with cross bedding
Maastricitian (65-68 m.y.)		Alternating sequence of sandstone, siltstone, shale and claystone with coal seams
	Mama Formation	
Campanian (68-78 m.y.)	Nkporo Formation (Enugu Shale)	Shale and mudstone with sandstone lenses

The lateritic soil deposit in the study area were formed as residual soils by chemical weathering of the geologic formations in the study area.

Ajali Formation (Ajali sandstone) originated from continental depositional environment. Dominant mineral is likely to be kaolinite. Nsukka Formation and Mamu Formation are paralic, that is, consisting of sandstone and shale sequences. Shaley formations of most rocks originates from marine depositional environment and are likely to contain significant amounts of montmorillonitic clay mineral, a swelling clay mineral that will also cause the swelling of any soils that they are associated with (Reineck & Singh, 1975).

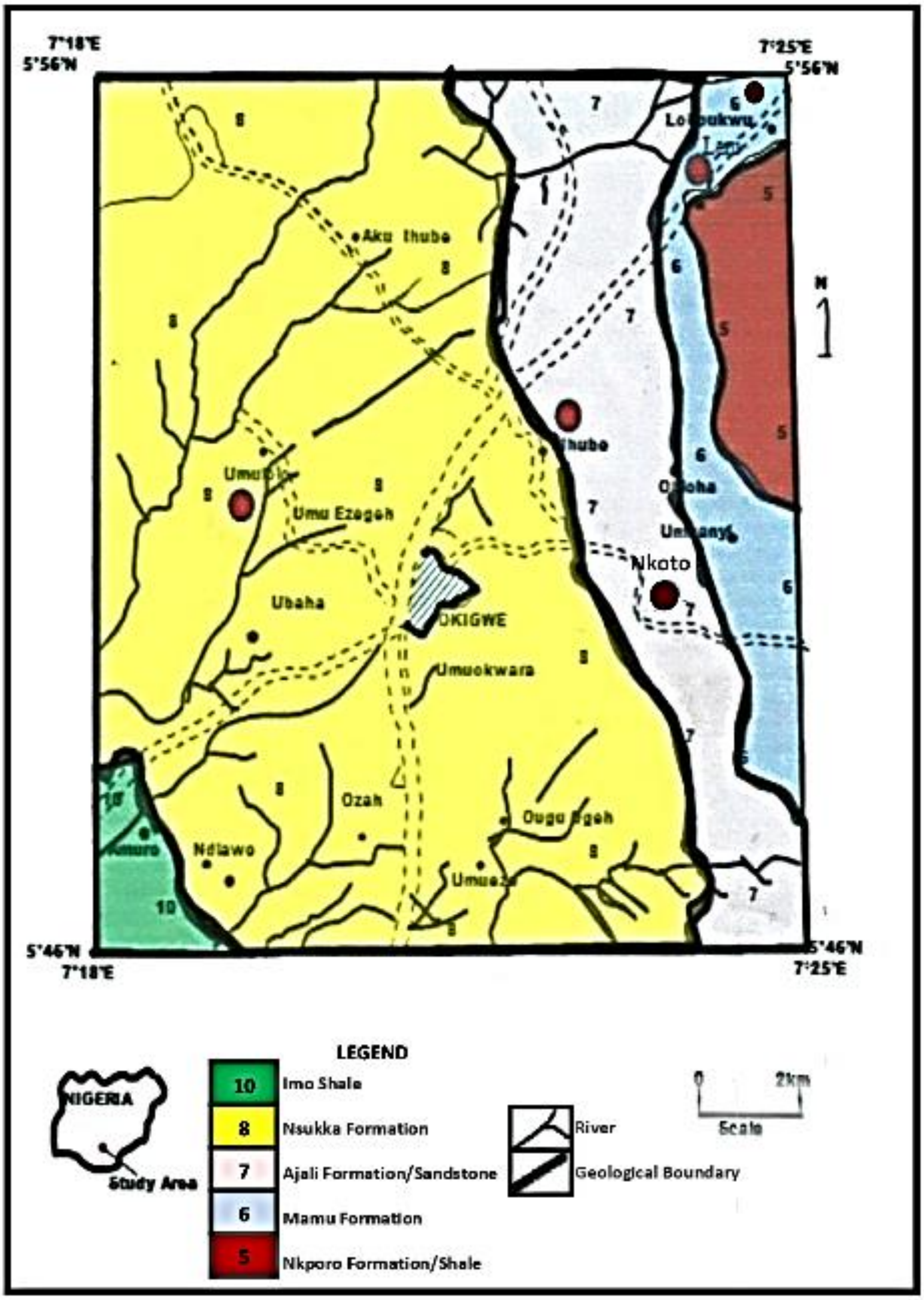

Fig. 1: Geological map of Okigwe Area and locations of soil sampling points (Adapted from Uduji et al., 1994)

3. Materials and Methods

3.1 Sample collection

The five (5) lateritic soil samples used in the study were collected from existing borrow pits used by construction companies as sources of laterites in Okigwe Area. The locations of the soil deposits were selected to represent lateritic soils derived from various geologic formations in the area (Fig. 1 and Table 2). One (1) sample was therefore collected from Umulolo to represent soil derived from Nsukka Formation, while two (2) samples were collected from Ihube-Okigwe and Nkoto- Okigwe (1each) to represent soils derived from Ajali Formation. The Two (2) samples collected from Leru and Lokpukwu (1 each) represented soils derived from Mamu Formation. The technique for sample collection followed that of Spangler and Hardy (1973). In each borrow pit, samples were collected at several sections (0.5m, 1m and 1.5m) mixed together (about 5 kg in all) and packed is polyethene bags for laboratory analyses. Table 2 shows description of sampling locations.

Table 2: Location of Sampling Points for Laterites Used in the Study.

Location	Coordinates Latitude	Longitude	km / Road	Geologic Formation
Umulolo (1)	$5^0 51'$N	$7^0 19'$E	Km 4, Okigwe-Arondizuogu Road	Nsukka Formation
Ihube-Okigwe (2)	5^0 52′N	7^0 22′E	Km 4, Okigwe – Enugu Expressway	Ajali Formation
Nkoto-Okigwe(3)	5^0 49′N	7^0 23′E	Km 2, Okigwe-Uturu Road	Ajali Formation
Leru (4)	5^0 52′N	7^0 24′E	Km 20, Okigwe-Enugu Express Road	Mamu Formation
Lokpukwu (5)	5^0 55′N	7^0 24′E	Km 22, Okigwe – Enugu Express Road	Mamu Formation

3.2 Laboratory tests

Some geotechnical tests were carried out on samples in the laboratory. These include Atterberg limits, linear shrinkage, particle – size analysis, compaction (Standard Proctor) and California Bearing Ratio (CBR). The geotechnical test were performed in accordance with the British Standard Institution, BS 1377 (1990), American Standard for Testing Materials (ASTM 2008a, and ASTM 2008b) at FUTO Institute of Erosion Studies (IES) Laboratory and Quality Control Laboratory of ARAB Contractors, Owerri, Nigeria.

4. Results and Discussion

4.1 Results

The results of geotechnical tests on the soil samples are shown on Table 3. Figures 2 and 3 are particle-size distribution curves of the soil samples and the plots of the soil samples on Casagrande Plasticity Chart, respectively.

Table 3: Summary of Geotechnical Properties of Lateritic Soils Derived from Various Geologic Formations in Okigwe Area.

Parameter	**Geologic formation/location**							**Federal Ministry of Works Standard (1970)**
	Nsukka Formation	**Ajali Formation (Ajali Sandstone)**			**Mamu Formation**			
	Umulolo (1)	Ihube – Okigwe (2)	Nkoto – Okigwe	Average	Leru (4)	Lokpukwu (5)	Average	
Liquid limit (%)	38.00	33.00	23.00	28.00	52.00	54.20	53.10	<36
Plastic limit (%)	27.70	22.70	13.60	18.15	31.60	36.60	34.1	-
Plasticity Index (%)	14.30	10.30	9.40	9.85	20.40	18.10	19.25	<12
Linear shrinkage (5)	8.30	5.00	4.60	4.80	8.90	9.10	9.00	<8
%Fines (<0.075mm)	36.10	19.90	19.70	19.70	43.00	36.70	39.83	<30
Coefficient of Uniformity (Cu)	18.50	16.30	7.51	11.91	14.40	8.67	11.54	>4
Max Dry Density (Mg/m^3)	2.10	2.04	1.92	1.98	1.90	1.96	1.93	>1.76
Opt. moisture content (%)	9.5	10.80	11.60	11.2	11.00	18.00	14.5	-
CBR (unsoaked) (%)	67	74	76	75	48	38	43	>80
CBR (soaked) (%)	22	29	29	29	27	22	25	>30

FUTOJNLS 2017 VOLUME- 3, ISSUE- 2. PP- 178 - 189

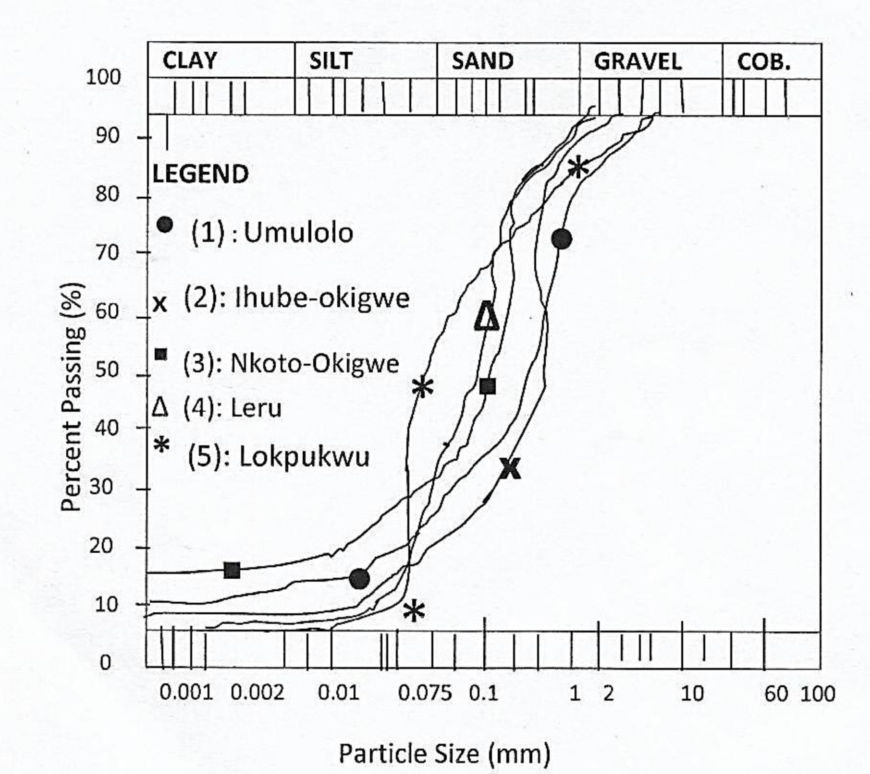

Fig. 2: Particle-size distribution curves of the studied soils

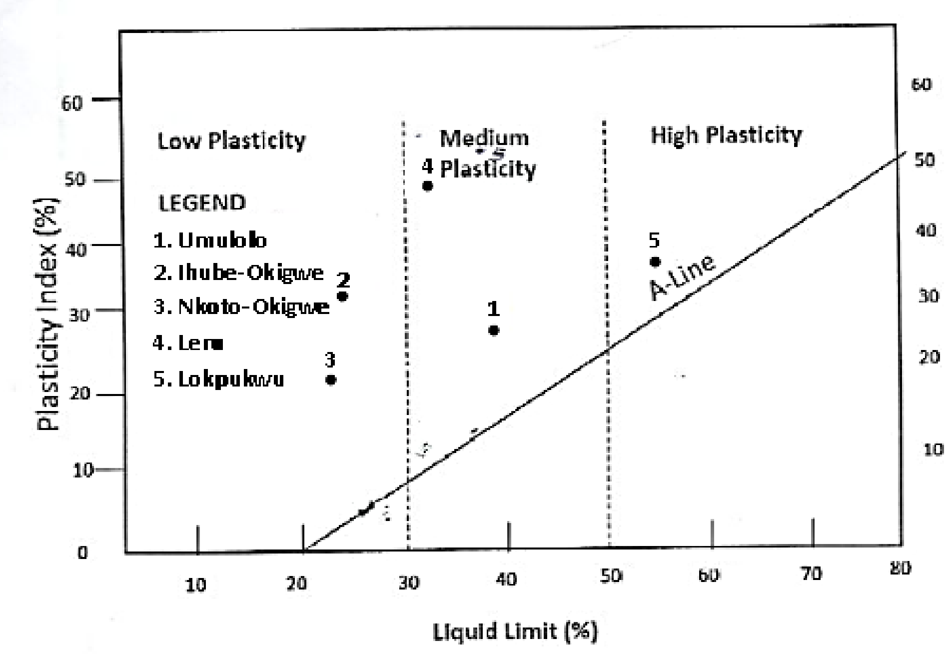

Fig. 3: Plots of the studied soils on Casagrande Plasticity Chart

4.2 Discussion

4.2.1 Particle-size Distribution Curves

From Table 3, the percentage of fines (<0.075 mm) passing No. 200 BS sieve are less than 30 % for samples from Ihube-Okigwe and Nkoto-Okigwe derived from Ajali Formation; but % fines are greater than 30 % for samples from Umulolo (representing soils derived from Nsukka Formation), and Lokpukwu and Leru (representing soils derived from Mamu Formation). On the basis of Federal Ministry of Works (FMW) (1970) standard, only soils derived from Ajali Formation have acceptable % fines (<30 %). Soils derived from Nsukka Formation and Mamu Formation have excess % fines that may reduce the strength of the compacted laterites (Matheis and Pearson, 1982; Singh, 2004). The particle-size curves of Fig. 2 are used to compute the Uniformity Coefficient (Cu) $\left(\frac{D_{60}}{D_{10}}\right)$ of the different soil samples (Table 3). All the soil samples have Cu values that are greater than 4.00, indicating that the soils are well-graded and can serve as very good road construction materials (Spangler and Handy, 1973). The well-graded nature of the soils makes them mechanically stable to perform satisfactorily as sub-base and base course materials.

4.2.2 Atterberg Limits

Table 3 also shows that only soils derived from Ajali Formation and collected at Ihube-Okigwe and Nkoto Okigwe satisfy the FMW standard for liquid limit (<36 %) plasticity index (<12 %) and linear shrinkage (<8 %). Soils derived from Nsukka Formation (and collected at Umulolo) and soils derived from Mamu Formation (and collected at Leru and Lokpukwu) do not satisfy the FMW standards for liquid limit plasticity index and linear shrinkage. They have very high values of these parameters. Low values of liquid limit and plasticity index in the soils are indications that the constituent clay mineral is the non-swelling kaolinite. When the liquid limits and plasticity index of the soils are high as in soils derived from Nsukka Formation and Mamu Formation, there is the possibility that swelling clay mineral like montmorillonite, may be contained in the soil. Similarly, soils derived from Nsukka Formation and Mamu Formation have unacceptable linear shrinkage values.

Plots of liquid limit against plasticity index (plasticity chart) of the results (Fig. 3) also confirm that soils from Ihube-Okigwe and Nkoto-Okigwe (Ajali Formation) have low plasticity, while soils from Umulolo and Leru/Lokpukwu (Nsukka Formation and Mamu Formation, respectively) have medium/high plasticity. Soils that have high plasticity characteristic have potential of constituting problem soils in engineering construction.

4.3 Compaction characteristics

The maximum Dry Density values of all the soil samples used in the study are within the range expected for such soils (when Proctor Standard is used) that are described as clayey sands (values >1.90Mg/m^3) (O' Flaherty, 1988) and they also satisfy the FMW standard (>1.76Mg/m^3).

4.4 California Bearing Ratio (CBR)

Results in Table 3 show that although soils derived from Ajali formation (Ajali sandstone) have the highest values of CBR (unsoaked and soaked: 74 % and 29 %), compared with values obtained for soils derived from Nsukka Formation (unsoaked and soaked: 67% and

22 %) and Mamu formation (unsoaked and soaked: 48 % and 27 %), none of the values satisfy the FMW standard/requirement of >80% (for unsoaked CBR) and >30% (for soaked CBR) for sub-base and base coarse materials. However, the soils are very good materials as fills in building foundations, dams and levees since the FMW requirement for such soil is CBR values of >15 %).

4.5 General observations.

On the basis of the geotechnical properties of lateritic soils derived from geologic formations in Okigwe Area that have been documented and discussed, soils derived from Ajali Formation may be said to be the best, followed by soils derived from Nsukka Formation and then, soils derived Mamu Formation. Ajali Formation comprise mostly sandstone while Mamu and Nsukka Formation comprise sandstone and shale. When shaly formation are decomposed, problem residual soils including expansive soils are also associated with such soils. Uduji et al, (1994) have confirmed the occurrence of expansive soils in Okigwe area (particularly in clayey soils derived from Mamu Formation).

However, these lapses or deficiencies (low CBR, high liquid limit, high plasticity index and high linear shrinkage) may be mitigated by treatment of the soil with appropriate percentages of cement, lime, bitumen and fly ash.

5. Conclusions

The geotechnical properties of five (5) lateritic soil deposits derived from 3 geologic formation 1 sample (Umulolo from Nsukka Formation); 2 samples (Ihube-Okigwe and Nkoto - Okigwe) from Ajali Formation; and 2 samples (Leru and Lokpukwu) from Mamu Formation were determined and the results evaluated in terms of the influence of the parent rock/geologic formation on the quality of the lateritic soils as road construction materials. The geotechnical properties used in the study include Atterberg limits (liquid limit, plastic limit, plasticity index), Linear shrinkage, particle-size grading, Maximum Dry Density (MDD) and Califonia Bearing Ratio (CBR). All the soil samples studied are generally well graded (Uniformity coefficient, Cu >4.00) which is a characteristic of good quality laterites used in road construction. All the soil samples also generally have low CBR values, that are not acceptable for sub-base and base course materials in road construction.

Comparison of the results with the standard specifications of Federal Ministry of Works for sub-base and base course materials (pavement materials: LL <36, PL <12, LS <8, % fines < 30, CBR (soaked) <30 % and CBR (unsoaked) <80 % show that only the lateritic soils derived from Ajali Formation and located at Ihube – Okigwe and Nkoto-Okigwe satisfy every aspect of the geotechnical properties except CBR values (test results less than the standard). Although they have the highest values compared with soils derived from Nsukka Formation and Mamu Formation. Lateritic soils derived from Nsukka Formation and located at Umulolo and lateritic soils derived from Mamu Formation and located at Leru and Lokpukwu do not satisfy plasticity and strength properties requirements (values of LL > 36 %, PI >12 %, % fines >30%, linear shrinkage >8 % and CBR soaked <30 % CBR unsoaked <80 %). They are therefore likely to deteriorate faster than soils derived from Ajali Formation when used as road pavement materials, for sub-base and base course. Lithologic characteristics of parent rocks/geologic formations from which the lateritic soils in Okigwe area were derived therefore influence the geotechnical properties of lateritic soils are hence their qualities as road construction materials. The major cause of the variation in their geotechnical properties is that the parent rock of Ajali Sandstone is mostly sandstone with continental origin while rocks of Nsukka formation and Mamu formation are alternating sandstone/siltstone and shale with continental and marine origins for sandstone and shale, respectively. Soils derived from rocks of marine origin have tendency to exhibit swelling properties because of their potentials to contain the swelling clay mineral, montmorinollite.

The quality of the lateritic soils may, however be improved by treatment/stabilization with sharp sand (mechanical stabilization) or cement/lime (chemical stabilization) to increase the CBR values of all the soils used in the study and in addition, reduce the liquid limit, plasticity index and linear shrinkage values of soils derived from Nsukka Formation and Mamu Formation.

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