GEOTECHNICAL AND GEOCHEMICAL CHARACTERIZATION OF LATERITIC SOIL DEPOSITS IN PARTS OF OWERRI, SOUTHEASTERN NIGERIA, FOR ROAD CONSTRUCTION

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Abstract

Some *geotechnical and geochemical properties of some lateritic soil deposits derived from Benin Formation in parts of Owerri, Southeastern Nigeria, were determined and used to evaluate the suitability of the laterites for road construction. Three lateritic soil samples were collected from Ihiagwa Mgbirichi and Umuagwo (in parts of Owerri) and subjected to some geotechnical (Atterberg limit, compaction, particles-size distribution and California Bearing Ratio) and geochemical tests (major oxide composition) in the Laboratory, Results of the study show that the lateritic soils derived from Benin Formation have an average liquid limit, plasticity index, maximum dry density, optimum moisture content, unsoaked CBR and soaked CBR values of 29.70%, 9.70%, 2.00Mg/m^3, 9.33%, 48% and 24.00%, respectively. The average silica/sesquioxide ratio of samples from the three locations is 1.49. On the basis of average silica/sesquioxide ratio, the soil can be classified as a lateritic soil. A comparison of the determined geotechnical properties with standard specifications of materials for roads by Federal Ministry of Works (liquid limit <36%, plasticity index <12%, maximum Dry Density >1.6Mg/m^3, unsoaked CBR >80% and soaked CBR >30%) show that the soils met every aspect of the geotechnical properties except the CBR values as good construction materials. Nevertheless, the soils can still be used as road construction materials if the CBR values are improved by stabilizing them with Ordinary Portland Cement.*

Keywords: ***Lateritic soil, Benin Formation, Anambra Basin and construction materials.***

1.0 Introduction

Lateritic soils are reddish brown residual soils that are formed by the chemical weathering of pre-existing rocks such as granite, shale, limestone, schist sandstone and gneiss (Gidigasu, 1976; Okeke et al., 2013). They are commonly formed in tropical climatic regions of the world. Over 85% of major oxides constituents of laterite is made up of SiO_2, Al_2O_3 and Fe_2O_3 (Adeyemi, 2002; Matheis and Pearson, 1982). The reddish brown colouration of these soils is due to their Fe_2O_3 contents. According to Bell (1993), lateritic soils may be defined on the basis of 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 2.0. When the ratios are greater than 2.0, the soils are classified as non-lateritic soils. Chemically, laterites and lateritic soils may be described as hydrous aluminium-iron oxide (Singh, 2004). The dominant clay minerals in most laterites and lateritic soils is kaolinite and since kaolinite has the least affinity for water among the clay minerals, when present in such soils will enable them exhibit moderate shrinkage on exposure to dryness and moderate expansion in the presence of water. Lateritic soils may also contain montmorillonite clay mineral. The presence of this clay mineral in such soils will cause the soil to swell when in contact with water and shrink when exposed to dryness, thus making them unsuitable as construction materials .Lateritic soils are widely used in the construction industry for road construction (highway sub-base and base-course materials) and fills (including dams, foundation fills and levees) (Gidigasu, 1976; Simon et al., 1973). 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). Their generally high strength, low compressibility characteristics and availability gives them an outstanding quality as road construction materials.

The study area, parts of Owerri, southeastern Nigeria lies between latitude 5°18^{1}N-5^{0}27^{1}N and longitude 6^{0}54^{1}E-7^{0}06^{1}E The area has a generally flat topography with neighbouring towns such as Nekede, Obinze, Eziobodo, Ohaji, Umuapu etc (Fig. 1). There are two distinct climatic 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 2,400mm (Nigerian Meteorological Agency, 2007).

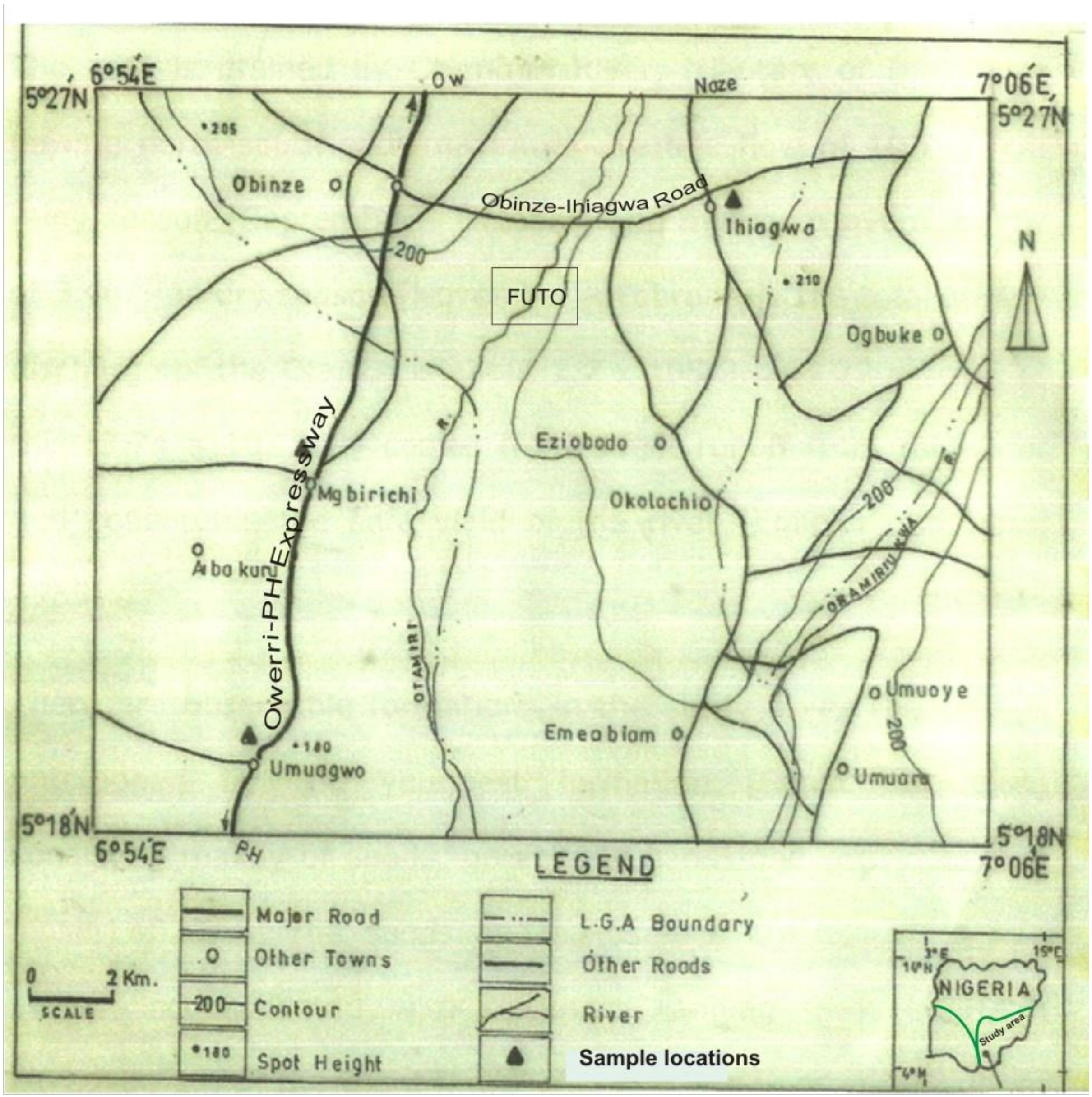

Fig 1: Location map of the study area (Parts of Owerri, Southeastern Nigeria)

In this study, the geotechnical and geochemical properties of some lateritic soil deposits derived from Benin Formation collected from Ihiagwa, Mgbirichi and Umuagwo were determined and the results used to evaluate their suitability as road construction materials.

2.0 Geology of the Study Area

The study area, parts of Owerri, is underlain by the Benin Formation, which consists of unconsolidated sandstone with lenses of clay (Onyeagocha, 1980). Benin Formation along with other sedimentary units/formations of Niger Delta Basin and Anambra Basin outcrop extensively in the study area and entire Imo State. These other sedimentary units/formations are shown in Table 1 and Fig. 2 (Reyment, 1965; Short and Stauble, 1967; Offodile, 1975;Ofoegbu, 1985; Okeke, 2001; Okeke and Agbasoga, 2001; Okeke et al., 2011).

Table 1: Generalized Regional Stratigraphy of Imo State (Reyment, 1965; Ofoegbu, 1985)

Formation	Age	Max-approx thickness (m)	Characteristics
Benin Formation	Recent – Miocene (0-25 m.y.)	2000	Unconsolidated yellow and white sandstones with lenses of sand/ clay
Ogwashi-Asaba Formation	Miocene-Oligocene (25-35 m.y.)	500	Unconsolidated sandstone with mudstones and lignite seams
Ameki Formation	Eocene (35-55 m.y.)	1460	Grey to green sandstones shales and thin limestone units.
Imo Formation	Paleocene (55-65m.y.)	1220	Blue to dark grey shales and sandstone members: Umuna and Ebenebe sandstone members.
Nsukka Formation	Maestrichitian (Upper Cretaceous (65-68m.y.)	350	Alternating sequence of sandstone and shales with coal seams.
Ajali Formation	Maestrichtian (Upper Cretaceous (68-75m.y.)	400	Friable sandstoe with cross bending and shale lenses.

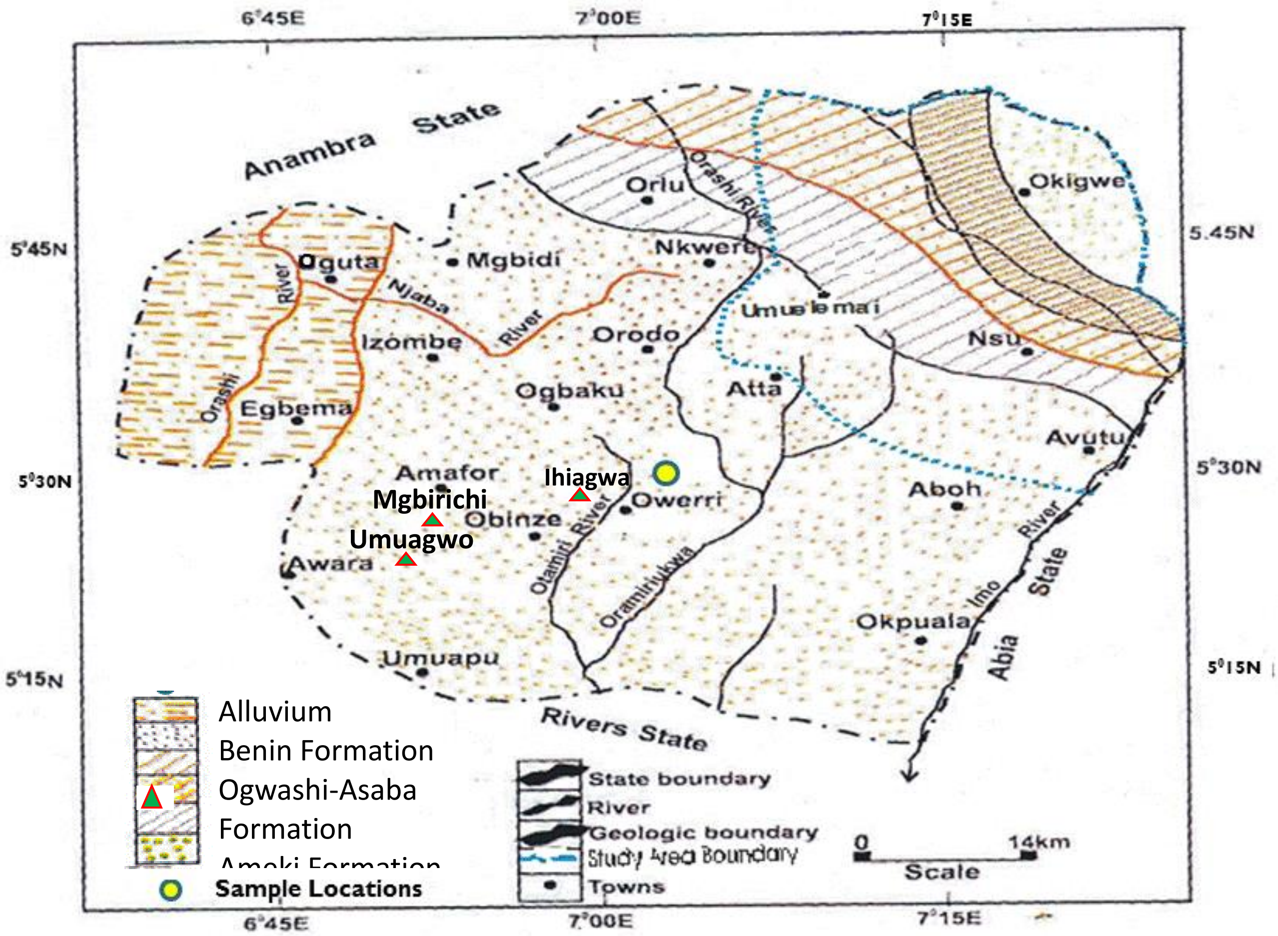

Fig 2: Geologic map of Imo State showing study area/sampling locations (Adapted from Okeke, 2001).

3.0 Materials and Methods

3.1 Sample collection

The three lateritic soil samples used in the study were collected from borrow pits that were used as sources of road construction materials in the study area. Two of these borrow pits are located along the Portharcourt-Owerri Expressway which was dug by Arab Contractors and the rest located at the Ihiagwa sand mines which was dug by local sand miners. All the three samples were derived from Benin Formation (Fig. 2). The samples were collected from Ihiagwa, Mgbirichi and Umuagwo, respectively (Fig.1). The technique for the sample collection followed those of Spangler and Handy (1973). In each borrow pit, samples were collected at several sections (depths of 1m, 1.5m and 2m) mixed together (about 5kg in all) and packed in polythene bags for laboratory analysis. Table 2 shows description of sampling locations.

Table 2: Description of sampling locations.

Towns	Borrow Pit/Sample No.	Sample Type	Location			Parent geologic formation
			Coordinates		Km/Road Owerri-PH Rd	
			Latitude	Longitude	Km/Chainage (CH)	
Ihiagwa	Borrow Pit 1 (1)	Soil	5^0 27'N	$7^0$06' E	Km or Chainage CH 21+400, Owerri-FUTO road	Benin Formation
Mgbirichi	Borrow Pit 2 (2)	Soil	$5^0$22' N	$7^0$38' E	CH 26+300, Owerri-Port Harcourt Road	Benin Formation
Umuagwo	Borrow Pit 3 (3)	Soil	5^0**18'** N	$6^0$54' E	CH 32+300 Owerri-Port Harcourt Road	Benin Formation

3.2 Laboratory tests

Some geotechnical and geochemical tests were carried out on the samples in the laboratory. These tests include Atterberg limits, compaction, (standard protor), particle-size distribution, California Bearing Ratio (geotechnical) and major oxide tests (geochemical). The geotechnical tests were performed in accordance with British Standard B.S 1377 (1990), Akroyd (1957) and Singh (1992); while the geochemical tests were carried out using the Atomic Absorption Spectrophotometry (AAS) (Loring and Ramtala, 1992).

4.0 Results and Discussion

4.1 Results

Tables 3 and 4 show summaries of geotechnical and Geochemical properties of studied soil samples, respectively. Figures 3 and 4 show the plots of the soils on Casagrande Plasticity Chart and grain-size distribution curves, respectively.

Table 3: Summary of geotechnical properties of lateritic soil deposits in parts of Owerri, SE Nigeria

Parameter	Location			
	Ihiagwa	Mgbirichi	Umuagwo	Average
% Fines	15.80	13.30	16.20	15.10
% Sand	72.20	80.70	77.80	76.90
% Gravel	12.00	6.00	6.00	8.00
Liquid limit(%)	31.00	26.00	32.00	29.70
Plastic limit(%)	19.70	19.40	20.80	19.67
Plasticity index(%)	11.30	6.60	11.20	9.7
Dry density(Mg/m^3)	1.77	1.85	1.84	1.82
Max dry density(Mg/m^3)	1.95	2.03	2.02	2.00
Optimum moisture content(%)	8.00	10.00	10.00	9.33
CBR (%) (unsoaked)	63	39	43	48
CBR (%) (soaked)	33	11	28	24

Table 4: Summary of geochemical properties of lateritic soil deposits In parts of Owerri, southeastern Nigeria

Major oxides	Ihiagwa (1)	Mgbirich (2)	Umuagwo (3)	Average
SiO_2 (Silica)(%)	37.6	34.6	36.1	36.1
Al_2O_3 (Alumina)(%)	27.4	25.4	25.10	26.0
Fe_2O_3 (Haematite)(%)	25.0	22.0	24.2	24.0
CaO(%)	0.27	0.25	0.24	0.25
MgO(%)	0.20	0.17	0.20	0.19
Silica/sesquioxide ratio	1.47	1.49	1.52	1.49

4.2 Discussion

4.2.1 Geotechnical properties

4.2.1.1 Atterberg limits and clay mineralogy

Table 3 shows the summary of the geotechnical properties while Fig 3 is the Casagrande Classification Chart of the studied soils. The soil sample obtained from Ihiagwa has a liquid limit value of 31.00%. The soil sample obtained from Umuagwo has a liquid limit value of 32.00% and plasticity index value of 111.20% while that obtained from Mgbirichi has 26.00% and 6.60% respectively. A comparism of these values with standard specifications of materials for roads by Federal Ministry of Works (1970), (liquid limit <36% and plasticity Index <12%), the samples obtained from the three locations are suitable for road construction as sub-base and base-course materials. According to Fig 3, all the samples plot between low and medium plasticity and this may be attributed to the presence of high amount of kaolinite in the soil. The low values of liquid limit and plasticity Index of the studied soils are indicative of the absence or very low contents of montmorillonite clay minerals in the soils. The value of the Plasticity Index of the samples are less than 12%, and thus may be classified as having low swelling potentials (Ola, 1981).

In the absence of x-ray diffraction analysis, the studied soils were plotted on the Bain's chart for identification of clay (1971). All the soils plotted on the D-zone (Fig 4), which indicates that kaolinite is the dominant clay mineral in the soils. Since kaolinite has the least affinity for water, among the clay minerals, the studied soils would exhibit moderate shrinkage on exposure to dryness and moderate expansion in the presence of water.

X-ray diffraction analysis of the soils will be necessary to confirm the clay mineral constituent of the soils. Rapid deterioration or failure of roads built with laterites may arise if the soils have high swelling clay components (montmorrilonite) which are sensitive to moisture changes (expansiveness and/or low strength compaction and CBR) values and these type of soils are referred to as problematic soils (Gidigasu, 1973).

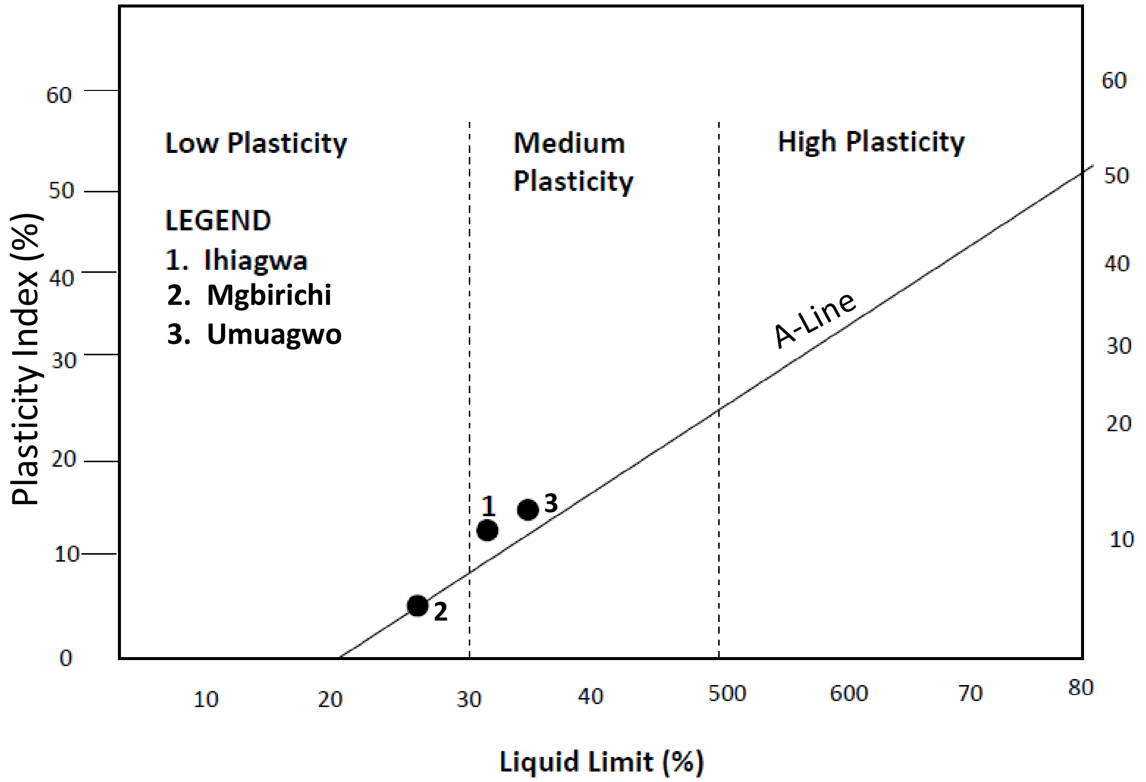

Fig 3: Plot of the studied soils on Casagrande Plasticity Chart (Adapted from Casagrande, 1943)

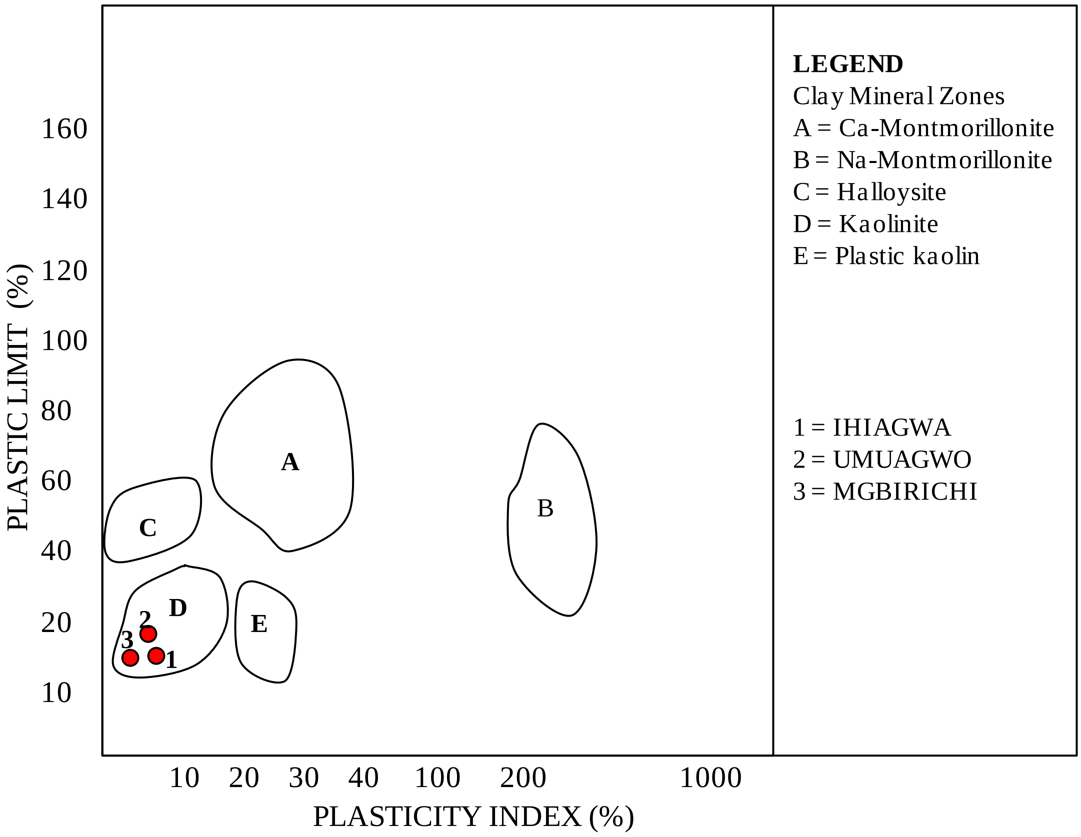

Fig 4: Clay mineral classification chart (Adapted from Bain, 1971)

4.2.1.2 Compaction characteristics

The soil sample derived from Ihiagwa has a maximum Dry Density (MDD) of 1.95Mg/m^3 and an Optimum moisture content (OMC) of 10.0% while that of Mgbirichi are 2.03Mg/m^3 and 10.0%, respectively. The maximum dry density of soil from Umuagwo is 2.02 Mg/m^3 and optimum moisture content is 8.0%. (Table 3). Comparing these values with the standard specifications of materials for road by Federal Ministry of Works (1970), Maximum Dry Density (MDD) > 1.6Mg/m^3 and Optimum Moisture Content (OMC) <12%), all the soil samples satisfy the compaction characteristics standard and as such are qualified to be used as sub- base and base-course materials in road construction.

4.2.1.3 Particle-size distribution

The soil samples have a high amount of sand (72.20-80.70%), a relatively high content of fines (13.30-16.20%) and low content of gravel (6.00-12.00%) (Table 3). The relatively high content of fines (silt and clay) in the lateritic soil samples have both positive and negative implications. The clay fractions will act as binders when the lateritic soils are compacted during road construction (Gidigasu, 1976). They may also be moisture sensitive particularly if montmorillonite clay mineral is present in the soils.

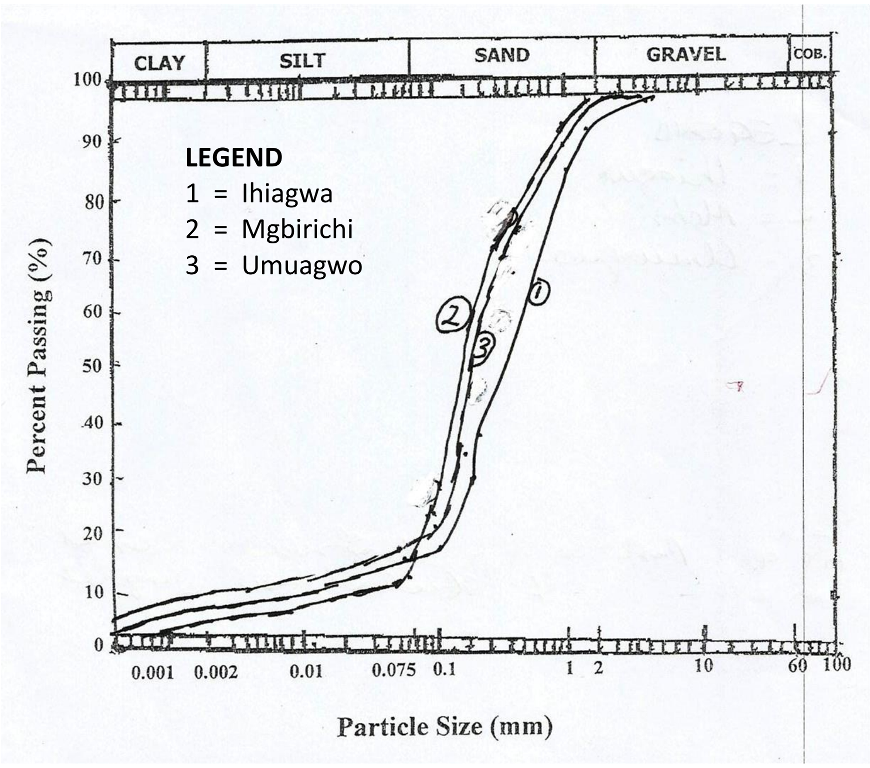

Fig. 5: Particle-size distribution curves of the studied soil samples

4.2.1.4 California Bearing Ratio (CBR) values

According to Table 3, lateritic soil sample obtained from Ihiagwa has a CBR (soaked and unsoaked) values of 33% and 63%, that of Umuagwo is 28% and 43% while that of Mgbirichi is 11% and 39% respectively. Comparing these values with standard specifications of materials for roads by Federal Ministry of Works (1970) (CBR > 80% for Unsoaked and > 30% for Soaked), all the samples do not satisfy the CBR standard and as such are not qualified to be used as road construction (Sub- base and base-course) materials. The low CBR values of the lateritic soil samples may be attributed to the presence of relatively high amount of fines in the soils. Mechanically, the CBR values or the Bearing capacity of the soils can be improved by stabilizing them with sand to reduce the influence of fine grained particles on the roads built with them. Also, the soils can be stabilized with ordinary Portland cement (addition of 5-8% of cement by weight of dry soil to the soil) to increase their bearing strength. (Ingles and Metcalf, 1972).

4.2.2 Geochemical properties

Table 4 shows the summary of the geochemical properties of the studied soils. On the basis of silica/sesquioxide ratio (Gidigasu, 1973; Bell, 1993), the soils can be classified as lateritic soils because the average value of the silica/sesquioxide is 1.49. Bell (1993) has suggested that the ratio of the silica/sexquioxides of iron (Fe^{3+}) and aluminium (Al^{3+}) molar ratio for the classification of soils. He classified soils with molar ratios less than 1.33 as true laterites, those with ratios between 1.33 and 2.0 as lateritic soils and those greater than 2.0 as non-lateritic soils.

According to Gidigasu (1976) and Bell (1993) the equation for computation of silica/sesquioxide ratio is given below:

Silica/sesquioxide molar ratio =

$$\frac{\frac{\%\ \text{of}\ SiO_2}{\text{Mol.weght of}\ SiO_2}}{\frac{\%\ \text{of}\ Al_2O_3}{\text{Mol.weight of}\ Al_2O_3} + \frac{\%\ \text{of}\ Fe_2O2_3}{\text{Mol.weight of}\ Fe_2O2_3}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

5.0 Conclusions

Lateritic soil deposits derived from Benin Formation in parts of Owerri, southeastern Nigeria are being used in road construction projects in the study area. All the studied soil samples collected from Ihiagwa, Mgbirichi and Umuagwo have well-graded particles-size distribution curves and low/medium plasticity which are some of the aspects of good quality laterites used for construction of roads. Generally all the soils meet the standard specifications in terms of geotechnical properties apart from the aspect of CBR strength requirements for good quality road construction materials. The CBR values (both soaked and unsoaked) of all the soils are not within (below specified values) the acceptable limits for good quality lateritic soils used in road construction. Their low CBR values may be improved (increased) if they are stabilized with Ordinary Portland Cement. On the basis of their silica/sesquioxide molar ratios, the soils can also be classified as lateritic soils.

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References

Adeyemi, G.O., (2002); Geotechnical properties of lateritic soils, developed over quartz schist in Ishara area, southwestern Nigeria. Journal of Mining and Geology, **38**(1), pp.65-69.

Akroyd, T.N.W., (1957). Laboratory Testing in Soil Engineering. Soil Mechanics Ltd. London.

Bain, J.A (1971) A plasticity chart as an aid to the identification and assessment of industrial clays. Clay minerals, **9**(1) pp. 1-7

Bell, F.G., (1993); Engineering Geology, Blackwell Scientific Publications, Oxford, London. 359p.

British Standards (BS) 1377, (1990). Specification for Roads and Bridges in Nigeria. 2, pp. 137-275.

Casagrande, A., (1943); Research work on the Atterberg Limit of soil/rock materials, **13**(8) pp. 121-136

Federal Ministry of Works, (1970); Specification for roads and bridges in Nigeria, 2, pp. 137-139.

Gidigasu, M.D., (1973); Review of identification of problem lateritic soils in highway engineering. Transport Research Board, Washington 497p.

Gidigasu, M.D., (1976). Laterite Soil Engineering: Elsevier Scientific Publishing Company, Amsterdam 749p.

Ingles, O.G. and Metcalf, J.B., (1972). Soil Stabilization: Principles and Practices. Butterworths Pty. Limited, Melbourne. 509 p.

Loring, D.H. and Ramtala, R.T, (1992). Manual for geochemical analysis of marine sediments and suspended particulate matter. Earth Science Rev. 32, pp. 235-283.

Matheis, D. and Pearson, M.J., (1982). Mineralogy and geochemical dispersion in lateritic soil profile of Northern Nigeria. Chemical Geology, Elsevier, Amsterdam. **35**(1&2), pp. 129-145.

Nigerian Meteorological Agency (2007). Rainfall Data in Nigeria. Federal Ministry of Aviation, Abuja, Nigeria.

Offodile, M.E (1975). A Review of the Cretaceous of the Benue Valley. In: Geology of Nigeria (C.A Kogbe, ed) Elizabethan Publishing Company Lagos, Nigeria, pp. 319-330

Ofoegbu, C.O (1985). A review of geology of Benue Trough, Nigeria J.African Earth Science, 3, pp. 283-291.

Okeke, O.C (2001). Assessing the Sustainability of Aggregate Production in Imo State, Nigeria. J.Mgt.Technol. 3, pp. 183-189.

Okeke, O.C and Agbasoga J.C. (2001). Evaluation of Ihiagwa Gravel Deposit as Aggregates for Concrete and Highway Pavements. J. Mining and Geology, **37**(1), pp. 77-84.

Okeke, O.C., Ezeoke, E.I. and Onuoha B.O. (2011). Geotechnical Evaluation of Some Lateritic Soil Deposits in parts of Anambra Basin Southeastern Nigeria, for road construction. Int. Journal of Environmental Science, **7**(2), pp. 108-115.

Okeke, O.C., Ogbunyiba,O.O. and Chukwujekwu, D. (2013). Geotechnical Evaluation of Lateritic Soil Deposits in parts of Abuja (Nigeria), for Road Construction. International Journal of Environmental Issues, **10**(1&2), pp. 148-160.

Ola, S.A. (1981). Mineralogical properties of some Nigerian residual soils in relation with building problems. Eng. Geology, 15, pp. 1-13.

Onyeagocha, A.C. (1980). Petrography and Depositional Environment of Benin Formation. Journal of Mining and Geology, **17**(2), pp. 147-151.

Reyment, R.A., (1965); Aspects of the Geology of Nigeria. University of Ibadan Press, Ibadan, Nigeria,149p.

Short, K.C. and Stauble A.J. (1967). Outline Geology of Niger Delta. AAPG Bulletin, 57, pp. 761-779.

Simon, A.B., Giesecke, J. and Bidlo, G., (1973). Use of Lateritic Soils for Road Construction in North Dahomey, Engineering Geology, Amsterdam, 7, pp. 197-218.

Singh, A. (1992) Modern Geotechnical Engineering. 3rd Edition, CBB Publishers and Distributors, New Delhi, India, 540p.

Singh, P., (2004). Engineering and General Geology (7th Edition) S.K. Kataria and Sons, Delhi, India. 590p.

Spangler, M.G. and Handy R.L. (1973). Soil Engineering (3rd Edition) Harper and Row Publishers, New York.

Thagesen, B., (1996). Highway and Traffic Engineering in Developing Countries. E. & FN Spon. London 248p.