GEOTECHNICAL AND GEOCHEMICAL CHARACTERIZATION OF LATERITIC SOIL DEPOSIT DERIVED FROM AJALI SANDSTONE IN IHUBE-OKIGWE, SOUTHEASTERN NIGERIA FOR ROAD CONSTRUCTION

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ABSTRACT

This work was carried out to evaluate the quality of laterite used for road construction in southeastern Nigeria in terms of its geochemical and geotechnical characteristics. The samples used in this study were collected from Ihube-Okigwe, which was formed as a result of chemical weathering of Ajali sandstone, which geologically lies within the Anambra Basin. Two samples were collected 5km apart and subjected to some geotechnical tests which includes Atterberg limits, grain size analysis, compaction and California Bearing Ratio (CBR) as well as geochemical analysis in the laboratory. Results of the study show that the lateritic soils derived from Ajali Sandstone Formation have average liquid limit, plasticity index, maximum dry density, optimum moisture content, unsoaked CBR and soaked CBR values of 23%, 9.4, 1.92mg/m^3, 11.6%, 74% and 29% respectively. Comparison of the values of the determined geotechnical properties with standard specifications of materials for road construction by Federal Ministry of Works (1970) (liquid limits <36%, plasticity index <12%, unsoaked CBR >80% and soaked CBR >30%) shows that the studied soils do not meet the requirements for standard CBR values (soaked and unsoaked) but the bearing capacity can be improved by adding Ordinary Portland Cement. The results obtained from the grain size analysis shows that the studied soils are well graded having an average coefficient of uniformity of 17.4. The major oxides measured include: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, MnO, K_2O, Na_2O, TiO_2 and P_2O_3. Results obtained from the geochemical analysis shows that the soils have a silica/sesquioxide molar ratio of 1.6 which classifies it as a lateritic soil. Generally, lateritic soils derived from Ajali Sandstone Formation in the Anambra Basin in southeastern Nigeria are suitable for road construction.

Keywords: lateritic soil, Ajali Sandstone Formation, Anambra Basin and road construction.

INTRODUCTION

Lateritic soils are reddish-brown residual soils that are formed by chemical weathering of pre-existing rocks such as granites, gneisses, Schists, Shales, Sandstones, limestones, etc. They are commonly formed in tropical climatic region of the world. Over 85% of major oxide constituents of the rock is made of SiO_2, Al_2O_3 and Fe_2O_3 (Adeyemi, 2002). The reddish – brown colour of lateritic soils is due to their Fe_2O_3 contents.

Lateritic soils may be defined on the basis of molecular ratio of silica (SiO_2) to Sesquioxides (Fe_2O_3 , Al_2O_3) (Bell, 1993). In Laterites, the ratios are less than 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 tropical soils. Chemically, laterites and lateritic soils may be described as hydrous aluminum-iron oxide (Singh, 2004). The dominant clay minerals in most laterite 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. Laterites and lateritic soils may also contain montmorillonite and illite clay minerals. The presence of montmorillonite in such soils will cause them to swell in presence of water and shrink on exposure to dryness, thus making them unsuitable as engineering materials.

Lateritic soils are widely used in the construction industry as materials for road construction (highway sub-grade and sub-base materials) and foundation fills (including dams and levees) (Gidigasu, 1976). They are generally well-graded with mechanically stable particle size distribution which enables them to perform satisfactorily as sub-grade and sub-base materials in road construction (Thagesen, 1996). Their outstanding quality as road construction materials is due to their generally high– strength, low –compressibility characteristics and availability.

The major towns in the study area are Okigwe, Ihube, Obiaha and Leru (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 1,500mm

(Nigerian Meteorological Agency, 2007). In this study, the geotechnical and geochemical properties of two lateritic soil deposits derived from Ajali Sandstone formation of the Anambra Basin are determined and evaluated for their suitability as engineering construction materials. The properties used in this study include Atterberg limits, compaction, particle size distribution, California Bearing Ratio (CBR) and chemical test for 10 major oxides.

GEOLOGY OF THE STUDY AREA

Ihube-Okigwe in Imo State is geologically within the Anambra Basin, which constitutes a major depocenter of clastic sediments and deltaic sequences (Nwajide, 2005). This basin is located in the southern portion of Nigeria and bounded by the Lower Benue Trough to the East and the Basement Complex of the southwestern Nigeria to the west (Fig. 1). The origin of the Anambra basin is closely related to the evolution of the Benue Trough to the effect that Abakaliki sector was folded and ulifted while the Anambra platform experienced subsidence and resting unconformably on the Precambrian Basement Complex. The stratigraphic succession of the Anambra basin in the study area is shown in Table 1.

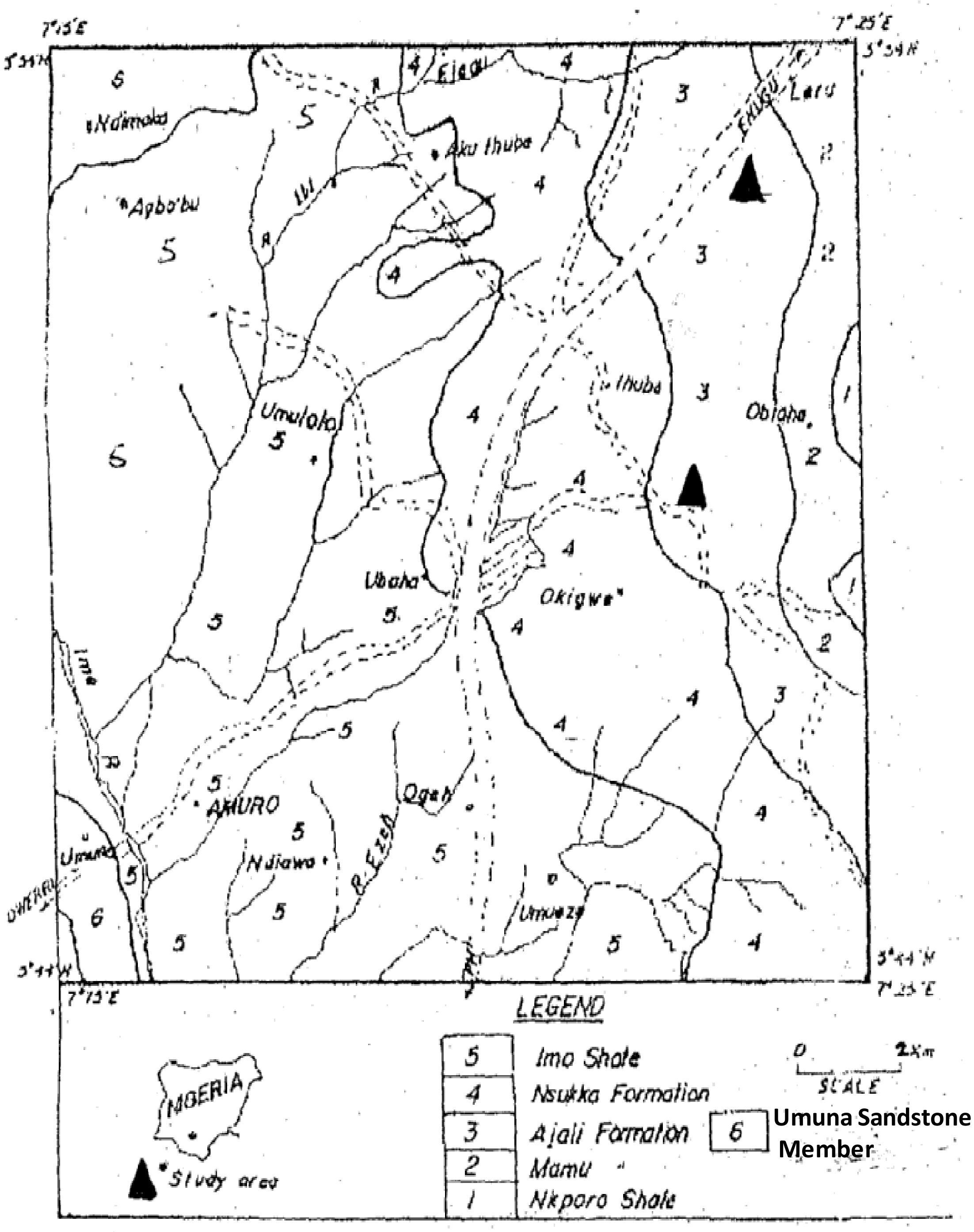

Fig.1: Geologic and Location Map of Amuro-Okigwe and environs (Adapted from International Journal of Scientific Innovations, Volume 4, Number 2, 2012)

Table 1: Stratigraphic Sequence in Anambra Basin (Modified from Nwajide, 2005)

<table>
<tr><th>Age</th><th>Basin</th><th colspan="7">Stratigraphic Units</th></tr>
<tr><td>Oligocene-Recent</td><td rowspan="3">Niger Delta</td><td colspan="7">Ogwashi-Asaba Fm</td></tr>
<tr><td>Eocene</td><td colspan="7">Ameki/Nanka Fm/Nsugbe Sandstone (Ameki Group)</td></tr>
<tr><td>Thanetian</td><td colspan="7">Imo Formation</td></tr>
<tr><td>Danian</td><td rowspan="4">Anambra Basin</td><td colspan="7">Nsukka Formation</td></tr>
<tr><td rowspan="2">Maastrichtian</td><td colspan="7">Ajali Formation</td></tr>
<tr><td colspan="7">Mamu Formation</td></tr>
<tr><td>Campanian</td><td>Nkporo Fm</td><td>Nkporo Shale</td><td>Enugu Fm</td><td>Owelli Ss</td><td>Afikpo Ss</td><td>Otobi Ss</td><td>Lafia Ss</td></tr>
<tr><td>Santonian</td><td>Southern Benue Trough</td><td colspan="7">Agwu Formation</td></tr>
</table>

MATERIALS AND METHODS OF ANALYSIS

Field Study And Sample Collection

The sample used for analysis in this study was collected from a borrow pit along Enugu-PH Expressway, near Ihube and Okigwe area. The borrow pit was dug by setraco construction company, from which lateritic soils are collected for the construction of the Expressway. At the location, the top of the soil was hardened which may be as a result of long-term exposure to the atmosphere. Before collecting the sample, the top of the soil was scrapped off with the aid of a shovel to remove the top soil which has been oxidized, so that fresh soil samples could be collected. Two samples were collected, each 5km apart and stored in bags prior for analysis. Caution was taken in order not to include organic matters surrounding the borrow pit by removing them before sample collection. Table 2 shows distribution of sampling locations.

Laboratory Analysis of Samples

The methods/procedures used in conducting the various tests are the standard procedures as stipulated by the British standards (BS 1377: 1990), Akroyd (1957) and Singh (1992). The chemical tests were carried out using X-ray fluorescence spectrometry.

Soils used for engineering purposes are affected by construction activities which are generally near surface or superficial soil deposits. The suitability of soils for a particular purpose depends on one or more of its engineering properties and these properties are determined through the use of physical characteristics and their inter-relationship. Some of the geotechnical and chemical properties of laterites evaluated in the laboratory during the course of this study include;

i. Atterberg limits
ii. Compaction test
iii. Grain size analysis
iv. California Bearing Ratio
v. Chemical test for 10 major oxides (Si_2, Al_2O_3, Fe_2O_3, K_2O, Na_2O, MgO, MnO, CaO, TiO_2 and P_2O_5).

The average results for the two samples were obtained during analysis and used for statistical treatment, computation and interpretation.

Table 2: Shows description of Sampling Locations

Towns	Coordinates		Parent geologic formation
	Latitudes	Longitudes	
Sample 1 Ihube-Okigwe	N05^0 53.786^1	E007^0 23.719^1	Ajali formation
Sample 2 Ihube-Okigwe	N05^0 50.531^1	E007^0 23.325^1	Ajali formation

RESULTS AND DISCUSSION

Table 3: Shows summary Data used in plotting particle size distribution of the soils

B.S. Sieve Size (mm)	Sample 1 % Passing	Sample 2 % Passing	Average % Passing
4.75	100.00	100.00	100.00
2.36	99.60	99.58	99.60
1.18	94.50	94.70	94.60
0.60	81.40	81.80	81.60
0.425	72.20	70.20	71.20
0.150	29.50	27.30	28.40
0.075	18.70	1.90	19.20
<0.075	-		

Table 4: Shows the chemical composition of the soils

Major Oxides	Sample 1 Values (%)	Sample 2 Values (%)	Average Values (%)
SiO_2	37.67	39.53	38.60
AL_2O_3	31.05	29.03	30.04
Fe_2O_3	18.08	16.50	17.29
K_2O	1.70	2.02	1.86
Na_2O	4.08	3.60	3.84
MgO	2.98	3.00	1.99
MnO	0.06	0.04	0.05
CaO	5.70	6.10	5.90
TiO_2	0.52	0.66	0.59
P_2O_5	0.04	0.02	0.03

TABLE 5: Summary of The Result of the Laboratory Analysis Carried out on the Soil Samples from Ihube-Okigwe Area, Imo State.

PARAMETERS	VALUES
Liquid limit (%)	23.0
Plastic limits (%)	13.6
Plasticity Index (%)	9.4
% of Gravel	0
% of Sand	80.8
% of fines (silt and clay)	19.2
Coefficient of uniformity (CU)	17.4
Maximum dry density (mg/m^3)	1.92
Optimum moisture content (OMC) (%)	11.6
CBR (soaked) (%)	29
CBR (unsoaked) (%)	74
Silica/sesquioxide ratio	1.6

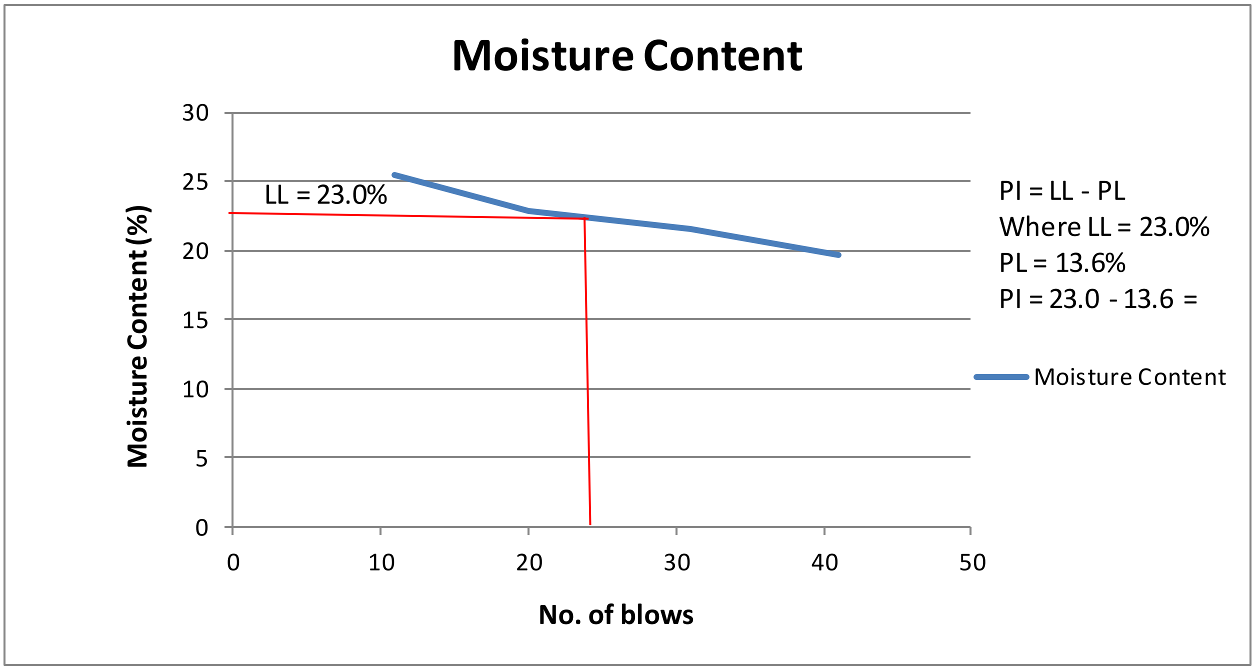

Fig. 2: Showing a graph of moisture content (%) against no. of blows.

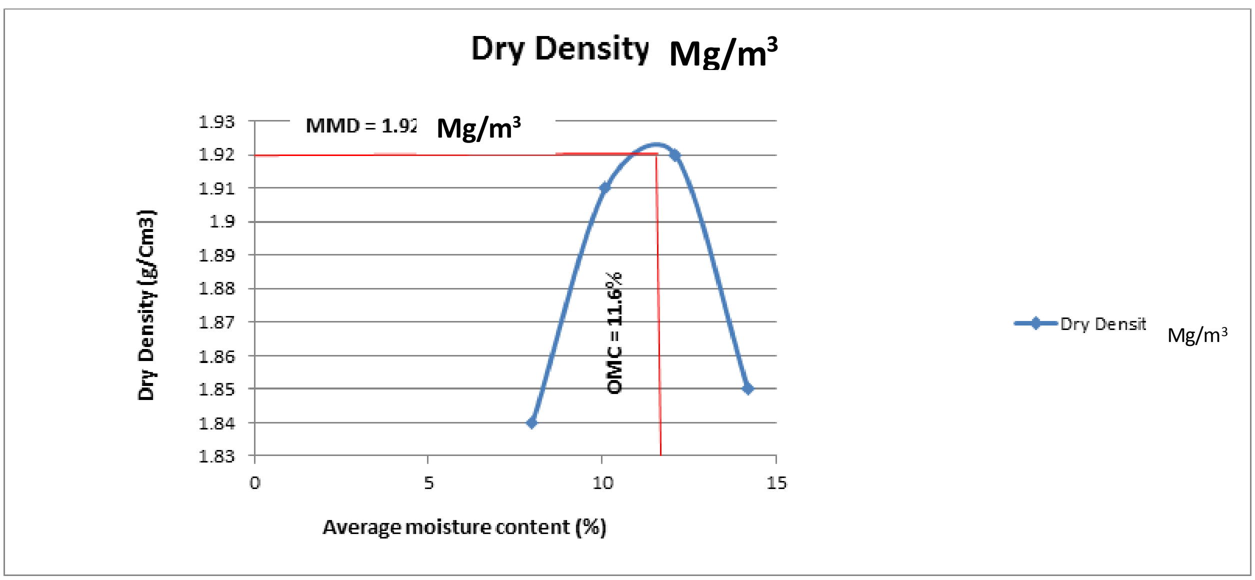

Fig.3: A graph of dry density (Mg/m^3) against average moisture content (%).

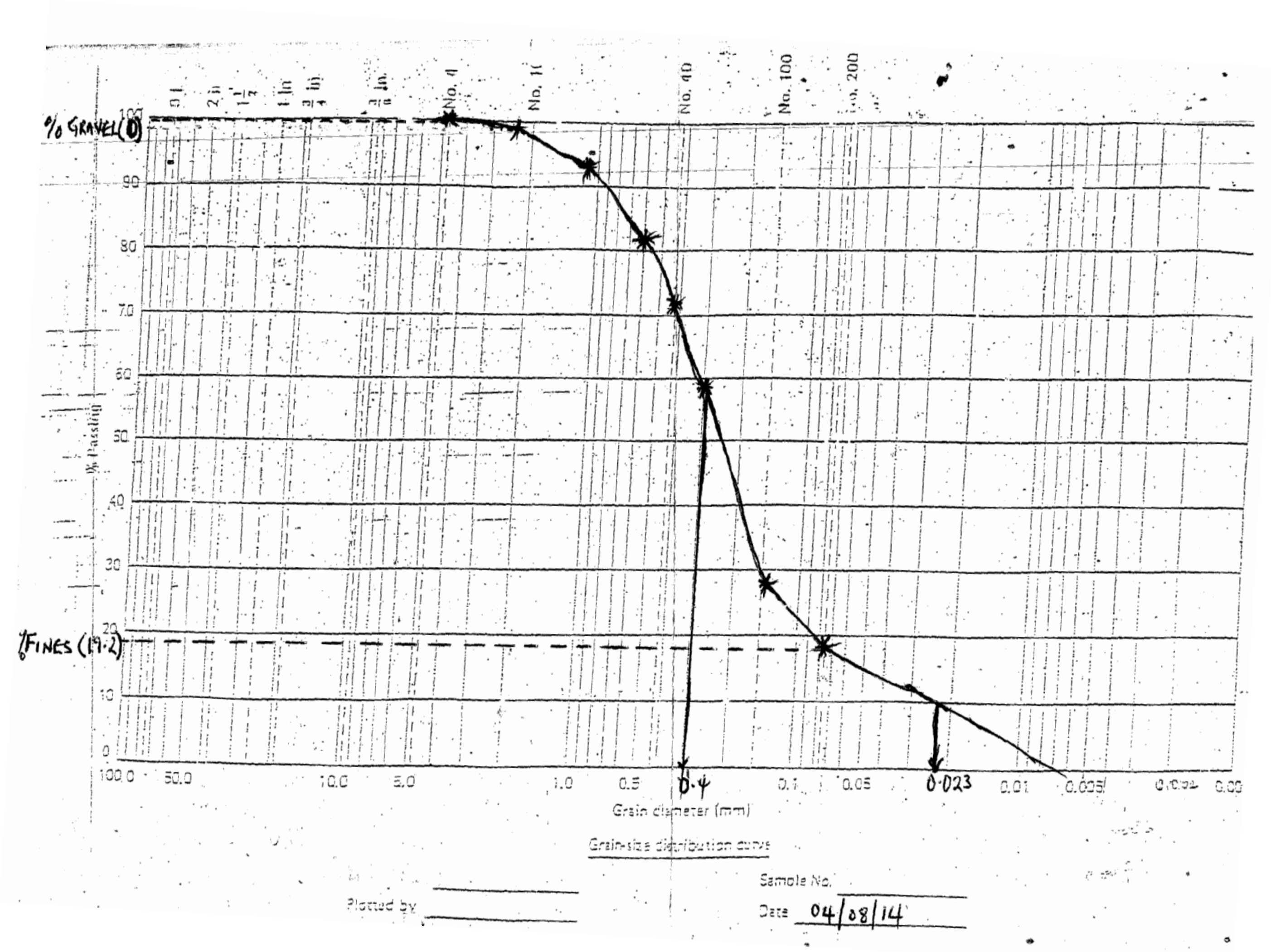

Fig.4: A graph of percentage passing against grain diameter (mm)

$\% \, of \; Gravel \; = \; 0\%$

$\% \, of \; Fines \; (Silt \; \& \; Clay) \; = \; 19.2\%$

$\therefore \; \% \, of \; Sands \; = \; 100 - 19.2 - 0 \; = \; 80.8\%$

$$Coefficient \; of \; uniformity \; = \frac{D_{60}}{D_{10}} = \frac{0.4}{0.023}$$

$$= 17.39$$

$$\cong 17.4$$

Geotechnical Characteristics

Atterberg Limits

The Atterberg limit is simply, the moisture content of a soil at a critical state and plasticity index. The pressure of water in fine grained soil can affect its engineering behavior. Therefore, the amount of water that is present in a soil is an important property to note before it is used for engineering purposes. The plastic characteristics of a soil is an important factor employed in the selection of lateritic. Soils both for highway construction (i.e as sub-grade and Base-course materials and for foundation filling. Excessive plasticity often leads to waviness which is a type of road failure that results from the plastic flow of wet soils upon the application of axle load.

Figure 2 shows the plot of the average moisture content (%) against the number of blows. Considering the plot, the liquid limit has the value of 23% and the plasticity index value of 9.4%. The specifications of the Federal Ministry of Works (1970) on the use of laterites as sub-grade and base-course materials for road construction recommends liquid limit <36% and plasticity index <12% respectively. A comparison of the determined liquid limit and plasticity index of the studied soils with the standard specifications above, shows that the lateritic soils derived from Ajali formation in the study area (Fig. 1) is suitable for road construction (as sub-grade and base – course materials) and foundation filling. The value of the plasticity index of the studied soils is less than the recommended upper limit of 25 for plasticity index of sub-base materials for road construction in tropical Africa by the French [Simon et al., (1973)]. Thus, would exhibit low swelling potential during the wet season (Ola, 1982). The low plasticity index and liquid limit is an indication of the presence of high amount of kaolinite and absence or very low content of montmorillonite in the soils.

Compaction Test

When the compaction characteristics of a soil are known, it is possible to prepare samples in the laboratory at the same dry density and moisture content as that likely to be attained after compaction in the field. These soils can be subjected to analyses and result derived from these analyses can enable the stability, deformation and other characteristics to be assessed. The relationship between the dry density and moisture content of a soil subjected to a particular compactive effort provides reference data for the specification and control of soil placed as fillings or embankment.

Figure 3 shows a plot of the average dry density (mg/m^3) against the average moisture content (%) of the soil samples. This plot shows that the studied soils have an average maximum dry density (MDD) of 1.92 mg/m^3 and optimum moisture content (OMC) of 11.6%. The lower maximum dry density and optimum moisture content exhibited by the studied soils may be attributed to their lower affinity for water and low swelling potential.

Grain Size Analysis

The result of the grain size analysis (Table 3) and the plot of the percentage of particles passing against the particle size (Figure 4) of the studied soil. This plot shows that they have an average coefficient of uniformity (CU) of 17.4 which classifies the soil as well graded. The soils contain a high amount of sands of about 80.8%, 19.2% of fines (silt and clay) and 0% of gravel. The relatively high content of fines in the soils have both positive and negative implications. The clayey materials will act as a binder when the lateritic soils are compacted during road construction (Gidigasu, 1976). They may also be moisture sensitive, particularly if there is montmorillonite clay minerals in the soils. According to Matheis and Pearson (1982) and Singh lateritic soils is kaolinite. When an axial load is applied on the soil, it will exhibit a high degree of compaction because of the presence of high amount of sands, a relatively high content of fines and the absence of gravel in them.

California Bearing Ratio

The California Bearing Ratio is often employed in the estimation of the bearing of a soil, used as highway sub-grade, sub-base and base course materials. The studied soil shows the CBR values of 74% for unsoaked sample and 29% for soaked sample which was compacted at the optimum moisture content of the modified AASHTO level (Table 5).

Based on the guidelines the use of laterites by the Federal Ministry of Works (1970), that recommends a CBR of >80% for unsoaked and >25% for samples compacted to 95% of modified AASHTO optimum moisture content and soaked for 4 days (96 hours), the studied soil can only be used as sub-base material but cannot be used as sub-grade and base –course materials. It can also be used for foundation filling.

Geochemical Characteristics

Table 4 shows the result obtained from the geochemical analysis.The silica/sesquioxides molar ratio can be calculated using the formular below;

$$\text{Silica/sequioxides molar ratio} = \frac{\dfrac{\%\text{ of } SiO_2}{\text{Mol. wt of } SiO_2}}{\dfrac{\%\text{ of } Al_2O_3}{\text{Mol. wt of } Al_2O_3} + \dfrac{\%\text{ of } Fe_2O_3}{\text{mol. wt of } Fe_2O_3}}$$

Where; the molecular weight of SiO_2 is 60, that of Al_2O_3 is 102 and that of Fe_2O_3 is 160 respectively.

Thus from the result above, the silica/sesquioxides molar ratio of the soil sample is;

$$= \frac{\frac{38.60}{60}}{\frac{30.04}{102} + \frac{17.29}{160}}$$

$$= \frac{0.643333}{0.2945098 + 0.1080625}$$

$$= \frac{0.643333}{0.4025723}$$

$$= 1.59$$

$$= 1.6$$

Gidigasu (1976) have suggested the used of the silica/sesquioxides of iron (Fe^{3+}) and aluminum molar ratio for the classification of soils. He classified soils with molar ratios les than 1.33 as true laterites, those with ratios between 1.33 and 2.0 as lateritic soils and those having a ratio greater than 2.0 as non-lateritic tropical soils.

From the computation of the silica/sesquioxides molar ratio, the studied soil can be described as a lateritic soil.

CONCLUSIONS AND RECOMMENDATION

Conclusion

The study involves determination of geotechnical properties and the analysis for major chemical oxides of a lateritic soil derived from Ajali formation in Ihube-Okigwe area south-Eastern Nigeria. This study have shown that;

i. The soil is highly lateritised considering the silica-sesquioxide of iron (Fe^{3+}) and aluminium molar ratio.

ii. The low maximum dry density and optimum moisture content shown by the soil is attributed to its lower affinity for water and low swelling potential.

iii. The grain size distribution characteristic reveals that the soil is well graded and would hence be a good highway construction material.

iv. The low plasticity index and liquid limit of the soil may be attributed to the presence of high amount of kaolinite thus qualifying it as good sub-grade and sub-base materials.

v. The values of both the unsoaked and soaked California Bearing Ratio (CBR) shows that the soil can only be used as sub-base material. In conclusion, the soil sample satisfies every other aspect of geotechnical and geochemical requirements of lateritic soils as good road construction materials but does not satisfy the aspect of the California Bearing Ratio when used as sub-grade and base-course materials.

Recommendations

Since the studied soil cannot naturally be used as sub-grade and base-course material for road construction regarding the low California, Bearing Ratio (Low Strength), it is therefore recommended that;

i. The California Bearing Ratio values should be improved by adding Ordinary Portland Cement to provide stability

ii. It is also recommend that during compaction, the modified protor test method should be used to compact at higher compactive effort when used as sub-grade and base-course materials. Furthermore, there is need to investigate the quality of lateritic soils from other parts of southeastern Nigeria as this would provide comprehensive data on the highway geotechnical and geochemical properties of the lateritic soils in southeastern Nigeria.

REFERENCES

Adeyemi, G.O., (2002); Geotechnical properties of lateritic soils, developed over quartz schist in Ishara area, southwestern Nigeria. Journal of mining and geology, vol.38(1), pg.65-69.

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

Bell, F.G., (1993); Engineering Geology, Blackwell scientific publications, Oxford, London. Pg. 359.

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

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

Gidigasu, M.D., (1973); Review of identification of problem lateritic soils in highway engineering. Transport Research Board, Washington 497. Pg. 96-111.

Gidigasu, M.D., (1976). Laterite soil Engineering. Elsevier Scientific Publishing Company, Amsterdam, 554p and 749p.

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

International Journal of Science and Technological Resource. E-mail:devconsort@yahoo.com.

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

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

Nwajide, C.S., (2005), "Anambra Basin of Nigeria: synoptic basin analysis as a basis for evaluating its hydrocarbon prospectivity". In: Okogbue, C.O. (Ed.), Hydrocarbon Basin. In: Reijers, T.J.A. (Ed.), Selected chapters on Geology, SPDC., 133- 147.

Ola, S.A., (1982). Geotechnical properties of an attapulgite clay shale in Northwestern Nigeria, Engineering Geology, Amsterdam, 19, pp.1-13.

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

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.

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

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