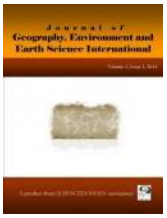

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Evaluation of Ihiala Laterites for Use as Sub-grade Material in Road Construction

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Authors' contributions

This work was carried out in collaboration between all authors. Author EIO designed and supervised the study and also drafted the manuscript while author OEE carried out the field study, laboratory as well as statistical analysis. The literature search was carried out by author HCO. All authors read and approved the final manuscript.

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ABSTRACT

Ten soil samples were collected randomly from Ihiala area at a depth of about 1m using hand auger and shovel for evaluation as a sub-grade material in road construction. These samples were analyzed to determine their chemical and geotechnical properties of pH, natural moisture content, specific gravity, particle size distribution, atterberg limits, Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and California Bearing Ratio (CBR). The pH values ranges from 3.77 to 4.87 in samples 1 to 8 and 10. Silica/sesquioxide ratio values ranges from 0.08 to 0.84 in samples 1 to 8 and 1.66 in sample 9. The result of pH, chemical component analysis and silica/sesquioxide ratio analysis confirmed all the samples to be laterite except sample 9. American Association of State Highway and Transportation Officials (AASHTO) soil classification system, classified samples 1 and 7 as under A-6 soil group; samples 2, 5, 8 and 9 fall under A-2-4 group; sample 3 fall under A-7 group; samples 4, 6 and 10 were grouped under A-4. Using the Unified Soil Classification System (USCS), sample 3 is classified under SM (Silty Sand) while all other samples are grouped under SC (Clayey Sand). The MDD of the soil samples ranges from 16.6 to 18.8

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KN/m^3 with their OMC ranging from 10.8 to 16.00%. The CBR of the samples ranges from 2% to 11% which shows that not all can be used for sub-grade. Generally, using the Nigerian Federal Ministry of Works and Housing (NFMWH) specifications, sample 2 is a good sub-grade material; samples 6, 7, 3, 5, 8 and 9 are fair for sub-grade while samples 1, 4, and 10 are not suitable for sub-grade. It is recommended that stabilization techniques should be applied on these samples that are not suitable for sub-grade in order to improve their strength.

Keywords: Laterite; sub-grade; geotechnical properties; road construction.

1. INTRODUCTION

The level of development in the Southeastern Nigeria has brought increased construction of engineering projects such as road even in the remote areas resulting to the increased exploitation of natural resources such as laterite. Laterite which is extensively mined in many parts of the world including southeastern, Nigeria is used for road construction and other engineering projects. Significant occurrence of laterites abounds in the area and is commonly extracted using surface mining technique. Laterite, which is also known as residual soil is a soil rich in iron and aluminum, and is commonly considered to have formed in hot and wet tropical areas. They are found abundantly in the tropics and sub-tropics. Nearly all laterites are of rusty-red coloration, because of high iron oxide content, but the colours can vary through red, brown, violet to black, depending largely on the concentration of iron oxides [1]. There have been varied definitions for laterite. However, most researchers agree with the definition of [2] that laterite is a highly weathered material rich in secondary oxides of iron and aluminum, and describes it further as nearly void of bases and primary rock-forming minerals (silicates) but may contain large amount of quartz and kaolinite; and either hard or capable of hardening. Two fundamental characteristics that distinguish it from all other minerals are its chemical composition and its crystal structure [3].

Sub-grade according to [4] is a natural soil or embankment construction prepared and compacted to support a pavement. He also defined pavement as constructed layer of durable material of specified thickness, usually of concrete, asphalt or bituminous materials, designed to carry wheeled vehicles. Several researchers have carried out works on the geotechnical properties of Lateritic soils in various places. [5], analyzed the engineering properties of Lateritic soils from Anambra Central Zone, Nigeria. Accordingly, they revealed that Lateritic soil from Anambra Central zone can be classified under the America Association of State Highway and Transport Officials [6] classification system as clayey gravel (A-2) indicating excellent material for road works. [7], also assessed the geotechnical properties of Abia State Lateritic deposits. They showed that the Lateritic soils from Abia State are silty soil and very poor (A-4-1) based on America Association of State Highway and Transport Officials [6] classification system. Road accident is usually caused by bad roads as a result of wrong application of construction materials especially laterite as sub-base and base material by construction companies [8] and [9]. For a material to be used as either a base course or sub-base course depends on its strength in transmitting the axle-load to the sub-soil and/ or sub-grade (the mechanical interlock). The characteristics and durability of any constructional material is a function of its efficiency in response to the load applied on it. The mineralogical composition of the lateritic soil has an influence on the geotechnical parameters such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity and petrographic properties [10].

Engineers in developing countries are faced with the challenges of locating suitable laterite for use as subgrades in engineering road construction. Laterite varies in its nature and properties. The inconsistency in the nature and properties of laterites is important for sustainable road network.

The index properties of residual soils vary from region to region due to the heterogeneous nature and highly variable degree of weathering controlled by regional climatic and topographic conditions, and the nature of bedrock, [11]. These properties also vary with the depth. The degree of weathering, climatic and topographic conditions is known factors that differentiate laterite from other soils in the temperate or cold regions.

Laterites contribute to the general economy of the tropical and subtropical regions where they are widely utilized in civil engineering works as construction materials. As road construction material, they form the sub-grade of most tropical road, and can also be used as sub-base and base courses for roads that carry light traffic. The use of unsuitable soil type in road construction results in instability and subsequent failure. Major road failures in some areas have been attributed to bad construction materials [12]. The condition and standard of the road network of a region and a country as a whole play a significant role in the socioeconomic development of the area. Adequate information on the geotechnical properties of laterite such as strength, grain size distribution, compaction properties and the bearing ratio are important in order to make a

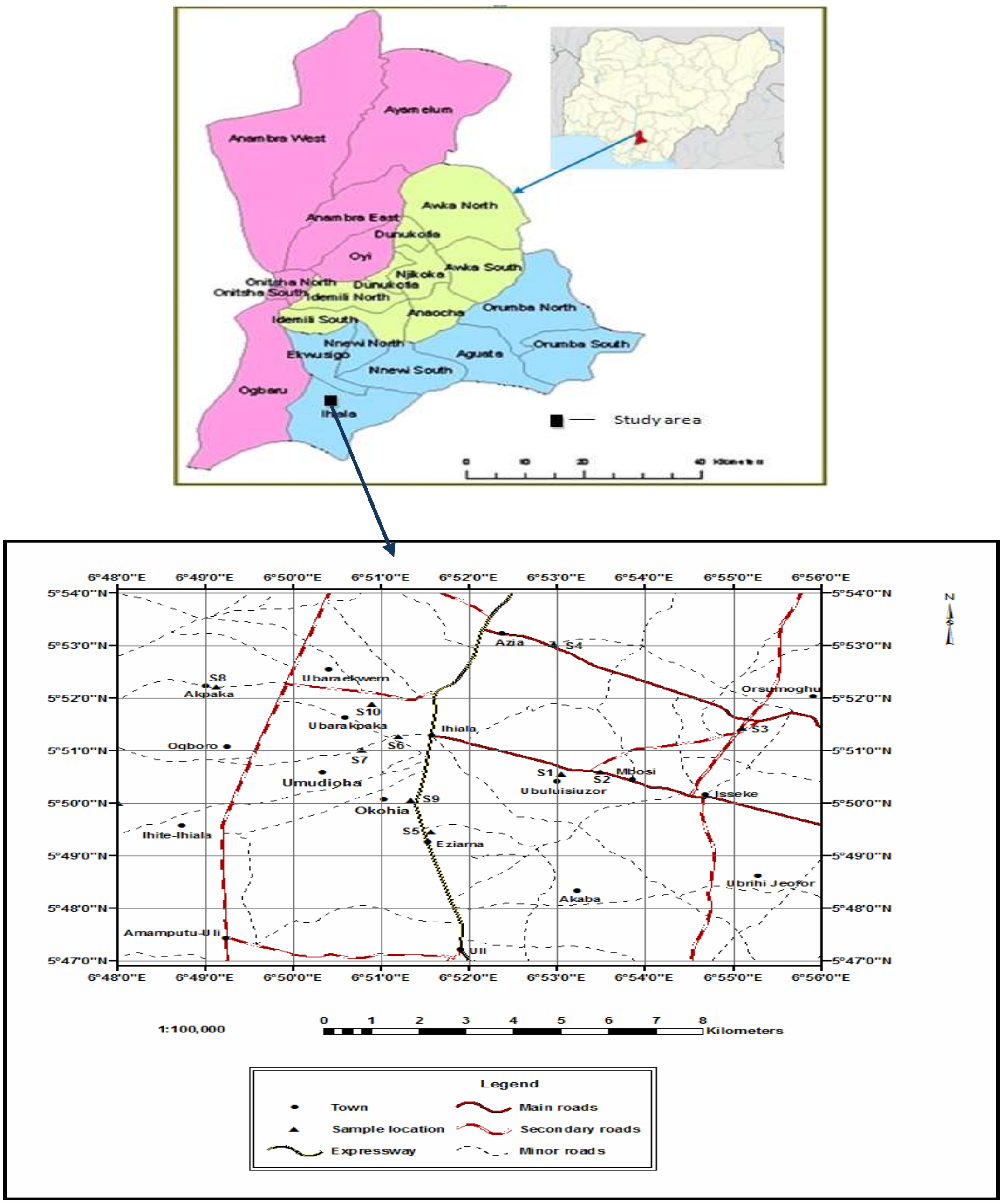

Fig. 1. Location map of the study area

convenient choice for this basic material [13] as the durability and strength of roads depend on these information. Laterite is currently excavated from the study area and transported to other parts of the state for engineering purposes though miners are ignorant of the quality of these laterites. Thus, the study aims at the evaluation of the quality of the laterites in Ihiala and environs for their use as a sub-grade material in road construction. The use of the laterite in road construction will be cost effective since this construction raw material is readily in the locality. Exploitation of laterite in the area is not without implications. Large scale exploitation of laterite in the study area has resulted in a high degree of degradation of arable land, ecological instability, reduction in fauna and flora population density, contamination of the environment, landslide and landscape alteration.

1.1 Location and Accessibility of the Study Area

The study area is bounded by latitudes 5° 47'N and 5° 54'N and longitudes 6° 48'E and 6° 56'E (Fig. 1). It is located in the southeastern part of Nigeria that is characterised by two distinct climatic conditions [14]: the rainy season (April to September) and dry season (October to March). The tropical rainforest vegetation significant in the area is gradually turning into savanna due to climate change. The underlying geology is predominantly sand with intercalations of shale and this has implications on road construction. The heavy average rainfall amount of about 2000 mm [15] has also affects the stability of constructed road networks.

2. MATERIALS AND METHODS

A total of ten samples of about 25 kg each, were randomly collected at laterite exposure within the study area using a hand auger and shovel at a depth of about 1 m. A Ground Positioning System (GPS) was used to measure the coordinates. All samples were carefully labeled and arranged in bags for the various analyses. The samples that were used for the determination of the natural moisture were sealed in polythene bags to maintain their natural moisture condition. The samples were then transported to the soil mechanics laboratory in Civil Engineering Department at Nnamdi Azikiwe University Awka, Nigeria in order to determine their geotechnical/engineering and chemical properties.

The chemical components of the laterite samples were determined using Varian AA240 Atomic Absorption Spectrophometer (AAS) following APHA (American Public Health Association) 1995 method. pH test was done using hand held pH meter Hanna model. Particle size analysis, liquid limit, plastic limit, compaction and California Bearing Ratio (CBR) tests were all performed in the laboratory in accordance with BS 1377 (1990) standard using mechanical sieve shaker, casagrande apparatus, British Standard mould with 2.5 kg rammer and California Bearing Ratio machine respectively. The compaction characteristics of the samples were determined using Proctor's method.

Liquid limit was determined by placing about 250 g of soil sample from thoroughly mixed portion of soil material, passing 0.425 mm in a porcelain dish and mixing with 15 to 20 ml distilled water by alternately and repeatedly stirring, kneading and chopping with spatula. Further water increment of 1 to 3 ml was added and the process repeated until sufficient water has been thoroughly mixed with the soil. A portion of the mix was pressed into the cup using a spatula and carefully spread into position while avoiding entrapment of air bubbles. The liquid limit was taken as the moisture content corresponding to 25 blows. Similarly, for plastic limit was determined using about 20 g of soil sample, passing 0.425 mm sieve. The sample was thoroughly mixed with distilled water and kneaded for about 10 minutes to form a plastic ball. The ball was molded between the fingers and rolled between the palms, such that the warmth from the hand slowly dried it. The thread was then rolled between the fingers and a glass plate using steady pressure which reduced the diameter to about 3 mm, the pressure was maintained until the thread crumbled. This crumbling point is the plastic limit.

Liquid limit was carried out in accordance with American Society of the International Association for Testing and Materials method D423 standard [16] and the value taken as the moisture content corresponding to 25 blows. Similarly, plastic limit was determined in accordance with BS 1377 test 3 Standard (BS 1377-1990). About 20 g of the sample was kneaded for about 10 minutes to form a plastic ball. The ball was rolled between the palms to form thread which is then rolled between the fingers and a glass plate using steady pressure until the thread crumbles. This crumbling point is the plastic limit. The bulk density was determined by dividing the mass of wet soil by the volume of the cylindrical mould while the dry density was determined as follows: (P_d) = P_b x 100/100+m where, P_b = bulk density and m= moisture content (%).

CBR was carried out using compression machine to estimate the bearing capacity of high way sub-bases and sub-grades. The apparatus used consist of a motor driven compression machine with a constant penetration rate of 1 mm/min; for this particular test, a loading with a range of 0-10KN was employed. A standard CBR mould, fitting and tools were used. Particles with diameter larger than 20 mm were removed via sieving. About 8 kg of sample was compacted dynamically using the BS ordinary method where the samples were loaded into the mould in three layers and each layer subjected to 62 blows from a 2.5 kg hammer dropping from a fixed height of 300 mm. The load measuring device was connected to the compression machine. The cylindrical plunger, diameter 49.5 mm cross sectional area of 1925 mm^2 and a length of 250 mm was connected to the load measuring device. The mould with the sample and surcharge weights was placed in the machine (each surcharge ring of 2 kg is equivalent to about 70 mm thickness of super imposed construction). The plunger was seated on top of the specimen in such a way that it can move freely from the surcharge weight. The measuring device was adjusted to read zero. The machine was then switched on to start loading. Readings were taken at 0.25 mm displacement, after 7.5 mm penetration the machine was stopped. The moisture contents were determined for top, middle and bottom of the specimen.

3. RESULTS AND DISCUSSION

The results of chemical and geotechnical analysis of the soil samples from the study area are presented in Table 1.

The results from the locations in the study area have similar values which show uniformity in their climatic factors and weathering processes. The uniformity in the topographic conditions also supports the similarity in the values. The acidity/alkalinity test and the chemical composition tests performed were for the purpose of identification. The chemical tests show that all the samples are laterite except sample loc 9. The result of the specific gravity test performed on the samples show that they have low specific gravity which could be as a result of decrease in silica/sequioxide ratio. In the sieve analysis, the percentages of sand in the samples are higher than the percentages of fine apart from Loc 3. The high percentages of sand could be attributed to the underlying geology and weathering processes prevalent in the area. [17] observed that harsh climate and land use practices influence soil properties. The sample constitute of sands, silts and clays.

Table 1. Properties of the samples from the study area

Properties	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Loc 7	Loc 8	Loc 9	Loc 10
pH	4.8	4.6	4.5	4.6	4.1	3.9	4.9	3.8	7.9	3.9
S/SR	0.71	0.84	0.36	0.38	0.08	0.33	0.31	0.20	1.66	0.63
Sand %	58.52	65.74	47.81	60.09	65.99	60.42	61.05	64.95	65.83	62.13
Fines	40.07	34.21	52.07	39.77	34.00	39.60	38.93	35.06	34.11	37.84
MDD(N/m^3)	18.30	18.8	16.6	18.6	18.20	18.4	18.4	18.6	18.1	17.9
OMC (%)	13.70	13.31	16.00	13.3	13.00	10.80	12.70	13.00	13.20	13.20
CBR (%)	3	5	4	2	4	11	6	4	4	3
SG	2.60	2.50	2.40	2.40	2.50	2.50	2.50	2.50	2.40	2.40
NM (%)	17.10	16.21	18.81	13.42	14.53	15.04	15.08	12.65	13.99	15.05
LL (%)	33.50	23.80	53.00	27.75	30.00	30.15	34.00	32.00	28.00	28.90
PL (%)	19.19	17.25	36.07	22.21	21.46	21.46	15.80	23.51	20.44	18.85
PI (%)	14.31	6.55	16.93	5.54	8.54	8.69	18.20	8.49	7.56	9.50
USCS	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC
AASHTO	A-6	A-2-4	A-7	A-4	A-2-4	A-4	A-6	A-2-4	A-2-4	A-4
Colour	Reddish Brown	Dark Brown	Red	Reddish Brown	Reddish Brown	Reddish Brown	Reddish Brown	Reddish Brown	Reddish Brown	Reddish Brown

S/SR (Silica/Sesquioxide Ratio), SG (Specific Gravity) NM (Natural Moisture)

Table 2. Classification of the samples based on AASHTO soil classification

Sample name	2.00 mm (No.10)	0.425 mm (N0. 40)	0.075 mm (No. 200)	Liquid Limit	Plasticity index	Group classification	Significant constituent material	Rating as subgrade
Loc 1	>50	>51	>35	<40	>10	A-6	Clayey soil	Poor
Loc 2	>50	>51	>35	<40	<10	A-2-4	Silt/clayey gravel and sand	Good
Loc3	>50	>51	>35	>41	>10	A-7	Clayey soil	Poor
Loc 4	>50	>51	>35	<40	<10	A-4	Silty soil	Fair
Loc 5	>50	>51	<35	<40	<10	A-2-4	Silt/clayey gravel and sand	Good
Loc 6	>50	>51	>35	<40	<10	A-4	Silty soil	Fair
Loc 7	>50	>51	>35	<40	>10	A-6	Clayey soil	Poor
Loc 8	>50	>51	<35	<40	<10	A-2-4	Silt/clayey gravel and sand	Good
Loc 9	>50	>51	<35	<40	<10	A-2-4	Silt/clayey gravel and sand	Good
Loc 10	>50	>51	>35	<40	<10	A-4	Silty soil	Fair

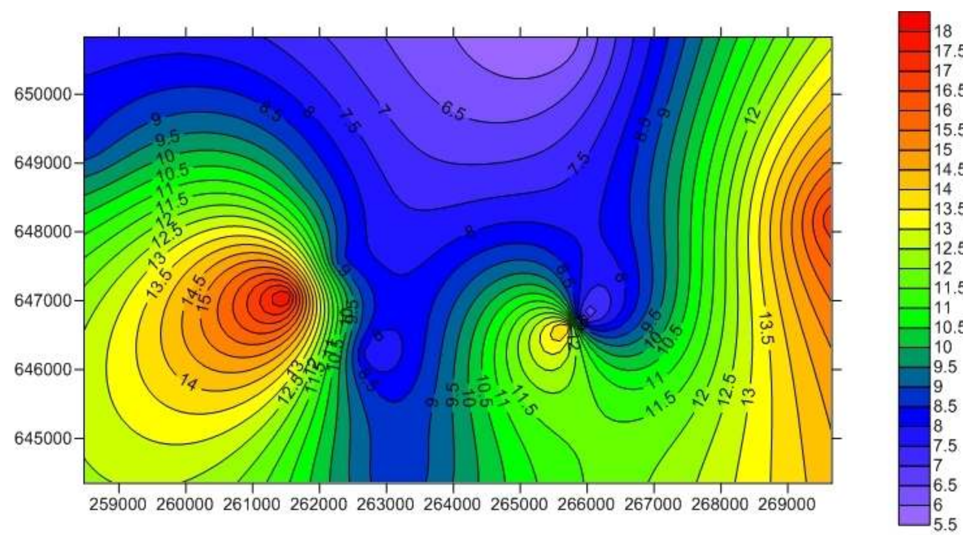

Fig. 2. Distribution map of plasticity index in the area

From Table 1, Loc 3 has the highest percentage of fines, liquid limit (LL), plastic limit (PL) and plasticity index (PI). This shows that the higher the quantity of fine in a lateritic sample, the greater the LL, PL and PI, and that plasticity index decreases with decrease in the quantity of fines. In other words, the more the presence of fines in a lateritic soil, the higher the plasticity of the soil and obviously the less the permeability of the soil [18,19]. The result of the atterberg limit test for the ten samples is also shown in Table 1. The samples revealed low to medium plasticity with the values of the plastic limit (PL) ranging from 6 to 20%. The values of the liquid limit (LL) obtained from samples vary from 23.8 to 53.00% indicating the probable absence of expandable clay materials. The values of the plasticity index of the soils ranges from 5.54 to 18.20% classifying the soils as having low to medium swelling potential confirming the result of [20]. Fig. 2 shows the distribution of the plasticity index in the area.

30% of the samples comprising Loc 1, Loc 3 and Loc 7 are rated as poor subgrade material based on AASTHO Table 3. The AASHTO system uses both grain-size distribution and Atterberg limits data to assign a group classification and a group index to a sample. Group index values near 0 indicate good soils, while values of 20 or more indicate very poor soils. However, a soil good for highway subgrade may be very poor for other purposes.

Following the Unified Soil Classification System (USCS), 90% of the samples are classified as good in terms of their suitability as a construction material Table 3. Based on the USCS, the samples are grouped as clayey sand (SC) and silty sand (SM). This is supported by the plasticity chart in Fig. 3.

Table 3. Classification of the samples based on 'Unified Soil Classification System' (USCS)

Sample name	Group symbol	Suitability as a construction material
Loc 1	SC	Good
Loc 2	SC	Good
Loc 3	SM	Fair
Loc 4	SC	Good
Loc 5	SC	Good
Loc 6	SC	Good
Loc 7	SC	Good
Loc 8	SC	Good
Loc 9	SC	Good
Loc 10	SC	Good

From the compaction test, the Maximum Dry Density (MDD) of the soil sample ranges from 16.6 KN/m^3 to 18.8 KN/m^3 with the corresponding Optimum Moisture Content (OMC) ranging from 10.80% to 16.00%. The test reveals that Loc 3 has the lowest MDD and the highest % of fine. [21] established that maximum dry density decreases with the increase in fines thereby making the A-2 material exhibit the highest maximum densities while the A-7 materials have relatively lower densities. The result of the California Bearing Ratio (CBR) for the ten samples after 48 hours soaking ranges

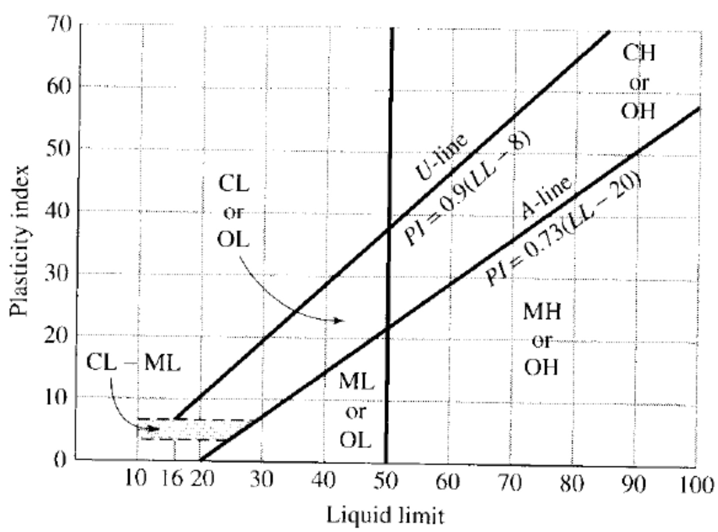

Fig. 3. Plasticity Chart (ASTM 1999)

from 2% to 11%. The values indicate that 30% of the samples are suitable as sub-grade following Nigeria Federal Ministry of works and housing [22] standard.

4. CONCLUSION

The evaluation of the physical, chemical and geotechnical/engineering properties of laterites from Ihiala and Environs reveals that some are suitable for use as sub-grade material in road construction. The chemical composition analysis and the pH show that all the samples are laterites except sample 9. Using AASHTO soil classification system, samples 1 and 7 are classified under A-6 group (poor), samples 2, 5, 8 and 9 fall under A-2-4 group (good), sample 3 fall under A-7 (poor) and samples 4, 6 and 10 fall under A-4 group (fair). Using USCS, almost all the samples were classified as clayey sand (SC) and rated good as construction material. Using AASHTO, USCS and [22] Standards, only samples 1, 4 and 10 are considered not suitable for use as sub- grade material in road construction and therefore recommended that soil samples should undergo appropriate tests to determine their suitability for a particular purposes and strength improved where necessary before it can be used as subgrade material.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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