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Technical Note

Adaptation of Ohia Pozzolan on Cemented Lateritic Soil as Base Material Improvement

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ABSTRACT

The effect of nanostructured Ohia naturally occurring pozzolan (kaolin clay) on the compressive strength of Umuntu Olokoro lateritic soil was investigated for use as base material improvement of south eastern roads. First, a preliminary exercise was conducted to determine the index, grading and consistency properties of the natural soil. The results show that the Umuntu Olokoro soil was an A-2-7 soil, according to AASHTO classification system and poorly graded (GP) on USCS classification. The soil also recorded a PI of 21.85%, which shows that the soil was highly plastic. The specific gravity of the soil was 2.67, OMC of 13%, Maximum Dry Density of 1.84 gm/cm3, California Bearing Ratio of 14%, Unconfined Compressive Strength of 194.26 kN/m2, 219.11 kN/m2 and 230.77 kN/m2 at 7, 14 and 28 days curing periods with material property of silty clayey sand and stiff material. Furthermore, the pozzolan additive was introduced in proportions of 3%, 6%, 9%, 12% and 15% by weight and the effect of the varying proportions studied. The results show that the introduction of the pozzolan improved the soil compressive strength, considerable and a maximum of 369.9 kN/m2 was achieved at 9% proportion of pozzolan at 28 days curing time. Having satisfied the material properties for use as a base material (200-400kN/m^2), pozzolan is a very good admixture material in the stabilization of lateritic soils for use as a subbase material for pavement construction.

1. Introduction

Soil is important in various engineering projects such as pavement construction, drainage systems, buildings, canals, retaining walls, etc. The degree of success in each case may be attributed to the Geotechnical characteristics of soil, design techniques, construction procedures, environmental factors and the nature of the service of the structure. In the earliest era, Nigeria consisted of uplifted continental land mass made up of basements. This resulted in the formation of lateritic soil, which is relatively of good quality for road construction work. The level of decay of structural facilities calls for concern from various bodies and agencies. For instance, in the southeast part of Nigeria, over 90% of the roads are in a state of despair and more worrisome is that the relevant agencies in the works sections and government are not doing anything to save this deplorable situation. Some of such roads are; Enugu/PortHarcourt highway, Umuahia/Uyo highway, Enugu/Nsukka Highway, Enugu/Awka highway, Uturu/Abakiliki highway, Umuahia, Ohafia highway, Umuahia/Owerri highway, Owerri/Portharcourt highway and many more. Worst of all is the Egunu/Portharcourt highway, which is supposedly

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a dual carriage-way connecting four southeastern states of Abia, Imo, Ebonyi and Enugu states. We all have a duty to save the environment and research works such as this are ongoing to proffer environment solutions. This research work has investigated into the stabilization potentials of naturally occurring pozzolanic soil, which is obtained at no cost from Ohiya site, Umuahia. While we have embraced the new trend in materials technology to alter the material properties, we have also compared our findings with an earlier study carried out on this material. The field of nanotechnology gave us a platform to try new procedures of applying the pozzolanic soil of Ohiya to study its effect on the compressive strength of Umuntu Olokoro lateritic soil as an additive. Nanotechnology is the science that uses and manipulates matter at a nano scale. At this size, atoms and molecules work differently, and provide a variety of surprising and interesting uses. Nanotechnology represents the design, production and application of materials at atomic, molecular and macro molecular scales, in order to produce new nanosized materials (Ahmad et al., 2013; Chang-Jun et al., 2010; Bao et al., 2011; Anitha et al., 2014; Anamika et al., 2012; Ali et al., 2011; Mercier et al., 2002; Chien-I et al., 2008; Ershadi et al., 2011; Fan et al., 2015; Hall et al, 2000; Kalpana et al., 2009; Kannan, 2010; Kavitha et al., 2015; Laila et al., 2010; Masaki et al., 2006; Osinubi et al., 2009; Reenu et al., 2014; Satish et al., 2015; Xiao et al., 2005). Nanomaterials are materials with one external dimension in the size range from approximately 1- 100 nanometers while nanoparticles are small objects that behave as a whole unit with respect to its transport and properties and they are particles between 1-100 nanometers in size. Many metallic compounds have shown to possess toxic and or carcinogenic properties. Among them are also essential trace elements such as iron or copper, which on conditions of disturbed homeostasis can cause cellular overload. One aspect having frequently been discussed in recent years is the question as to whether metal-based nano-particles exert higher toxicity when compared to water-soluble-metallic compounds or micro scale particles of the same metallic content. The benefits of pozzolan utilization in cement and concrete are threefold. First is the economic gain obtained by replacing a substantial part of the Portland cement by cheaper, pollution-free, natural pozzolan material and industrial by-products. Second is the lowering of the blended cement production.

A third advantage is the increased durability of the end-product. Additionally, the increased blending of pozzolan with Portland cement is of limited interference in the conventional production process and offers the opportunity to create value by converting large amounts of industrial and societal waste into durable construction materials.

Soil stabilization refers to the procedure in which a special soil, a cementing material, or other chemical or non-chemical materials are added to a natural soil or unique use of a natural soil to improve its properties (Abood et al., 2007). Soil stabilization techniques for road construction are used in most part of the world, although circumstance and the reasons for resorting to stabilization vary considerably (Janathan, 2004). Soil stabilization has widely been recommended for developing countries for various elements of their pavement construction especially Nigeria.

2. Nano Stabilization

Nanotechnological achievements provided a modern approach in Geotechnics. Each field of science had a specific definition for nanotechnology, and the National Nanotechnology Initiative (NNI) provided a comprehensive definition of nanotechnology as "nanotechnology" is the control, comprehension, and reformation of material based on the hierarchy of nanometers to develop matter with essentially new uses and a new constitution (NSTC, 2007). Years later, Geotechnical experts have keyed into this technology to develop ideas and procedures for using this tech to enhance the environment through engineering soil improvements and stabilization. This improves the bonding between stabilization additives or admixtures and stabilized engineering soil materials. Therefore, it becomes more reactive and potentially suitable for improving the properties of soil for various applications (Taha, 2009; Ahmad et al., 2013; Chang-Jun et al., 2010; Bao et al., 2011; Anitha et al., 2014; Anamika et al., 2012; Ali et al., 2011; Mercier et al., 2002; Chien-I et al., 2008; Ershadi et al., 2011; Fan et al., 2015; Hall et al. 2000; Kalpana et al., 2009; Kannan, 2010; Kavitha et al., 2015; Laila et al., 2010; Masaki et al. 2006; Osinubi et al., 2009; Reno et al., 2014; Satish et al., 2015; Xiao et al., 2005). Meanwhile Norazlan et al. (2014) was stated by using a small percentage of nanoparticle of kaolin to influence the basic properties and engineering of kaolin. There are increased research and development in nanoparticles that have been used as filler or additives for various desired effects. However, the specific objectives of this exercise were; (i) to investigate the effect of nanosized naturally occurring pozzolan soil on the compressive strength of stabilized Umuntu Olokoro lateritic soil and (ii) to proffer its use to remedy the dilapidated roads in the southeastern part of Nigeria neglected by government.

3. Materials and Methods

3.1 Materials

3.1.1 Umuntu Olokoro Lateritic Soil

Lateritic soil sample used for this study was collected from a borrow pit located at Olokoro, between latitude of 05°28'36.700" north and longitude 07°32'23.170" east from a depth of 2 meters, a distance of 5km along Ubakala road from Ishi Court Umuahia the Abia state capital in Nigeria (www.google.com, 2017) as shown in **Fig. 1.** The sample collected was in solid state and reddish brown in color. The soil obtained from this location was air dried in trays for six days, after which the soil was crushed. The dried soil was pulverized, using rubber covered pestle in the tray and sieve characterization with orderly arranged British standard to (1S:2720-part xvi, 1999); 4.36mm, 2.36mm, 1.18mm, 300μm, 212μm, 150μm, 75μm.

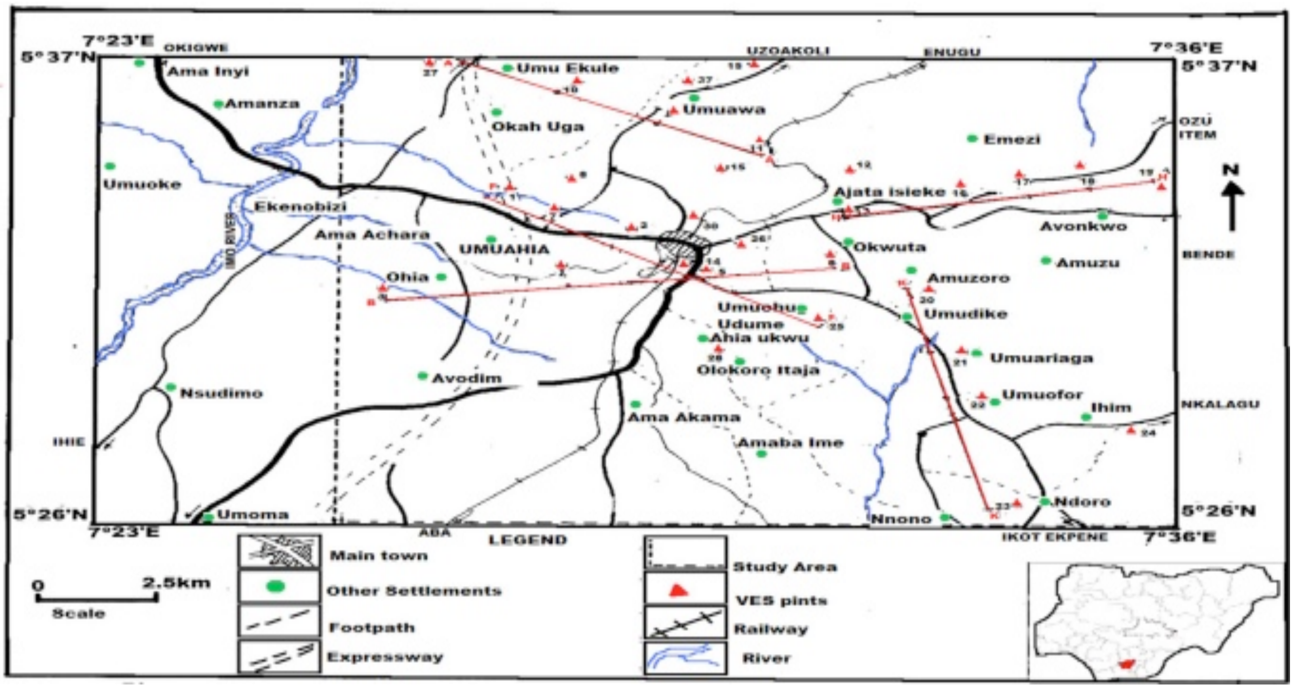

Fig. 1. Map of Umuahia Showing Olokoro and Ohia

3.1.2 Puzzolan Soil and Ordinary Portland

The pozzolan soil sample (kaolin clay) used for this investigation was collected from Ohia adjacent to the Mechanic village, on Enugu-Port-Harcourt highway in Umuahia South Local Government Area of Abia State, Nigeria as shown in **Fig. 2.** The sample was collected in a bagco bag and was air dried to eliminate the moisture in it for 7 days. It was then crushed to powder with core cutter and bulk density mold. Subsequently, the powder was completely pulverized and passed through 200nm sieve and stored for use. Ordinary Portland cement which satisfied the material condition in accordance to (ASTM C150) was used as a binder. A constant percentage of 5% was maintained throughout the experiment.

Fig. 2. Map of Umuahia Showing Ohia in Zone A

4. Methods

The following preliminary tests were conducted in accordance with (BS 1377-2, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; ASTM D4318-10, 2015; ASTM D698-12, 2013; ASTM D854-14, 2015; ASTM D7262-09; ASTM D1883-99, 2003; ASTM D6913-04, 2009; ASTM D2487-11, 2015; ASTM D2488-09a, 2015, 2013; ASTM D2166-65, 2015; ASTM D2166/D2166M-13, 2015); Sieve Analysis Test, Compaction Test (Standard Proctor Test), California Bearing Ratio Test (CBR), Atterberg Limit Test (Cassagrande apparatus), Unconfined Compressive Strength(UCS) Test, Specific Gravity Test, and Chemical Composition Test on the natural soil sample and results were obtained.

4.1 Unconfined Compressive Strength Tests

This was conducted at Niger Pet Geotechnical Engineering Laboratory, Uyo, Akwa Ibom State, Nigeria on the sample with admixture proportions of 3%, 6%, 9%, 12% and 15% in accordance to (BS 1377-2, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; ASTM D2166/D2166M-13, 2015; ASTM D2487-11, 2015; ASTM D2488-09a, 2015; ASTM D2166-65, 2015) and setup as shown in **Fig 3** (a & b).

(a) (b)

Fig. 3. Nigerpet laboratory Unconfined Compressive Strength (a) and (b) CBR test setup

5. Results and Discussions

It can be deduced from Tab. 1, that the soil;

• Has a plasticity index of 21.85% > 17% and that condition satisfies that Umuntu Olokoro lateritic soil is a highly plastic soil. Also the plasticity index falls between 20% and 35%, a condition for high swelling potential and between 25% and 41%, a condition for a high degree of expansion (Gopal and Rao, 2011)

• Has, from the consistency limits tests that the soil relative consistency and liquidity index, which are 1.69% > 1 and 0.91% < 1 respectively show that the soil is in a semi-solid or solid state, very stiff and plastic (Gopal and Rao, 2011)

• Is classified as A-2-7 soil on AASHTO soil classification, poorly graded, GP on USCS, the group index of 0 and of silty, clayey gravel and sand material (Gopal and Rao, 2011).

• Has optimum moisture content (OMC) of 13% and maximum dry density (MDD) of 1.84g/cm^3.

• Has Unconfined Compressive Strength (UCS) of 230.77kN/m^2 at 28 days curing time, which falls between 200 and 400kN/m^2, a condition for soils of very stiff consistency with respect to UCS, which satisfies the material condition for use as subgrade material (Gopal and Rao, 2011; NGS/FMWH, 1997).

• Has California bearing ratio of 14 which makes it good for the subgrade material (NGS/FMWH, 1997).

Table 1. Geotechnical Properties of the Test Soil

Property/Unit	Quantity
% Passing BS No. 200 sieve	25.40
Natural Moisture Content, (%)	10
Liquid Limit, (%)	47
Plastic Limit, (%)	25
Plasticity Index, (%)	22
Coefficient of Curvature, Cc	0.09
Coefficient of Uniformity, Cu	10
Specific Gravity	2.67
AASHTO classification	A-2-7
USCS	GP
Group Index	0
Material	Silty Sand
Condition/General Subgrade Rating	Good
Optimum Moisture Content, (%)	13
Maximum Dry Density (g/cm^3)	1.84
California bearing ratio, (%)	14
Unconfined Compressive Strength, (kN/m^2)	
28 days	230.77
14 day	219.11
7 days	194.26

From Figures 4 and 5 and Table 1, it can be deduced that the soil is a well graded soil with Cc equals 0.09, Cu equals 10 and possesses an absorbance of 1.154nm at the wavelength of 800cm.

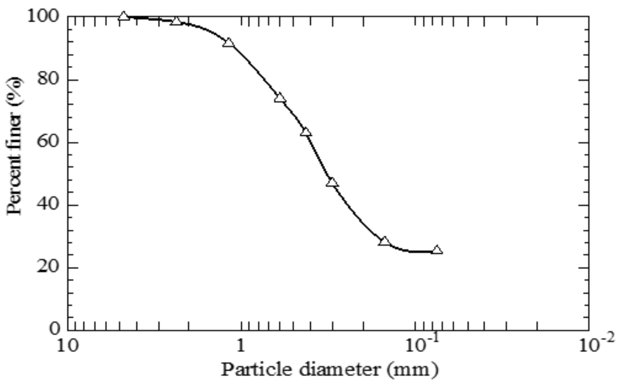

Fig. 4. Particle size distribution curve of the lateritic soil sample

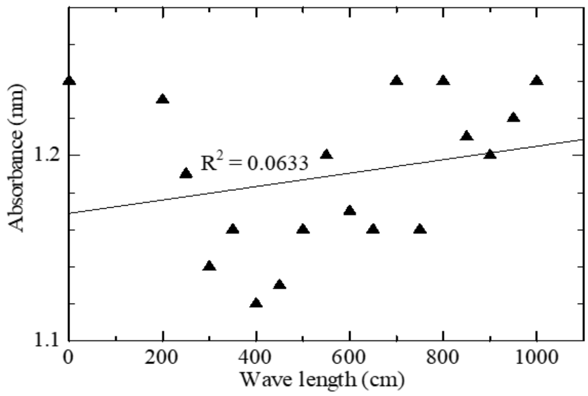

Fig. 5. Variation of Absorbance against wavelength for the lateritic soil using UV/VIS Spectrophotometer at 25^{0}C

5.1 Effect of Variable Proportions of Pozzolan on the UCS of Stabilized Lateritic Soil

From the effect of pozzolan additives on the unconfined compressive strength of the stabilized Umuntu Olokoro lateritic soil shown in Table 2 and Figure 6, it can be deduced that;

1. The addition of pozzolan as admixture to the stabilized Olokoro soil improved the strength of the sample from 194.26kN/m2 at control experiment to 192.8kN/m2, 273.1kN/m2, 286.5kN/m2, 300.4kN/m2 and 341.6kN/m2 at 3%, 6%, 9%, 12% and 15% respectively at 7 days curing period.

2. The strength improvement at 14 day curing period, though good, but was not consistent. It recorded the maximum compressive strength of 357kN/m2 at 15% by weight proportion of pozzolan.

3. While the strength improvement at 28 days curing time recorded a maximum of 369.9kN/m2 at 9%

proportion of pozzolan, the stabilized soil strength dropped at further addition of pozzolan to 12% and 15% within this curing period. This proved to be the best exercise and proportion to be used in the improvement of the compressive strength of Olokoro lateritic soil since civil facilities like roads are constructed for use as long term projects.

4. It is important to note the reasons behind the inconsistent results as contained in **Table 2**. It is possible that the addition of such naturally occurring material like pozzolan could affect the already known performance of ordinary Portland (OP) cement which served as a binder. This factor makes the studied mixture to lose strength after some days of curing and subsequently regained even more strength after a longer period. The initial strength gain by cement we know is spontaneous and rapid. And could also be lost by the reaction between cement and material admixtures hence the inconsistent behaviour we experienced in the above results.

Table 2. Effect of Pozzolan Additives on the Unconfined Compressive Strength (UCS) Test Result of the Stabilized Soil.

UCS,	Pozzolan proportion by wt, (%)					
kN/m^2	0	3	6	9	12	15
7 days	194.26	192.8	273.1	286.5	300.4	341.6
14 day	219.11	313.8	294.1	219.4	342.5	357.0
28 days	230.77	299.2	325.9	369.9	320.4	349.1

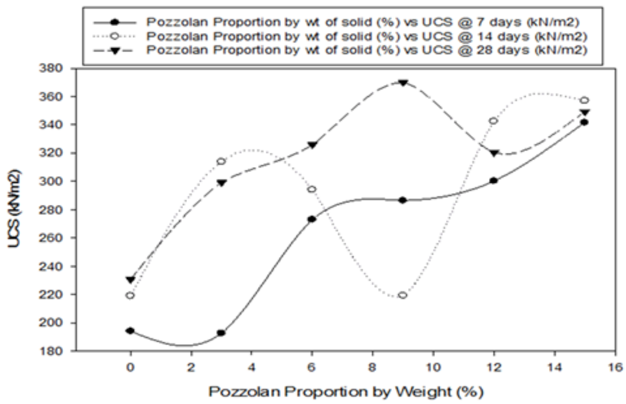

Fig. 6. Effect og Nanostructured Pozzolan on UCS

6. Conclusions

From the foregoing, it can be concluded as follows;

1. That pozzolan (kaolin clay) is a good admixture in the stabilization of expansive lateritic soils. This is for improvement of the compressive strength of the engineering soil properties for use as base material in pavement construction.

2. That this material additive should be used at 9% by weight of solid proportion to achieve the highest strength for a long term use of the pavement facility and the relevant ministries of Works and Housing should make use of the naturally occurring pozzolan soil for a cost effective facilities construction and rehabilitation because of its cementitious properties.

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Symbols and abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
Cc	Coefficient of Curvature
Cu	Coefficient of Uniformity
GP	Poorly graded
UCS	Unconfined Compressive Strengt

USCS	Unified Soil Classification System
PI	Plasticity Index
MDD	Maximum Dry Density
OMC	Optimum Moisture Content